Policy Modelling with ABSS:
The Case of Water Demand Management

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1 Introduction

A promising area of application for agent based social simulation is social policy analysis. This promise stems from the ability of ABSS models to describe key processes and relationships in actual societies. However, existing descriptive studies with ABSS have been too abstract convincingly to inform policy analysis. This paper describes the transition from one such study towards a usefully detailed and realistic model currently being developed to inform water demand management in the south of England during a period of climate change.

The FIRMA project, in which this work is being undertaken, was proposed specifically to use agent based modelling techniques to enable stakeholders to become involved in the model specification and validation process. The value of the agents approach in this context is that the stakeholders can assess whether agent behaviour, interaction among the agents and resulting system level properties are descriptively accurate.

Capturing water demand management issues with agent-based models is itself a highly non-trivial task. In the first place, stakeholders including both regulatory agencies and water supply companies have identified weather, drought or its absence, demographic factors and technology as essential elements in any description of the determinants of water demand. The models to be used in policy analysis will have to capture all of these phenomena. In practice, this requires an single model relating consumption to rainfall, temperature and humidity (weather), hydrology relating the weather to the level of groundwater (drought) and the effects of those on both water demand and public authorities' measures for managing that demand. So in a single model, we have to capture the weather system, the hydrological system, the behaviour of households and the behaviour of policy agencies and, moreover, to do so in a way that engages stakeholders in the model development and validation.

The procedure we have adopted is to construct a sequence of models at increasingly fine grain and increasingly lower degrees of abstraction. Each successive model is constructed on the basis of data provided by stakeholders and to validate each model with stakeholders.

The first model in this sequence, including revisions in the light of stakeholder assessments (validation), was reported by Downing *et al.* (2000). A summary of this report is presented for convenience in Section 2. Section 3 identifies the shortcomings of that model and the next step in rectifying those shortcomings by extending the scope of the model and by incorporating more detailed data.

2 Prototype water demand model, versions 1 and 2

The issue addressed by the first prototype model was the ability of policy authorities to influence domestic water consumption simply by exhorting the public to conserve water whenever conditions of drought prevail. Such exhortations have been effective in droughts in the UK but not in other European countries represented in the FIRMA project. So one aspect of the modelling exercise is to identify in general terms the conditions in which exhortatory demand management can be effective.

2.1 Model structure

The model was implemented in SDML which supports agents and agent containers. The containers can order the sequence in which agents fire their rules or the agents they contain can fire their rules effectively in parallel. The agent thamesValley is the container directly or indirectly of all of the components of the model. One of these components is the simple agent ground while the other is itself a container agent called thamesModel. The agent ground implements the hydrological model, determining the amount of water in the soil from temperature and precipitation data. The soil water is determined first at each time step of the simulation and asserted to the database of ground. The agents contained by thamesModel, in particular policyAgent representing the policy authorities, can read the clause specifying the current level of soil water from ground's database. policyAgent has rules to determine from the soil water level whether drought conditions prevail and, if so, whether domestic consumers should be exhorted to restrict their use of water and, if so, to what amounts. In all of the reported simulation runs, there were 100 agents representing domestic water users. Each domestic water user was an agent that itself contained a meta-agent.

A meta agent differs from other agents in that the meta agent treats the rulebase of its containing agent as a database. That is, a meta agent can read the rules held on the rulebase of its containing agent and it can write rules to the containing agent's rulebae as well. In the Thames prototype model, the meta agents write rules for their containing household agentss to determine their water use each month. Consequently, all of the reasoning about water use and the decisions about how much water to use in which conditions is encapsulated in the specification of the CitizenMeta.

2.2 The hydrological model

The purpose of the hydrological model is to simulate the occurrence of drought conditions on the basis of real precipitation and temperature data. The policy agent determines there to be a drought when soil water is less than 85 per cent of the soil water retention capacity for two or more consecutive months.

The current soil water content is determined from data for rainfall and temperature applied to the well established modified Thornthwaite algorithm to determine evaporation from bodies of water and transpiration from plants and animals. The difference between precipitation and evapotranspiration is the addition to the soil water in the month.

The model also yields the runoff of water but this value was not used in the Thames water demand model. It will however be used in extending the model to incorporate flood conditions.

