# DROUGHT MANAGEMENT IN SOUTH EAST ENGLAND:

# AN AGENT-BASED MODELLING EXAMINATION

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**ABSTRACT**

*The last drought experienced in the UK occurred between 1995 and 1997. In South East England this was experienced as the most severe groundwater drought since records began. This drought prompted a government call for better drought planning on the part of the privatised water service companies. The overarching question being addressed by this paper is 'what is the effectiveness of the new system of drought planning and the resilience of current planning strategies to changing patterns of demand and climate?' This question relates to the climate and demand pressures acting upon the water resources management system and their current impacts on the supply demand balance, the natural environment and the profitability of the privatised water sector. The question focuses on how individuals (as water consumers) and organisations (through policy development and implementation) respond to these pressures. The paper will examine the sufficiency of the response and resistance to successful drought management.*

*Research into climate risk and drought management in South East England has been undertaken through two European Framework 5 projects SIRCH (Societal and Institutional Responses to Climate Change and Climatic Hazards) and FIRMA (Freshwater Integrated Resource Management with Agents). This paper draws from these two projects focusing on the use of agent-based modelling to explore institutional drought management and household consumption patterns under different climate change scenarios.*

*Agent based programming can be distinguished from procedural programming in its explicit representation of stakeholders in the modelling code. This leads to the close involvement of stakeholders in model building and validation to ensure that agents appropriately represent stakeholder behaviours. Agent-based modelling process is used in the project not just to produce a final model but as a forum for social learning by sharing viewpoints between stakeholders and testing system perceptions.*

*This paper gives a brief outline of the issues, institutions and stakeholders involved in drought management in the UK, describes the agent-based methodologies used and discusses findings related to: agent-based modelling; climate and demand uncertainty; and water resources management.*

## 1 INTRODUCTION

The overarching question being addressed by this paper is 'what is the effectiveness of the new system of drought planning and the resilience of current planning strategies to changing patterns of demand and climate?' This question relates to the climate and demand pressures acting upon the water resources management system and their current impacts on the supply demand balance, the natural environment and the profitability of the privatised water sector. The question focuses on how individuals (as water consumers) and organisations (through policy development and implementation) respond to these pressures. The paper will examine the sufficiency of the response and resistance to successful drought management. The paper sets out to do this by drawing on the findings of case study work in the Thames Region conducted under two European Framework V projects SIRCH (Societal and Institutional Responses to Climate Change and Climatic Hazards) and FIRMA (Freshwater Integrated Resource Management with Agents, http://firma.cfpm.org/).

In general the paper aims to show that an agent-based approaches yield a richer base for policy making than traditional modelling approaches alone. Agent-based approaches allow for the involvement of stakeholders and the representation of their viewpoints and behaviours in modelling, areas that are not addressed in most approaches to risk. In the SIRCH and FIRMA projects, agent based modelling (ABM) was used to look at issues of risk and uncertainty in water management related to climate change and climatic hazard. In the FIRMA project, an ABM was developed to explore household water consumption behaviour in response to climate signals. Work is also being undertaken to consider this household behaviour in a larger ABM for drought management in the region.

The paper starts by setting out some traditional approaches to risk (Section 2) and approaches to risk in ABM (Section 3). The paper then gives an introduction to the Thames region (Section 4) before detailing the ABM work on household demand (Section 5) and drought management (Section 6). Finally the paper discusses ABM approach to risk in the case study applications (Section 7) and concludes with a summary of findings and notes on limitations and further work (Section 8).

# 2 TRADITIONAL APPROACHES TO RISK

Risk now occupies a central place in thinking about contemporary society. The work of the social theorists Beck (1992) and Giddens (1999), who argue that contemporary society is better understood in terms of risk rather than for example class, has helped give risk its central place in much contemporary intellectual debate. The concept also increasingly occupies a key position in policy terms.

