4 Presentation of Scenarios

4.1 *Introduction*

The previous chapters introduced first the context and then the tools that have been selected to address the challenges of modelling water demand. It is now time to delve into the details of the way scenarios themselves are represented. This chapter first provides remarks on the assumptions made in the modelling process and their origins. It then presents the data used for the climate and for the appliances, and then describes the components of the model as well as the different steps of the simulation, in order to provide a global view of the inputs and processes. Finally, a discussion on the representation of innovators is followed by exhaustive detailing of the scenario parameters.

4.2 *Model details*

The Agency's scenarios developed are based upon 4 assumptions.

1. The future is shaped by human choice and actions
2. The future cannot be foreseen, but exploring it can inform present decisions
3. There are many possible futures
4. Scenario 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 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 the social values through endorsements

The representation of the social values of households does not imply anything in terms of the modelling of the structures and the environment. There are 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. 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. Nevertheless, while it is easier to argue that individualism can be linked with the references in the model to the self-centred beliefs and rules, community can be a bit more difficult in the framework of this model. What is called community in the Environment Agency approach is actually referred to 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.

4.2.2 Representation of the governance structure through the distinctive characteristics of the scenarios

While social values can be represented in such a way that various ones can be generated easily, through a simple choice of different ranking and / or values of the endorsements themselves, this is not possible for the governance structure. As expressed earlier, there are issues with the meaning of such an indicator that prevent us from implementing it in a single and specific way. Consequently, unlike the first part of the influences, this classification of the scenarios will be done using a 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.

4.2.3 Representation of the regulator through availability of resource saving appliances

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 on the need for 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.

4.2.4 Metering is not represented because of the uncertainty of the effects.

Metering is not implemented in this model for two main reasons. First, the current issues for forecasts are rather in the evolution of unmeasured customers. Meter penetration level is currently 23% of households in England and Wales, so the main concern in water consumption remains unmeasured customers. Second, there are many ongoing studies regarding metering. While there is evidence it influences water consumption, it is not actually known in which proportion this happens, or what factors trigger the decision of opting for a water meter. Also, there are multiple reasons for a household to switch to a metered supply. Among them, the most common is the change of occupancy (*i.e.* moving out/in), while opting in is currently negligible. As a consequence, the effects of metering are yet unclear (OFWAT (1992)). Some preliminary results are available, but they do not show the kind of consistency necessary to believe they can be used to match the target system in a model.

Also, as already detailed, the agents in the current model are not mobile, geographically or socially. The limits, in the necessary knowledge to implement metering and in the usefulness of this implementation, explain the decision to ignore this component.

4.3 Model data

4.3.1 Climate data

The dataset 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 were generated during the course of the Climate Change: Demand for Water (CCDeW) project (Downing, Butterfield et al. (2003)). They are 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 et al. (2002)).

The climate data files include projected temperature as well as rainfall. For the parameters in the ground module, monthly average temperature and total precipitation time series for Central England for 1970-1997 were used, as well as a 51° latitude for calculation of the hours of daylight.

To match the UKCIP02 Medium-High emissions 2050 scenario the above time series were modified to reflect this UKCIP02 forecast for the upper Thames region. This involved modifying the temperature and precipitation data as follows:

Month	Compensation factor (%)
January	12.5
February	10
March	0
April	-5
May	-10
June	-20
July	-30
August	-20
September	-15
October	-7.5
November	0
December	10

Table 5: Monthly modification to precipitation time series

Month	Compensation factor (%)
January	1
February	1
March	1
April	1.5
May	1.5
June	1.5
July	2
August	2
September	2
October	1.5
November	1.5
December	1.5

Table 6: Monthly modification to temperature time series

Regarding the values for Ownership, Frequency and Volume, the data used in this model originate from the data used by the Environment Agency during their 2001 forecast. They only represent a part of the largest sample used by the Environment Agency since they are valid for one resource zone of one single company.

The data were collected by Three Valleys Water PLC, a company that supplies mains water to the North and East of London, an area which includes Stansted, Luton and Heathrow airports, and is only relevant to the unmeasured population of their resource zone 2. Despite being estimates, they represent the actual data reported by the company to the relevant stakeholders.

Consequently, these values for Ownership, Frequency and Volume are only an example of such data. Nevertheless, they represent a valid choice, since they are consistent with other data sources.

4.3.2 Water consumption estimates

In order to check how representative the data are, some specific uses are given by a Survey of Domestic Consumption (SODCON) and the Water Facts that seem quite consistent.

	SODCON	Water Facts	Average of the previous ones	Thames Water Demand Model (2001 estimate)	Min/Max	Three Valleys
Drinking, cooking and food preparation	21	29	25	22.8 (sundry[15])	21/29	30
WC flushing	49	53	51	42	42/53	36
Car washing and garden use	8.4	5	6.7	10.5 (0.4+10.1)	5/10.5	14.9
pool				0.3	#	
Washing up	5.6	14	9.8	8.7	5.6/14	15
Laundry	16.8	19	17.9	19.9	16.8/19.9	25
Personal washing and bathing	39.2	40	39.6	56.6	39.2/56.6	54
Total	140	160	150	160.7	140/160.7	175

All amounts are l/h/d

Table 7: Comparison of measured Pcc depending on various sources

The total PCC seems “standard”, the current value for metered households according to OFWAT being 150 litres/head/day, while the Pcc for the actual data used is slightly higher, at 175 litres.

This is not only explained by behaviour, it is also a consequence of different ownership patterns.

[15] The sundry indoor uses are based on population and household uses, *e.g.* for drinking, cleaning and hand washing.

Appliance Ownership	Measured	Unmeasured
(corrected survey figures)	%	%
Baths	98.6	98.2
power showers	32.8	30.3
other showers	61.0	54.6
washing machines	95.1	95.3
dish washers	46.2	38.6
sink/wash basins	100.0	100.0
outside taps	65.6	70.8
cold water storage tanks	N/A	N/A
ordinary toilets	91.1	94.7
dual flush toilets	13.2	9.7
possess sprinkler	26.0	14.8
possess hosepipe	66.6	74.9
other mains fed watering system	2.1	1.3
possess swimming pool	4.1	0.8
possess paddling pool	10.7	10.2
possess greenhouse	15.8	21.5
possess garden pond	13.9	17.2
possess car	89.2	87.8
Total responses (excluding nulls)	3,324	2,280

Table 8: Comparison between measured and unmeasured ownership

It is clear from this presentation of ownership that unmeasured households are less likely to have water efficient appliances (*e.g.* dual flush toilets), while more possibilities of external uses are present, with higher proportions of greenhouses, hosepipes and garden ponds.