2.3 The social model

The model was constructed to capture the fact that every individual has a limited but usually non-empty set of acquaintances. This was achieved by situating the household agents on a toroidal grid and enabling each agent to know every agent within a set number of cells in each of the four cardinal directions. In all of the simulation runs reported here, the grid size was 30^2 (= 900) cells, there were either 80 or 100 instances of *Citizen* distributed at random on the grid with no more than one agent to a cell and each agent had a horizon of 4 cells in the sense that it knew all agents in the four cells to the right, to the left, up and down.

Two abstract types of water consumption event are defined: private consumption events that are not visible to any but the consuming agent and public consumption events that are publicly visible. Each agent is able to observe the public consumption events of all agents known to it. Each agent decides how much water to use during each event and the frequency of use events measured by the number of events per month. This is also the information viewed by the agent's neighbours.

In addition, each household agent can read the exhortatory policy pronouncements of the policy agent. These pronouncements take the form of recommended frequencies of each activity (public and private) as well as consumption per use event. The frequency and consumption per event recommended by the policy agent are both determined by the previous month's use and the current shortfall of soil water below 85 per cent of capacity. So if, for all domestic households, the previous average frequency of a water using activity were f and the use per event were u and the current soil water magnitude is 75 (capacity = 100), then the policy agent would recommend that each household engage in the consumption activity on $0.75 \times f$ occasions (rounded down to the nearest integer) and that the use per event be $0.75 \times u$. In every drought month when the soil water diminishes, the frequency and use per event demanded by the policy authority is reduced according to the above formulae. The policy agent does *not* change the demanded frequency or use per event when drought conditions persist but the soil water increases. When the drought ends – because soil water exceeds 85 percent of capacity – the policy agent simply ceases to offer any exhortation.

This behaviour by the policy agent captures at coarse grain the behaviour actually observed with regard to the authorities' public pronouncements and statutory restrictions in the UK during periods of drought.

2.4 Agent cognition

The cognitive processes of the household agents were specified to capture observed patterns of demand for goods and services by representing social interactions that have been well documented by observation and experiment by social psychologists in a manner that also reflects the fact that individuals change their behaviour in response to a significant weight of evidence and social pressure but not in response to small changes in price, incomes or any other variable. The representation of the determinants of behaviour are described first and then the specific representations developed to capture the role of exhortation and social interaction.

The representation of the decision-making process is the *endorsements* mechanism devised by Paul Cohen (1985) and used to good effect in several social simulation studies (e.g. Moss and Sent, 1999; Moss, 1998) to capture observed behaviour. The endorsements mechanism entails the use of rules to attach tokens to objects. Two types of object were endorsed by household agents in the Thames prototype model: actions and other household agents. The actions available to the household agents are water-use actions consisting of use frequencies and consumption per use-event.

There is an endorsement scheme for each type of object to be endorsed. So in the Thames model there is one endorsement scheme for water-use actions and one for visible household agents. For all households, the tokens with which actions and agents, respectively, can be endorsed are identical.

The endorsements on actions are *globallySourced*, *neighbourhoodSourced*, *selfSourced* or *bestEndorsedNeighbourSourced*. The first three are straightforward. Globally sourced actions are actions that the policy agent is recommending publicly. Neighbourhood sourced actions are actions that are observed to be taken by visible neighbours while self sourced actions are actions preferred by the individual independently of any external influences. The fourth endorsement, *bestEndorsedNeighbourSourced*, is accorded to the action observed by the neighbour that is most highly valued among all of the visible neighbours of the agent. That agent is the neighbour that is most like the endorsing agent and is determined by the agents' endorsements scheme.

The endorsements on other agents are *closestActivityConsumption*, *closestActivityFrequency* or *closestActivityFrequencyAndConsumption*. The idea here is that other agents can be valued because their consumption per use-event is closer to one's own than the consumption per use-event of any other agent or because the frequency with which an agent engages in an activity is closest to one's own frequency of engaging in that activity. There is an added appreciation of any agent whose consumption is most like one's own in both frequency of events and consumption per event.