Considerable efforts are made to control, reduce or eliminate much identified uncertainty. Inevitably much of the risk cannot be eliminated for reasons of cost, the limits of knowledge, and factors inherent in humans and their institutions. We term this residual risk. People make provisions for residual risk either psychologically (through denial or fatalism) or through insurance and contingency planning.

A perennial problem in risk related policy is that perceptions of the costs and benefits of different risks often vary greatly between stakeholders. The formal institutions of government, science and the corporate world, tend to place more emphasis on aspects of risk which lend themselves to the standard tools of analysis and measurement, in particular probability statements (see for example Finkel and Golding, (1995)). These are convenient and enable the risk to be incorporated easily into economic and other calculations. However, the probabilistic approach may ignore important aspects of the residual risk, and may be misleading if key elements or parameters of the risk are overlooked (on this latter point see Bier (1999)).

Four characteristics of traditional modelling approaches to risk and uncertainty can be generalised as follows:

1 Prediction. Most mechanistic modelling perspectives seek to predict the behaviour of some target systems. For example, the ultimate goal of global climate models is to predict the

long-run evolution of the atmosphere and its response to increased greenhouse gas concentrations. Systems dynamics models are the prevalent tool in predictive models.

2 Optimisation. Policy evaluation models almost always recommend one decision or course of action as better than another. By evaluating a range of options against specified criteria and values, methods such as econometric or linear programming models, provide ‘solutions’.

3 Parameter uncertainty. Stochastic approaches estimate the uncertainty (or probability of different outcomes) based on ranges of values for the parameters in the model. The ranges may come from expert opinion or observed relationships, or are simply plausible boundaries.

4. Expert system. Most models are constructed to encapture the expertise of some discipline or topic. For instance, groundwater models might include the state-of-the-art in surface infiltration and sub-surface flow based on experiments and analyses in geophysics and hydraulics, among other disciplines.

These modelling characteristics and their application to problem-solving are clearly over-simplified but work to highlight how traditional approaches are ill suited to the complex character of hydrological risk. In applying traditional approaches, the target system is perceived as a machine to be controlled rationally, reducing destabilising pressures and maintaining equilibrium. However, the complex relationships between competing pressures, the need to evaluate economic, social and ecological factors, and the ability of agents (social or biological) to adapt to changes in their environment contribute to deep uncertainty. Most applications assume a single decision maker, or a ‘global commoner’ that does not learn from observations about how the real world actually behaves. Traditional approaches embedded in a single discipline, ignorance of many critical interactions, and reliability only for short time frames and confined geographical domains are inadequate. However, not only is there a paucity of adequate data, but the phenomena and process are themselves not fully understood (van Asselt and Rotmans, 1996).

The challenge of understanding hydrological risk management requires several levels of integration: natural and social dimensions; risk (including drought and floods) across the environment; individual, corporate and institutional behaviour; and technical expertise among decision makers and stakeholders. Complexity stems from the number of relationships; uncertainty from the many altered states of the future.

# 3 THE AMB APPROACH

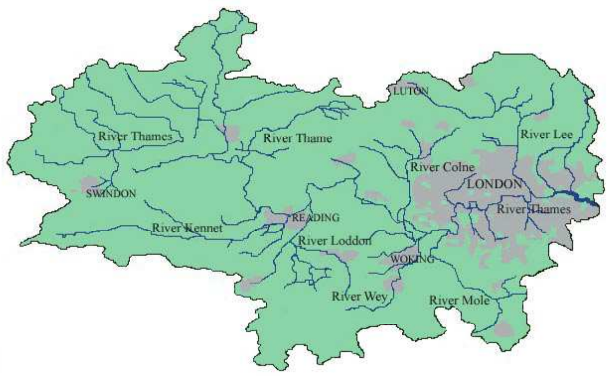
In the field of water resources management, institutional factors are likely to be at least as important as economic, technical or physical considerations in developing and implementing effective policies (Ingram et al., 1984). For example, risks associated with hydrological events are affected by both the nature of the hazard (duration, type etc.) and the institutional structures established to manage such hazards, which in many cases are likely to be a consequence of how preceding significant hazards were managed. Changing structures, of the environment, regulatory regimes, stakeholder positions, consumer preferences, for example, require evolutionary approaches (as distinct from those based on optimisation). This has lead to the development of ABM approaches to issues in water management.