The exception of swimming pools is explained by the regulations that force owners of such water hungry items to be charged by volume by their water company.

In the end, the consistency of the Three Valleys data with the different sources mentioned could be considered as good, in spite of differences that could be interpreted as changes due to regional variations. This is the case for ownership of dishwashers, or to a lesser extent, of swimming pools.

4.4 Inputs and Outputs

The model devised for this research is supposed to represent an artificial society. It is not a totally abstract system, and it is meant to be used by stakeholders, and not only analysed. It is supposed to provide some insight into patterns of behaviour for water demand within a group of agents. It is also an opportunity to try a different approach, 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. The previous chapter showed that there were three main areas for which the modelling had to hold particular attention:

- the environment, made of the agent’s location and the climate
- the imitation, composed of social influences and structures of preferences
- the innovation, including the rating, decision making and adoption of new technologies

A presentation follows of the underlying assumptions and the corresponding reasons for them.

4.4.1 Model components

4.4.1.1 The Agents

4.4.1.1.1 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.

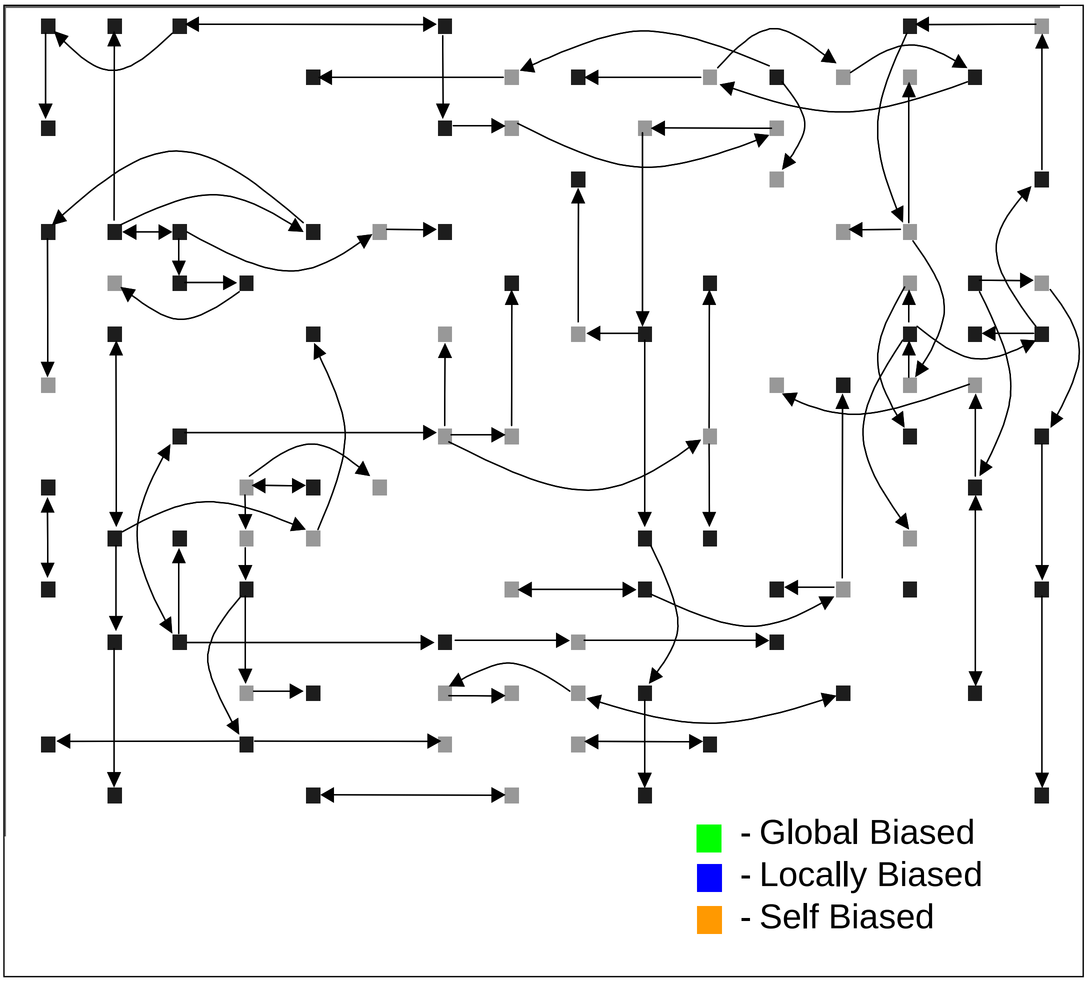

Figure 10: An example distribution of households (arrows show those households that are most influential to another)

The figure above is from Edmonds (2003) where the author discusses the relations between physical and social space. Edmonds describes the network between agents most influential to one another in a specific run of an earlier version of this model used in the CCDEW and FIRMA projects. In this article, the author expresses the view that “the particular network of social relations is important to the behaviour of the individual”, and demonstrates that removing the neighbour to neighbour influence increases the volatility of the results. Nevertheless, Gotts, Polhill et al. (2003) point out that, *“imitation of neighbours […] will not invariably prove superior to random choice among all possible alternatives”.* This is not contradictory to the results obtained by Edmonds but rather indicates that, as the authors conclude, it is necessary to analyse the processes involved in the imitation, the individual cognition, as well as the way decisions are made.

4.4.1.1.2 There is a policy agent

The Policy Agent 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 in the first chapter. The OFWAT and the Environment Agency are regulating the water companies, but the latter is the body representing the wise and knowledgeable voice of the government, if not the sensible voice of humanity. Of course that particular representation in the model is too simple to pretend to being any specific body or media, but it allows the implementation of an example of media that would broadcast with the same spirit.

For example, between 1976 and 2000 in the Thames region, the Environment Agency has declared only 8 droughts in 1977, 2 in 1990 and 3 in 1992, while in our model the Policy agent is more active (reacting, in the simulations, to 23 droughts of various duration during the period 1977-1997, and 30 in the period 1970-1997).

The Policy Agent is an important source of information and guidance. Only one is currently implemented, because this 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.

4.4.1.1.3 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 does not forecast, 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[16], agricultural[17], or socio-economic[18] 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 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.

4.4.1.1.4 Every household is defined by its set of Ownership, Frequency and Volume, which defines an output to the model

Some economic 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

[16] 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.
[17] An agricultural drought refers to a situation when the amount of moisture in the soil no longer meets the needs of a particular crop.
[18] A socio-economic drought refers to the situation that occurs when physical water shortage begins to affect people.

possess (or not) some specific appliance. The associated frequency of use, and volume per use are also informed by real data provided by stakeholders.