2.5 Simulation results

The results obtained from the first version of the Thames prototype confirmed that the combination of agents who are influenced by authority and word of mouth communication among socially influenced agents can be effective in managing demand. A typical pattern of drought and demand is depicted in Figure 1 where the lower saw-toothed line is the number of consecutive months of low so8il water and the upper line is the simulated domestic water use. By inspection, the volume of water consumption declined during the dry periods, which was when the policy agent was exhorting households to restrict their consumption.

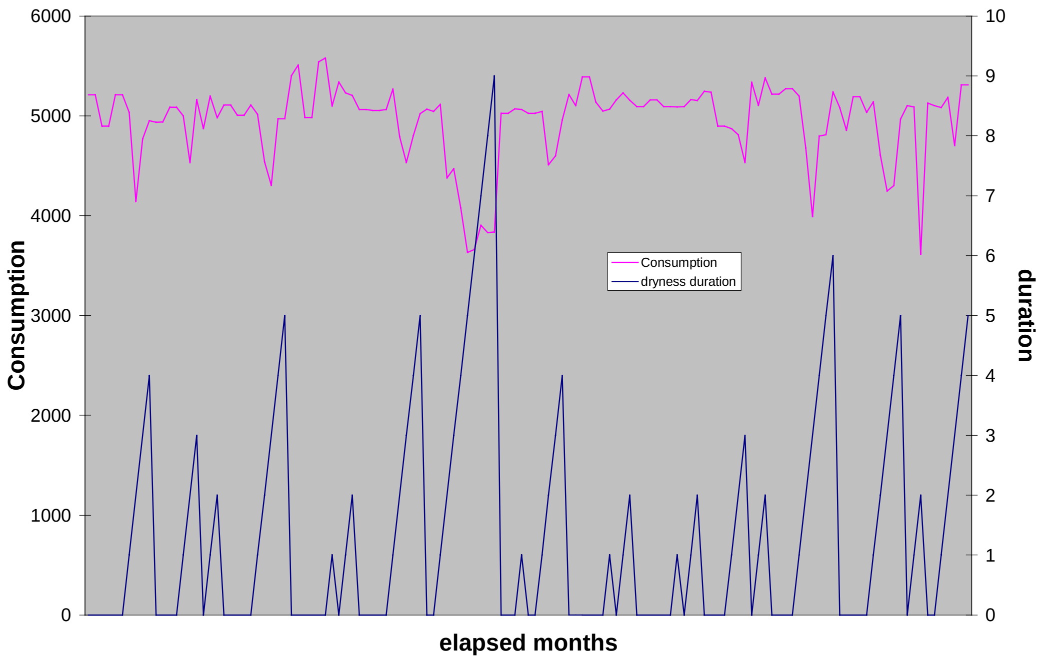

Figure 1:Drought and simulated domestic water use

Figure 4 reports a representative segment of the time series reported in Figure 1. The dip in consumption from April, 1990 until January, 1991 corresponds exactly to the period of exhortation by the policy agent. There are no lags and no residual consumption dip after the end of the dry period and policy agent's exhortation. Stakeholders from the relevant ministry of government, regulatory authorities and water supply companies pointed out that the simulated consumption patterns differ from what they have observed in that normal levels of water use recover more slowly than indicated by the model. The particulars of the representation of cognition were therefore changed in the revised model to accommodate that observation.

Capturing the statistical signature of domestic water use in relation to stakeholder observation was achieved in two steps.

The first was to change the objects endorsed as actions. In the first version of the model, the "action" was identified with the whole rule specifying the conditions in which a particular frequency and use-per-event would be adopted. The conditions were two aspects of the state of the environment: temperature and dryness. The temperature aspect could take on of the values in {*warm*, *cold*} and the dryness aspect could take one of the values in {*wet*, *dry*}. The environment was *dry* when soil water was less than 85 per cent of capacity. This was calculated from the hydrological model. The {*warm*, *cold*} aspect had no effect and, so, was set randomly.