Volume could be expressed per time, and not per use. This is not the case due to the nature of the data provided, and is nothing else than an average value of the former with respect to the frequency of use.

Due to the nature of this data, the volume is expressed per use, instead of as a time dependent debit. It can be noted that the ownership of appliances can be seen as an indirect way of representing wealth for a household. Although not a very accurate one, it can be tuned by the model user, eventually to the extent of imposing clusters of households that would possess (or not) some specific appliance.

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

4.4.1.1.5 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.

The approached used here, is to define a number base b and evaluate each endorsed object according to the formula

$$V = \sum_{e_i \geq 0} b^{e^i} - \sum_{e_i < 0} b^{|e^i|}$$

where e_i is a (usually integer) value associated with the i^{th} endorsement token. Negative values of endorsement tokens indicate naturally enough that they are undesirable. The higher the value associated with an endorsement token, the higher the class of tokens containing that particular token. The value of *b* is the importance of an endorsement token relative to the value of a token in the class below. If the base is 2, then an endorsement of class three contributes 8 to the endorsement value of an object while an endorsement of class two contributes only 4. For values of b larger than the number of tokens in any class used to endorse any object, the results from this evaluation scheme are the same as from Cohen's evaluation scheme. For smaller values of *b* it is possible for a large number of lesser endorsements to outweigh a small number of endorsements of greater value

4.4.1.1.6 Every agent has a memory

The memory of an agent is limited. It 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. Anderson (1993) is the reference from the cognition field used to implement this theory. The memory is associated in the model with a probability to remember 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 past actions, but it will forget less quickly (or remember more) those that were important at the time. When one makes a decision, it is likely to have a trace corresponding to its importance. The decision of buying a house, or proposing marriage remains in memory much longer than the decision to have rice or pasta for the next meal.

Hence the probability is as followed:

$$P(M) = \frac{\frac{|E|}{t^d}}{|\max E|}$$

where *P(M)* is the probability of remembering, *E* is the value of the endorsement, *t* is the time elapsed since the endorsement was created, *d* is the rate of memory decay, and *max E* is the maximum value of an action endorsement.

This function is consequently positive, between 0 and 1, and has the appropriate characteristics for our purposes (increasing with E, decreasing for *t* and *d*).

4.4.1.1.7 Every household is amenable to suggestion by the water authority to different extents

Every household can be different. 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 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 in our case.

4.4.1.1.8 Every household has public and private activities

Real life observation easily demonstrates that there are public and private behaviours. 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).

4.4.1.1.9 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.

4.4.1.1.10 Every household's demand is influenced only by its endorsements

Due to the purpose of the model, the focus is not the representation of instant demand. This study tries to analyse the social and cognitive influences upon consumption behaviour. 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. Nevertheless, this requires a much finer grain of analysis than can be devised. For example, climatic conditions of a bank holiday Monday in May would become the most important parameters for the demand for water. Also, this level of detail would certainly have huge costs in terms of data treatment, household surveying, and computation times. There are many difficulties for this research to use data gathered by the water companies. Firstly currently available data are difficult to obtain, and secondly, necessary data might not be yet collected, and could need the development of different surveying methods or questionnaires. Hence the requirement for finer grained data surely necessitates more time and influence upon the water companies than available to researchers at the moment.

4.4.1.1.11 Every household decides to use the pattern known by itself 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 its 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 so-called consistency principle is presented in "Social Psychology" (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 seems 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 agree with ideas we like and respect and to dissociate themselves or disagree with ideas from which we dissociate ourselves.*" This idea is also present in Heider's closely related balance theory (Heider (1958)) (and its representation as the A-B-C model, in which the links between individuals A and B and another object C must balance each other), and in what the psychologist Eysenck (1954) refers to as the radical – conservative (or liberal – conservative) factor. This logic in attitudes and beliefs is labelled cognitive consistency.

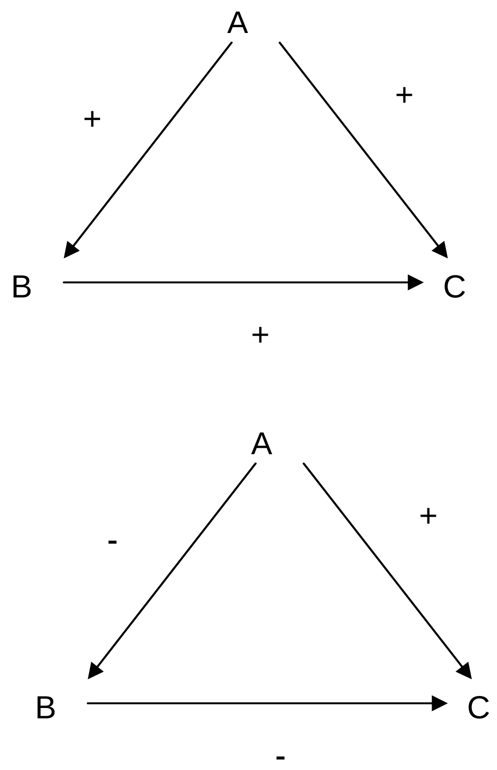

Figure 11: Representation of Heider's ABC model

4.4.1.1.12 Agents rate new products

As for every appliance, the emerging ones are subjectively rated. But unlike common ones that are already owned, these are rated on the basis of what information is communicated about them. They are eventually made available from a given point in time, from which they enter 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.

4.4.1.1.13 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.

4.4.1.2 The environment

4.4.1.2.1 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 temperature, sunshine time and precipitation. It is commonly and internationally used for that purpose (Thornthwaite 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

The value of the unadjusted Potential Evapotranspiration at temperatures above freezing is calculated as:

PET	Temperature (T) range
- 415,8547 + 32.2441T – 0.4325T2	26.5 ≤ T
16.5 (9 T / H) ^{a}	0 ≤ T < 26.5
0	T < 0

where H is heat defined as

$$H \equiv \left(\frac{T}{0.7}\right)^{1.514}$$

and the exponent *a* is

a ≡ 6.75e-7 H 3 - 7.71e-5 H 2 + 0.01792 H + 0.49239

Day lengths are calculated from the day relative to the winter solstice and the latitude. Monthly PET values are adjusted to reflect the difference in water use between a grass surface and a mixed landscape of grass, trees and shrubs. Monthly correction factors are:

Nov – Dec - Jan – Feb - March	April	May	June – July – Aug	Sept	Oct
0.8	0.9	1	1.1	1.05	0.85

Table 9: Monthly PET correction factors

4.4.1.2.2 Appliances break according to some probability distribution

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. Mean Time To Failure (MTTF) is its equivalent for non repairable ones, and the basis for a suitable warranty for the manufacturer. It should be noted that MTBF is commonly used for both repairable and non-repairable items. MTBF and MTTF are expressions of time, and represent the inverse of the failure rate (for constant failure rate systems). In that case, if a product fails 10 times in 250 hours, its MTBF is 25 hours.