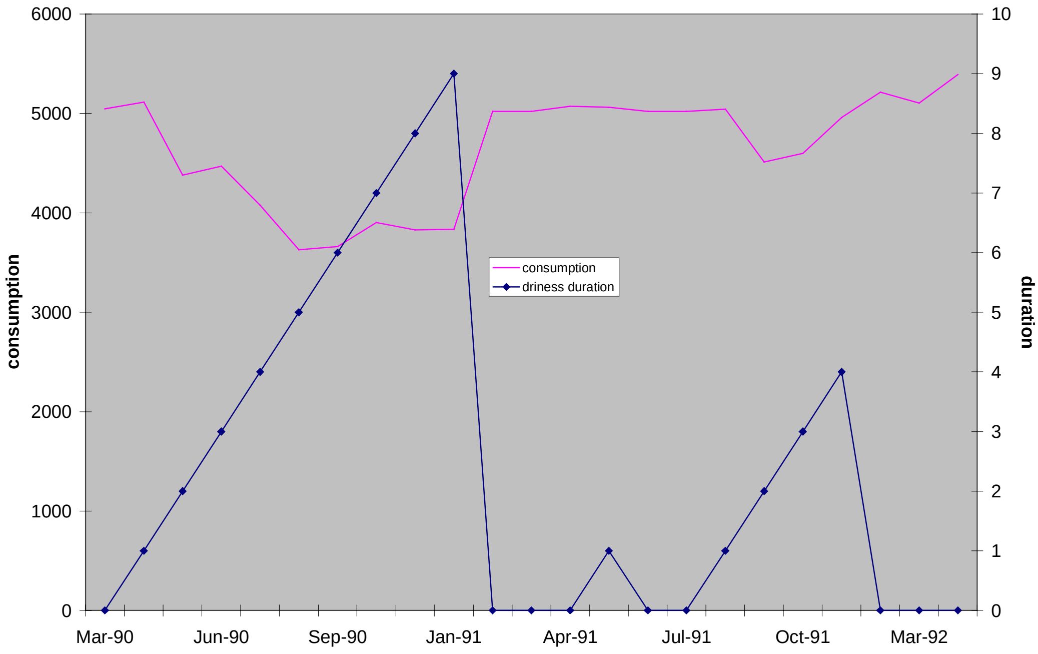

Figure 2: Drought and simulated domestic water use, March '90 – February '92

In the first version, the policy agent exhorted household agents to adopt the whole of an *if-then* rule of the sort

If (environmentalState [warm dry])

then (activityFrequencyConsumption ?activity ?freq ?cons)

Household agents in the first model version would remember both the *if* part of the rule and the *then* part of the rule and any endorsements would attach to the rule. This was the main reason why domestic consumption reverted immediately to normal when exhortation ended. The reason for the end of exhortation was that soil water increased to at least 85 per cent of capacity and so the dryness aspect of the environment changed from *dry* to *wet*. The rules that were adopted during the drought simply ceased to be relevant until the next drought. The rules themselves remained in memory, however, so that at the next onset of dryness, water demand declined immediately.

Consequently, the first change made to the representation of cognition in the revised model was to change the form of the exhortation from an *if-then* rule to the action part of the rule. As part of the same change, the household agents were respecified to note, remember and endorse the consumption frequency and use-per-event of their visible neighbours rather than the consumption *and* prevailing environmental conditions. This was an essential revision to enable the drought-induced consumption patterns to persist in the aftermath of the drought.

It was also necessary to endorse positively some level of frequency and use as normal and desirable. Without this endorsement there was a secular decline in aggregate water consumption of a kind we do not observe.

These changes in model specification had the intended effect as confirmed by the consumption and duration of soil dryness reported in Figure 3 giving a representative fragment of the simulated time series.