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 (Bloch and Geitner (1994)). This is composed of 2 arguments, the shape and the scale, and can model a wide range of data and life characteristics.

4.4.1.3 The interactions

4.4.1.3.1 Every household can observe its neighbours

On the grid, 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 of social distances and neighbouring that prevents us from using an already validated technique in this 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.

The Moore neighbourhood consists in using every adjacent cell to the agent's. Alternatively, the Von Neumann approach consists in only the horizontal and vertical adjacent cells. The possibility to enhance the neighbourhood is taken into account in the modified versions of these definitions. Therefore, strictly speaking, this model uses the modified Von Neumann neighbourhood, although because it can be set as a parameter, it can sometimes simply use the Von Neumann one.

4.4.1.3.2 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.

4.4.1.4 Organisation

4.4.1.4.1 The size of the grid is limited

The grid is limited for several reasons. It is easier to analyse a system that is itself limited, whether it is to a postcode area, a region, or a country. Second, because of the simulation methodology and tools used in this case, there is a computational cost associated with the sample size of the system. The way the model is devised, this cost does not scale up linearly with the system's size and density, but much faster. While increasing size involves relatively linear costs (until a threshold is reached depending on the computer hardware), increasing density does multiply the amount of calculations necessary for a given agent.

Moreover, the size of the simulation will have a direct positive influence on the difficulty of analysing the results of that simulation. This includes computing limitations (for example the time to answer a query), as well as the ease of representation and analysis. It is for example a lot more tedious to check on the network structure during a simulation with a large grid than a smaller one.

This raises the issue of the extent to which a system can be scaled. The lower limit is the use of an average system, or average agent. Every individual is then summed up into a single one. This approach is widely used in microeconomics, but it is argued (Kirman (1992)) that heterogeneity of agents is needed, not aggregation, in order to generate rational collective behaviour.

4.4.1.4.2 The grid is toroidal

Initially, the grid is two-dimensional. There is a possibility to make it into a torus, *i.e.* it becoming doughnut shaped. This is to avoid corner effects in the grid that would tend to limit the possibilities of neighbours for some agents. It does create another phenomenon to look at since it is changing the topology of the underlying network.

The torus simulates a space that is bigger than it is computation-wise, and a society that is composed of multiple comparable elements. But with this method, it also enhances the amount of possible links, having important consequences upon the network structure.

4.4.1.4.3 The grid is regular

While there are possibilities of generating non-regular grids, this is not the case here. The situation of the agents on the grid allows us to represent their location, the abstract idea of installing them on a grid that represents some social space permits us already to consider various characteristics such as social distance, cliques, and the existence of neighbourhood. It is therefore not necessary (at least at this stage) to introduce some additional feature into the model that is not proved to be more suitable than the current implementation.

4.4.1.4.4 The time levels are naturally defined

The interest of simulations relies on the possibility to study the dynamics of a system, its processes. In order to keep realism, and due to the constraints from imported data (temperature and precipitation), the time levels must match those for which the model is intended. The level of detail to take into account will constrain the definition of the different stages. In this case, time levels are months and years, while another is added for technical reasons (namely the iteration level, for the synchronisation of information for agents that cannot access the component of a database that is created during the current time period).

This concludes the presentation of the model components. Now is the time for describing the model as a whole, and the sequence of events as they would occur during the simulation.

4.4.2 Model structure and sequence

Hence, the structure of the model is as follows:

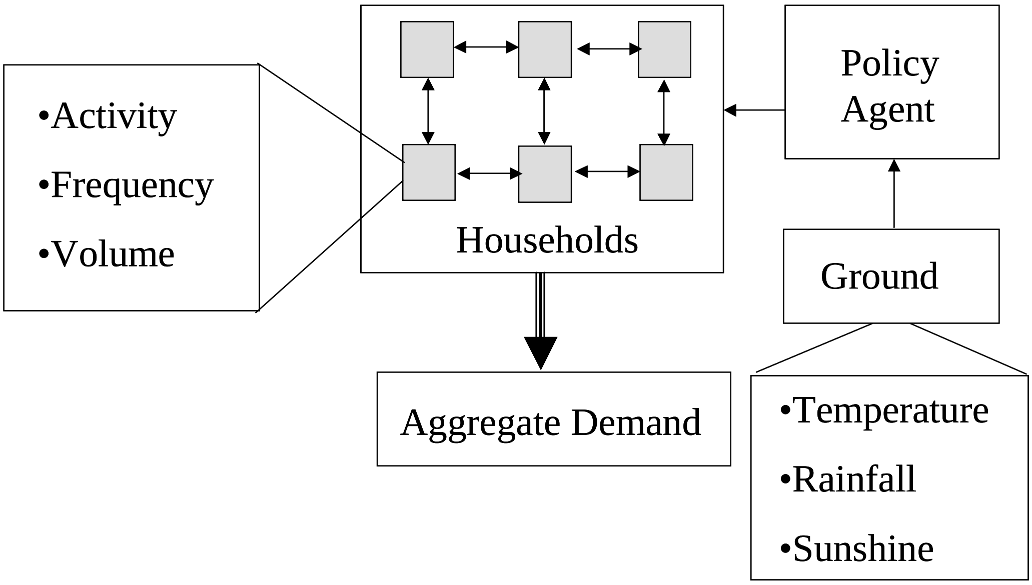

Figure 12: Model structure

The picture above 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.

The model is devised using SDML, which was described in the previous chapter. The formal stages used in order to represent more technically the process described in the previous chapter will now be presented.

When a simulation is run, the steps are as follows:

1. The simulation starts with initialising the Universe. This agent is unique, and like a matrix, will generate various kinds of agents according to the specifications provided.

2. Having read the rules in its rulebase, the Universal agent creates a first subagent called ThamesWorld. It also activates it so the software will read the instructions in this agent's rulebase.

3. In turn, the agent ThamesWorld generates and activates two subagents: FirmaModel, and ThamesGround. These agents will represent respectively the society, and the soil represented in the model.

4. At this moment, ThamesWorld will describe different time levels, called "run", "year" and "month". Since they are inherited, from this point onwards the subagents will recognise these time levels as well.

5. In the FirmaModel and the ThamesGround rulebases are most of the parameters of the model, such as the maximum runoff or the extent of the vision for the household. They will be read and kept in the database, and will be available to all subagents

6. The FirmaModel will generate subagents called Citoyens, and give them random locations on a grid. It will also generate the unique PolicyAgent.

7. Every agent of type Citoyen then generates and activates its own subagent, a metaCitoyen, which can be compared to a brain, in that it will change the preferences and will make the decisions for the Citoyen.

8. At the level of this metaCitoyen, and in the first rules to fire are those which specify individual parameters for the households, such as the values for the endorsements, or the initial values for the ownership, frequency and volume.

9. In the "content" period the important processes are defined. Since they depend on past choices and parameters, the description of its sequence needs to be considered from the first step in the simulation.

a. Once every agent is created, and the metaCitoyen is endowed with individual values as well as more global parameters, the behavioural processes take over the simulation.

b. In the first time step, every household is provided with some arbitrary behaviour, copied from the initial values it has received. Therefore, the parameters randomly chosen are in effect the first actions a household will undertake.

c. The initial values for frequency and volume are the results of a function. This function can have multiple shapes or arguments. In this research, it will be assumed that this function is either of a power law form, or a normal form. The distinction and its results are addressed in the following chapters.

d. Every action a household has been using is observed by itself, and therefore it is associated with one or several endorsements, such as “selfSourced”, or “recentAction”.

e. Once every household has acted, they observe each other. As they are all on a grid, a simple rule can find any neighbours of a specific household, according to the particular support or type of “vision” available.

f. From the observation of the surrounding households and the way they behave, every household collects information on others’ actions, as well as on their identity, and how similar or dissimilar they are in their ownership or use of appliances.

g. The information collected is treated using the filters provided by the endorsement schemes. A household will be endorsed as “most similar”, or with the closest overall volume of use for example.

h. If some new appliances become available at some stage, the households then integrate the overall list of appliances and actions that will be endorsed. When this happens, every household is aware of the availability of the new appliance at the same time. The differences in the way each agent values that information will make them more or less likely to select it in the end.

i. At this stage enters the Policy Agent. Since for any month there are data for temperature, rainfall and sunshine hours, the status of the soil moisture is updated. The Policy Agent collects this information and according to its value may react or not. If the soil moisture is less than a specific threshold for a given number of consecutive months (here 85% for 2 months), it then broadcasts a message.

j. The message in itself consists of actions, *i.e.* of a set of appliance, frequency and volume. It is at first calculated to be below the societal average for each variable, and will decrease further if policy is still need in the next month.

k. So the household has several sources of information: its own observations, the eventual availability of new appliances, and the eventual presence of a message from the Policy Agent.

l. All these sources of information are compared with the household's subjective mind frame, represented by the endorsements. Any information on an action, an appliance or an agent will be analysed, and as some will match the definition of an endorsement, their value for the household will change. As an example, the history of a particular action in one of the simulations is described as follow:

Month 1: used, endorsed as *self sourced*

Month 2: endorsed as *recent* (from personal use) and *neighbour sourced* (used by agent 27) and *self sourced* (remembered)

Month 3: endorsed as *recent* (from personal use) and *neighbour sourced* (agent 27 in month 2).

Month 4: endorsed as *neighbour sourced* twice, used by agents 26 and 27 in month 3, also *recent*

Month 5: endorsed as *neighbour sourced* (agent 26 in month 4), also *recent*

Month 6: endorsed as *neighbour sourced* (agent 26 in month 5)

Month 7: replaced by action 8472 (appeared in month 5 as *neighbour sourced*, now endorsed 4 times, including by the most alike neighbour – agent 50)

m. Once the endorsement values of all possible items of information are known, the metaCitoyen is in a position to make choices. The output of this process is the selection of new appliances. According to the agent's previous ownership, to the potential new appliances, and to the probability that they are broken, a new set of endowments is selected.

n. The frequency and volume corresponding to this appliance are chosen using the same method, comparing the individual evaluations for the actions observed to keep the highest one.

10. As the meta-agents have made their choices, every agent simply executes this "order".

11. Finally, at the FirmaModel level, the individual consumption for a household is computed, and aggregated into monthly data, in order to be collected in a file.

12. Once all the rules have fired in the month, SDML jumps onto the next, and the process carries on.

In order to keep consistency in the simulation the smallest time level is not the month, but the iteration. For every month, there are two iterations. During the first one the information is gathered and stored, and during the second one, the selection process and the storage of the results take place.

4.5 Representation of innovators

The starting point is the observation of the introduction of power showers as a substitute for traditional showers. It leads to the conclusion that some new devices can appear and have important consequences upon household consumption. It is hence necessary to implement innovation, which raises the problem of representing innovators in order to study the diffusion of a technology.

4.5.1 An issue with several dimensions

Several different points of view on innovation are worth investigating. The way it appears and the way it diffuses are the main ones. I am not going to discuss and implement a way of modelling the emergence of innovation.

Although it is an interesting field of research, it is not one that matters in the present work. This research is focused on water demand. As such, it is only interested in how the new technologies will be adopted not which ones will emerge. One could argue that these two questions are linked, and that depending upon the nature of the technology, it will be adopted more or less easily. Several studies show this fact (Rogers (1995)). This additional problem would nevertheless make this present research harder to validate and remote from its original aim.

The complexity of modelling the emergence of innovation is certain. Existing models mainly deal with firms more than households (Gilbert, Pyka et al. (2001)). Since we expect to reach some understanding of the target system from our representation, the implementation of a whole theory of innovation emergence would eventually increase the difficulty of devising the model, as well as the difficulty of eventually concluding from it. Also, it would make it more likely to be criticised from a theoretical point of view.

The need to consider innovation actually comes from the observation of a real phenomenon. In the early ’90s, a new kind of appliance appeared: power showers. They were aimed at replacing showers, and were relatively easy to install. They included an internal boiler and pump, and would then replace the older shower jet and only required a water pipe and an electricity source. They were reasonably cheap and improved the water pressure from the shower jet. But that came at a cost. The additional pressure meant using about double the amount of water for the same use, reaching nearly the amount used in a bath. The frequency of use itself did not change much though (and even increased according to some of our data). The result was a major change in water demand levels and patterns. This is the reason why it is necessary to build our representation in such a way that events like this can be included.

Hence this research must give the user the freedom to include the emergence of new devices and their appropriate characteristics. It is then a matter of following the diffusion of that innovation through the society and its effects on local or global demand.