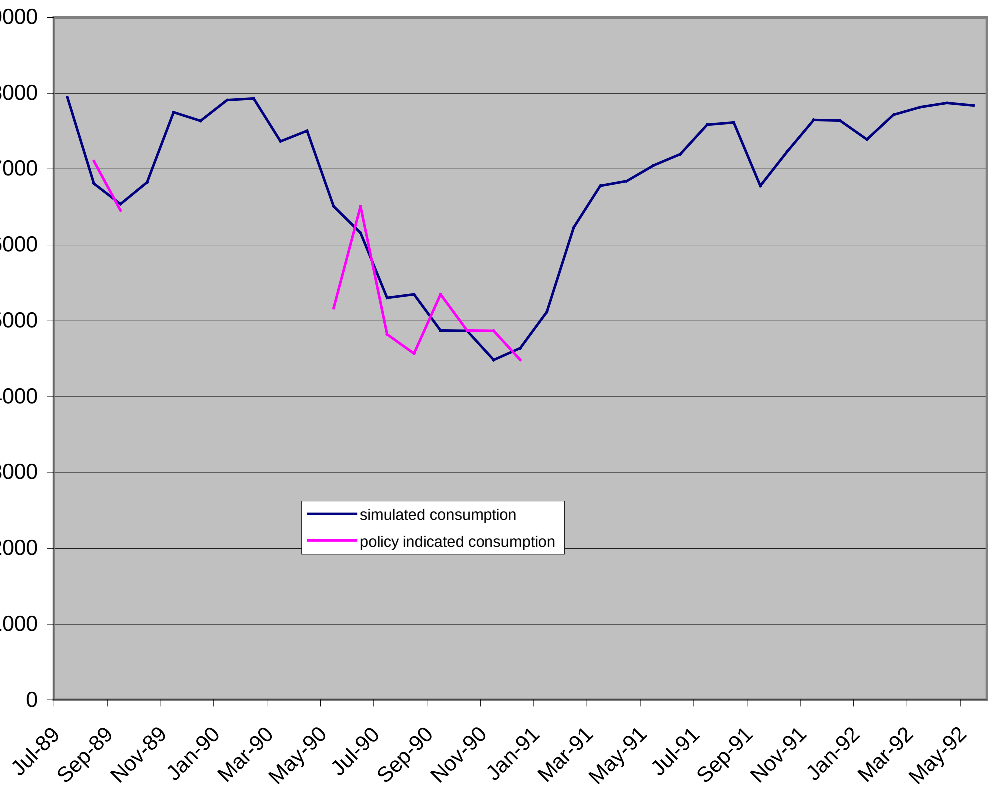

Figure 3: Exhortation and domestic use (simulated)

3 Data and stakeholder driven extensions of the model

The first set of prototype models has been extended to incorporate data provided by stakeholders about the microcomponents of domestic water consumption. In this model, households continue to be located on a 2-dimension grid, but this time the grid which is used to specify demographic properties which themselves determine such attributes as the ownership or not of a garden. A garden is necessary to have a sprinkler and a hose. The other items that will define a household are: bath, boiler, car, combi-boiler, dishwasher, dual flush toilets, garden, hand basin, hose, power shower, sprinkler, standard shower, toilets and washing machine. Each of them has associated frequency of use and volume per use characteristics. This data supports the replacement of the abstract public and private water consumption activities of the first set of models with concrete consumption activities as indicated in Table 1.

Table 1: Household water use microcomponents

Appliance	*UK (l/use if not specified)*	*Rate of ownership (year 2000)*
bath	80	0.97-8 (estimate)
shower	35	0.75
washing machine	80	0.79
dishwasher	25	0.35
toilet cistern - standard	9.5	0.91
toilet cistern - low flush	6.5	0.13
power shower	15 l/min (avg.: 7 min use)	0.21
Efficient washing machine	50 l/load	0.40 (estimate?)
dishwasher	20 l/load	0.21
combi boiler	100 l/day	0.6

Among the different activities related to those items, some depend on other parameters than just an individual frequency of use. They might be related to temperature, or rainfall and humidity. So far, the only explicit weather influence is upon what is categorised as public activities. They are garden activities, i.e. hose and sprinkler use

Another factor influencing the use, frequency, and even the ownership of devices is the communication among households. They actually can observe some of each other's behaviour in terms of water use. The way their "neighbourhood vision" is set within the model is the following. As explained above, every household can be defined by its location on the grid. We will then arbitrarily consider that they can observe other households that share one axis with them (i.e. that have either the same abscissa or ordinate) within a user-selected range. But not all neighbours are equal. They are differently valued. The observation of their frequency of use, as well as the volume, or even the ownership might have an effect on the observer. They are implemented as endorsement through a method from Cohen (1985). It is based on a very intuitive rule: people tend to like most those who agree with them, and they tend to agree with those they like the most. Each household will then endorse his neighbours, as well as their activities with respect to their observations. So both the household itself and its activities (or instead the components of that activity) are assessed.