The focus is not on the generation of innovations, but because the consequences of innovations must be taken into account, diffusion has to be as well. That is why some representation of innovation diffusion amongst households must be implemented, while the innovation theory itself can be left aside.

4.5.2 Innovation and innovators

It is necessary to define the concepts, and some characteristics of the current literature on innovation.

Quite an exhaustive view of innovation diffusion can be found in Rogers (1995). He defines diffusion as “the process by which an innovation is communicated through certain channels over time among the members of a social system”.

Rogers presents all (or nearly) the aspects of innovation, from its generation to its consequences, through the study of its diffusion through the characteristics of the technology, of the user, and of the underlying network. It is noticeable that the diffusion of innovation depends a lot on the nature of the innovation. Innovations have specific characteristics that could explain the rate of adoption, *i.e.* the success or the failure of a given technology: relative advantage, compatibility, complexity, trialability, and observability. Some even display self-reinforced dynamics, when the technology can benefit from network externalities. What is taken into account then is the global influence of the number of adopters in the system, not only locally (Blume (1993), Ellison (1993)).

These characteristics are obviously tightly dependent on the technology itself and hence will not be included extensively in the present study for the aforementioned reasons. The common literature, mainly composed of surveys, presents these characteristics of the technology along with the characteristics of the individuals to explain the success or failure of some specific cases.

The survey-shaped studies on diffusion are numerous. Surveys have been done on villages in the Andes (Rogers (1995)), on computer software (windows 95), on farmers adopting a specific type of corn or seeds, on doctors prescribing new drugs, on plane hijackers, on contraception methods adopted by women in different countries, etc.

The vast majority (if not all) of these try to analyse the reasons for adoption, and specially the first adoptions. And most of them conclude that socio-economic status is related with innovativeness.

After many studies and debates, a scale and a classification appeared. Proposed by Rogers in 1962, it is based on the assumption that the frequency of adoption follows a bell-shaped curve, and the associated cumulative curve is S-shaped. The adopters are then categorised depending on their time of adoption.

- The innovators are the first 2.5%
- The early adopters are the next 13.5%
- The early majority is the next 34%
- The late majority is the next 34%
- The laggards are the last 16%

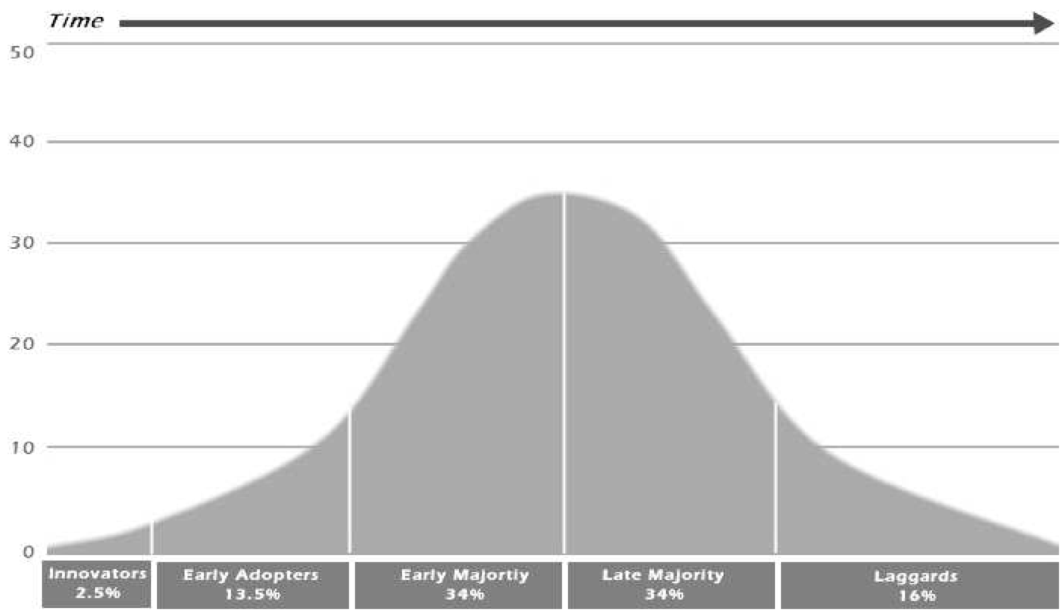

Figure 13: Identification of the class of adopters based on the timing of adoption by the various groups

These numbers are based on the intervals each side of the average time of adoption. The innovators are more than 2 standard deviations less than the average, while it is only one for early adopters, the early majority is situated within a standard deviation less than the average, the late majority is within a standard deviation more than the average, and the laggards are adopting a technology after a period of time that is more than the average plus one standard deviation.

This kind of categorisation is useful in order to characterise every type of individual. Hence, from the venturesome innovators to the traditional laggards, many generalisations can be drawn on the innovators and the diffusion of innovation. The bell-shaped curve for the adoption frequency in the case of a successful technology is stated in Rogers (1995).

Generalisation 7-1: Adopter distributions follow a bell-shaped curve over time and approach normality

While the general characteristics of a product, or condition for success, are generally similar through the literature, there are a variety of approaches towards the individual himself and the subjective influences upon him. A branch of the literature only describes ex-post the social, economical, psychological and cultural characteristics of the individual, as a synthesis of many surveys. Whereas the network component is seldom taken into account, using the network properties and the situation of individuals within that network is actually the other possible way to discuss the diffusion of innovation.

Intuitively, a model that would consider only internal or external influences does not seem close to representing real life phenomena. Those who actually tried to implement both reached better results with a mixed model, as in the ATM system case study by Dos Santos and Peffers (1998). While their external influence model assumes that adoption is only driven by information from a source external to the social system, the internal influence model assumes that adoption is driven by communication within a specific community or social system. The mixed model assumes both of these, and corresponds to the Bass model (a model based on differential equations, and hence for which it is a necessity to know the global proportion of adopters, or market potential).

The Bass model was devised in 1969, and attempts to predict the adoption of a new product or technology. Bass (1969) suggested that the likelihood that an individual would adopt a technology at a given time *t* was given by the equation

$$L(t) = p + \frac{q}{\overline{N}} N(t)$$

where

$N(t)$ is he number of customers who have already adopted the innovation by time t;

$\overline{N}$ is a parameter representing the total number of customers in the adopting target segment, all of whom will eventually adopt the product;

p is the coefficient of innovation (or coefficient of external influence);

q is the coefficient of imitation (or coefficient of internal influence).