Another type of agent is implemented in the model. It is called a policy agent and represents the broadcasted view of institutions like the Environment Agency, or the governmental or regional authorities. It is an agent that is reacting to the state of the environment, and specially the dryness of the soil on a monthly basis. After two consecutive months of dryness (the latter being defined as less than 85% of soil water retention capacity), a restriction message will be broadcasted. The households will then react differently to this message depending on another of their characteristics, namely their propensity to follow the authorities' exhortations. The state of the soil observed by the policy agent is for the moment computed through a proxy method to find a potential evapotranspiration value, which will allow us to compute the remaining soil water as the difference between the sum of the precipitations and inherited soil water, and actual evapotranspiration (as the potential evapotranspiration times a correction factors depending on the month)

The indicator of our system is the total water consumption for a household. It is computed at the end of every step. The sequence of events in the simulation is the following:

1. Initialisation of all the parameters, some automatically, some asking for user inputs.
2. For each time step, the state of the soil is computed (although it is for the moment based on monthly data).
3. At the same time, the policy agent assesses whether restrictions must apply, and households' consumption events and associated activities are (or not) triggered, based on their previous endorsements.
4. The households then observe their visible environment, including other households' behaviour, rate them and potentially change their own rules according to those observations.

The households' activities are then quite depending on the climate in general, and the weather in particular. Public activities, for example, are linked to the instant temperature and rainfall, as well as a longer-term dryness of the soil, through the policy agent.

4 Some examples of rules

The sprinkler consumption rule:

Rule	Comment
And time month ?m\ time year ?y\ time day ?d\ greater ?m 3\ less ?m 11\	Retrieves the time, and checks it is between April and October
at ground (and lastMonth (soilWater ?lmsw)\ soilWater ?sw\ greater ?lmsw 85\ greater ?sw 85)\	Retrieves the soil water state, and checks that it is not a drought period (defined by 2 consecutive months of dryness)
loadedData ?y ?m ?d ?rain ?temp\ = ?rain 0\ lastDay (and loadedData ?y ?m ?d ?lastRain ?temp\ = ?lastRain 0)	Checks it is not raining today and it wasn't raining yesterday
sprinkler 1\ personalSprinklerVolume ?vol\ is ?res ?vol / 7\	If a sprinkler is owned, then the associated consumed volume is retrieved, and the actual consumption is computed

The toilets consumption rule:

Rule	Comment
and personalWCFrequency ?freq\ (if dualFlushToilets 1\ personalDualFlushVolume ?vol\ personalToiletsVolume ?vol)\ is ?total ?freq * ?vol\	Retrieves the frequency of use of toilets, and checks whether a low flush cistern is present. Adapts the volume per use, and computes the total consumption

The dishwasher total consumption computation:

Rule	Comment
and dishWasher 1\ personalDishwasherFrequency ?freq\ personalDishwasherVolume ?vol\ is ?total ?freq * ?vol\	If a dishwasher is present in the household's endowments, retrieves the associated frequency of use and volume per use to compute the

Note that when the first rule, it means that the event of using a sprinkler has happened, whereas the two others are just computation rules.

5 Conclusion: models and policy formation

The second stage of water demand modelling has moved from the adoption of abstract water consumption activities with randomly specified frequencies and volume of water used on each occasion to concrete activities incorporating data about actual frequencies and volumes. The model has also been extended to specify ownership of the appliances that are necessary for water consumption and the volumes per use with those appliances.

In terms of model scope, the introduction of the pattern of ownership enables us to take into account the effects of technological change and the effects of migration involving the purchase of new appliances (with perhaps smaller volumes of water consumption) as well as demographic changes which determine changing patterns of ownership.

In terms of policy formation these are crucial issues. Almost everything to do with water use and supply entails some element of conflict. Increased domestic use may conflict with industrial use. Increased agricultural use may conflict with leisure use. Increased supply may require new reservoirs and conflicts with other land uses. Consequently, different stakeholders will want to make different assumptions about water demands in order to justify different and conflicting views of the future.

The modelling exercise reported here will not resolve those conflicts but it will enable to different stakeholder to explore the consequences of their different assumptions within a formal and common framework. This will be an undoubted advance in the use of ABSS for social policy formation.

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