The basic assumption of the model is that the probability of initial purchase by a consumer is related linearly to the number of previous adopters. Adopters are composed of both innovators and imitators. The number of previous adopters does not influence innovators in the timing of their initial purchase, while imitators are strongly affected by the number of adopters. Obviously, innovators have greater importance at the launch of a new technology than after it has become widely disseminated.

This model implies exponential growth of initial purchases to a peak and then exponential decay. The first component *p* refers to a constant propensity to adopt that is independent of how many other customers have adopted the innovation before time *t*. The second component is proportional to the number of customers who have already adopted the innovation by time *t*, and represents the extent of favourable interactions between the innovators and the other adopters of the product (imitators).

The main issue in this kind of modelling is that the market size must be known *ex ante*, as well as some additional conditions. Either the technology must have been recently introduced and its initial pattern of diffusion be known, or some similar technology adoption pattern can be found in history and used as a substitute. Extensions to the Bass model were devised, adding for example prices, advertising and other marketing variables into a generalised Bass model (Bass, Krishnan et al. (1994)).

One might feel that the structure of individuals' preferences needs to be distinguished from the underlying support for the interactions, namely the network. This is in a sense pointing towards Granovetter's idea that the communication (and hence the diffusion) in a system is largely dependent on the structure of the system (Granovetter (1985)). The possibility of a diffusion phenomenon that is not depending on social characteristics of the individuals was raised for example in Steyer (1995). He developed a model of diffusion based on avalanches, expressing social dynamics not anymore in terms of exponential law (as in the Bass model and its derivatives), but in terms of power law. This leads to the increased importance of the support of interactions.

Valente (1996) went even further in this direction, using models of diffusion with threshold effects, where no social component is present, and only the surroundings of an individual matter. It is using three examples (the diffusion of a medical innovation, the diffusion of hybrid corn, and the diffusion of family planning in

Korea), to demonstrate that the commonly used categorisation of individuals[19] can be obtained either via a model representing the social system, or via a model representing the individual personal network.

Importantly the focus has shifted from the diffusion of innovation in a “global system” point of view, or the whole network, to reach a “local system” point of view, or the local network. This research uses the latter. Diffusion as a whole is only the consequence of the decision making of an individual. Therefore the intent is not to propose a new standard representation of innovation, but a more sensible representation of innovators and their decision-making.

4.6 Assumptions and representation of a scenario

The assumptions for each scenario presented in this section reflect my understanding of Appendix 3 (“Micro-component forecast assumption tables”) of “A scenario approach to water demand forecasting”, representing the view of the Environment Agency.

Analysis of the assumptions underlying every scenario is difficult. Not really because of the assumptions themselves, but rather because of the lack of information about the way the scenarios have been generated. Nevertheless, the particulars of every scenario can be presented and debated (market penetration of devices, ownership and volume, absence or presence of future saving technologies, regulations and eventually metering) if some source of information can be found.

The various characteristics of scenarios for every micro component are as follows.

4.6.1 Toilets

The standard frequency of use for all WC type is assumed to increase from 4.12 in 1996 to 4.3 by 2021 due to the increase in density amongst the population.

4.6.1.1 Full flush toilets (9l)

Ownership

[19] Although composed of only 4 distinctive groups in this case: early adopters, early and late majority, and laggards.

scenario	A	B	C	D
Replacement rate	1/40	1/30	1/20	1/40

Volume is considered constant.

4.6.1.2 Dual Flush toilets (7.5l)

Ownership

scenario	A	B	C	D
Replacement rate	1/40	1/30	1/20	1/40

Volume is considered constant.

4.6.1.3 Low volume toilets (7l)

Ownership

scenario	A	B	C	D
Replacement rate	1/40	1/30	1/20	1/40

Volume is considered constant.

4.6.1.4 Dual flush toilets (4.5l)

Ownership

scenario	A	B	C	D
Replacement rate	1/40	1/30	1/20	1/40

Volume is considered constant. The different flushing uses are either 6 or 4 litres, used respectively with a ratio of 1/3 and 2/3.

4.6.1.5 Low volume toilets (6l)

Ownership

scenario	A	B	C	D
Replacement rate	Residual from 2001	Residual from 2001	1/20 Residual from 2015	1/40 Residual from 2015

Volume is considered constant.

4.6.1.6 Future technology

Ownership

scenario	A	B	C	D
Substitutable technology	N/A	N/A	4l low volume from 2015	4/2.5l from 2015

Volume is 4 litres in scenario C, and 3.25 litres in scenario D

4.6.2 Personal washing

4.6.2.1 Bath

Ownership declines from 97% in 1991 to 91% in 2021, keeping a minimum of 85%.

Frequency declines from 0.34 litres/head/day in 1991 to 0.31 litres/head/day in 2021.

Volume is considered constant.

4.6.2.2 Standard shower

Ownership

scenario	A	B	C	D

Penetration and replacement rate	Residual from PS (base 96%)	Residual from PS	From 50% in 1997 to 96% in 2025, replacement rate 1/20 after 2010	Same as C, rate 1/15

Frequency changes from 0.35 uses/head/day in 1991 to 0.5 uses/head/day in 2021, without going over a maximum of 0.6 uses/head/day.

Volume is considered constant.

4.6.2.3 Power shower

Ownership

scenario	A	B	C	D
	Max 50% in 2025	Max 59% in 2025	5% in 1991, 50% in 2021, then rate of decline 1/20	5% in 1991, 50% in 2021, then rate of decline 1/15

Frequency

scenario	A	B	C	D
	0.52 /h/d in 1991 to 0.6 in 2021, max 0.61	0.52 /h/d in 1991 to 0.6 in 2021, max 0.61	0.52 /h/d in 1991 to 0.6 in 2021, max 0.61	Similar to the others, but max 0.57 in 2010

Units are uses/head/day.

Resource zones with frequency higher than 0.61 remain constant for the period.

Volume

scenario	A	B	C	D

Volume per use	From 100 litres to 150 litres in 2025	From 100 litres to 150 litres in 2025	Constant (100 litres)	Constant (100 litres)

4.6.2.4 Hand basin

Everything remains constant

4.6.3 Clothes washing

4.6.3.1 Automatic washing machines

Ownership reaches saturation to 94% by 2015 then reduces by 0.5%/year in scenario D.

Frequency reduces from 4.5 uses/head/week in 1991 to 4.3 uses/head/week in 2021 for scenarios A, B and C, but remains constant from 2015 onwards in scenario D.

Volume:

scenario	A	B	C	D
Volume per use	Reduces to 80l by 2010, then constant	Reduces to 50l by 2025	Reduces to 40l in 2025	Reduces to 40l in 2025

4.6.3.2 Washing by hand

Ownership is obtained as residual from the users of washing machines.

Frequency and volume are constant. Therefore Per Capita Consumption (PCC) for this appliance depends on ownership only.

4.6.4 Dishwashing

4.6.4.1 Dishwasher

Ownership:

scenario	A	B	C	D

Evolution per annum	1.7% then 1.5% per year from 2010	2% per year	1.7% increase per year	1% per year

Frequency is considered as constant.

Volume:

scenario	A	B	C	D
tendency	Reduces to 30 litres in 2010	Reduces to 20 litres in 2025	Reduces to 15 litres by 2025	Reduces to 15 litres by 2025

4.6.4.2 Washing up by hand

Ownership is residual from dishwasher ownership.

Frequency is considered constant.

Volume is considered constant.

4.6.5 Garden watering

4.6.5.1 Garden sprinkler

Ownership

scenario	A	B	C	D
Tendency	Same as scenario B, with only +0.25%/year from 2010	+0.5%/year, maximum of 29% in 2025 (South East England only) and 20% others	Constant from 2010	Reduced to 7.5% in South East and 5% others

Ownership is currently 25% of garden owners.

Frequency

Scenario	A	B	C	D
Frequency of use	20 uses/year in 1991 to 25 in 2021	20 uses/year in 1991 to 25 in 2021	Increasing till 2010 then constant	Increasing till 2010 then halves

Volume is considered constant.

4.6.5.2 Other garden watering

Ownership is 54% in 1997/98 and in the South East of England increases by 0.5% per year with a maximum of 70% in 2025. It is constant for other regions.

Frequency

Scenario	A	B	C	D
Frequency of use	39 uses/year in 1991 to 58 in 2021	39 uses/year in 1991 to 58 in 2021	Increasing till 2010 then constant	Increasing till 2010 then halves

Volume increases for scenarios A, B and C from 132 litres in 1991 to 153 litres in 2021. In scenario D, volume decreases from 2010 to halve by 2025.

4.6.6 Car washing

Per Capita Consumption due to car washing with hose and bucket increases from 0.9 litres/head/day in 1991 to 1.5 litres/head/day in 2021 in scenarios A and B. In scenario C it is constant, and it declines in scenario D.

4.6.7 Direct heating system

Ownership of combination boilers is 13% for 2000, constant in scenarios C and D after 2015.

Frequency is 5 uses/household/day and remains constant.

Volume is 5 litres and remains constant.

4.7 Scenario drivers

Detailed and general characterisations of the scenarios are of course linked. Nevertheless, the way they are derived from one another is not clearly stated. This will have important influences upon the model design.

The different grains of description for the scenarios seem clear. On one hand there is a global situation with generic circumstances of governance structure and societal state, while on the other hand there are details about the various appliances, their appearance, replacement rates, and evolution of their characteristics of use. But going from one to the other requires a deep understanding of complex interactions, and the generation of assumptions. For example, the necessary assumption used that there will not be any major unpredictable event that would change the background of the study (such as the terrorist attack in 2001, it could be a nuclear incident, or some major earthquake/flooding, some financial crash, etc.)

It is not without difficulty that one can generate such accurate assumptions, starting only from a somewhat generic definition of environment.

The precise steps used by the Environment Agency to improve the grain of analysis are not publicly available. They are certainly based on detailed studies and extended knowledge of the common resources and the associated issues. The statistical methods they use are generally well devised according to the constraints they face.

Probably the most appropriate way to represent the various scenarios in a model would be to have indicators, variables that would correspond to the generic ways to classify the scenarios, and hence select or generate them. This straightforward method is difficult to apply in this case for several reasons.

The Environment Agency states that the scenarios differ according to governance structures and social values.

These indicators are not absolute. While one can argue about what are community or individual-oriented values, their definition can be given. Composed of perceptions, of values of what is good or bad, it might not be possible to represent them on a continuous axis (or thanks to a continuous indicator).

Implementing such differences within a Multi agent model is not possible though. There cannot be a single straightforward indicator that would signify something in a case, and something else in another.

For example globalisation in the case of a community-oriented society could have a different meaning (as translation into reality) from globalisation in the case of an individual oriented situation. There are different levels for which the word globalisation can be understood, and that cannot be implemented as such in the case studied here.

Another reason is that these scenarios have been selected as the most representative ones amongst certainly a fair number. Whether all of them could have been categorised this way is a question that will remain unanswered, but it seems unlikely.

The fact that the presentation of the scenarios lacks details has implications for the implementation, *i.e.* the model design.

Ideally, the different variables represented by the diagram axes would be implemented so they can be changed at will, preferably in a simple way. As presented above, this is not possible here. Therefore, the starting point of the scenario selection will be the social values, to which a specific indicator will be attributed, while the governance system will be imposed upon the variables in the model according to the details given in the fine description of the scenarios.

More precisely, the social values will be represented by the values of some specific endorsements, while the governance system will be represented by what are described as the consequences of such a state, *i.e.* the specific replacement rates and other details of the scenarios.

4.8 Conclusion

This chapter presented the way the scenarios are described by the Environment Agency, and will be implemented in SDML.

Section 4.2 pointed out four assumptions that the model relies upon:

- Social values are represented by endorsements;

- The governance structure is represented through the characteristics of a scenario;
- The presence of a regulator is represented through the availability of resource saving appliances;
- Uncertainty of its impact on water demand prevents us from including metering into the model.

Section 4.3 presented the source and details of climatic data. It is assumed that climate will change according to the UKCIP medium high assumptions. The data used for ownership, frequency and volume used for all appliances comes from Three Valleys PLC and are consistent with a sample for an unmeasured population.

Section 4.4 detailed the model components. It described the components and their characteristics, their main behaviour and the algorithms used to implement it.

Section 4.5 presented a point of view on the representation of innovators in the literature, pointing out the fact that the amount of information available while running the model is not compatible with the information required by a global equation (similar to the one in the Bass model). The analysis of threshold effects justifies the decision to use the agent rather than the society as the base to implement the diffusion of innovation.

Section 4.6 described all the assumptions from the Environment Agency's reference publication.

Section 4.7 discussed the scenario drivers, arguing that indicators would be the best way to represent social values and governance. Since governance values could have different meanings in the various situations of social values, there cannot be a single straightforward indicator, hence the remark at the beginning of this section that governance structures that characterise a scenario are represented via the values of the parameters of this scenario.

The next chapter describes the way these scenarios are implemented, results of the simulations for individual scenarios, and an analysis of the sensitivity of the results obtained.