Agent-based models are not generally predictive tools, rather they become mechanisms by which behaviours and their possible consequences can be explored. The models, used with a participatory approach, explore the nature of problems, examine the viewpoints of different actors and their inter-relationships to discuss the impacts of different behaviours on other actors and on the system over time. The result is not an optimum course of action but increased awareness concerning of choices perspectives and possible impacts. In some models, parameter uncertainty can be tested using stochastic methods, but more frequently the focus is on random patterns for the representation of stakeholder-defined uncertainty.

Agent-based modelling can be seen as a tool and mode of discourse rather than a means to monitor, predict and provide. Agent-based simulation models hold promise for realistic representations of observed behaviour. Artificial intelligence and multi-agent systems have been employed to investigate a range of social interactions (Gilbert and Troitzsch, 1999).

# 4 WATER RESOURCES IN THE THAMES REGION

The Thames Region (shown in Figure 1) is the catchment area of the River Thames and its tributaries. There are 5,330 km of main river in the region 12 900 km2 in area (EA, 1999). The region is located in the south east of England with the city of London at the down-stream end of the catchment. The region represents less than ten percent of the land area of England and Wales but contains twenty-three percent of the population, generates just over twenty-seven percent of GDP, and has a similar percentage of all construction work (EA, 1998, 1998b). The region continues to attract high levels of growth (EA, 1998) and further housing development will place heavy demands on existing infrastructure networks (CPRE, 1999).




Adapted from EA (2001b)

Figure 1: The Thames Region

The Thames Region is amongst the driest in the UK; annual effective rainfall is 235 mm (338 mm in west and 116 mm in east) with the northeast part of the region most at risk of drought (EA, 2000). Approximately 55% of the effective rainfall within the catchment every year is abstracted annually with 86% of this water going to public water supply (EA, 2001b). The majority of public water supply is abstracted to provide domestic water supply to the 12 million people living in the region mainly concentrated in the major population centres -- such as London and surrounding satellite cities. In recent years, rapidly growing urban centres in the upper Thames, have placed a strain on local water supply. Overall, the rate of water demand in the Thames Region has risen by over 50% since the early 1960's but until recently, water resources were not seen as a constraint on development in the region. Potential shortfalls in the water supply-demand balance are already foreseen under the growth levels predicted for certain areas (EA, 2001b).

Combined with growth pressures, the region has also had to cope with increasing insecurity of supply as there has been a "remarkable variability in hydrological conditions in the UK over the last decade" (Brown, 1992; IOH, 1995; Marsh, 1995). These changes have resulted in several riparian and hydrological systems fluctuating well beyond usual levels (Arnell et al., 1994).

The UK, as a whole, has experienced four major dry periods in the last twenty years (Brown, 1992; CEH, 1998; IOH, 1995). However, as water resources in the Thames region are groundwater-supported, single-season meteorological droughts affect water resources less severely in Thames than in other regions in the UK. The most recent groundwater drought, running over consecutive seasons from 1995 to 1997, is the most severe since records began; many boreholes were at or below historic minima in 1997 and the early months of 1998 (CEH, 1998, 1999). These tendencies in climate and hydrological change have raised questions regarding the resilience of water resource management strategies that are based on demand projections and industry design standards (Marsh, 1996) and "tests the conventional wisdom that depicts nature as tending toward stability or near constant balance" (Zimmerer, 1994).

The impact of climate change on both water resources (Arnell et al., 1994) and demand patterns (Herrington, 1996) has recently been integrated into water management planning in England and Wales. In the same year, the economic regulator of the water industry announced that climate change, formerly excluded from consideration in the economic regulation process, would be taken into account in the next review of water company performance. Climate change uncertainty and the risk of drought therefore set a backdrop against which the appropriateness of water management decisions can be seen and tested.

# 5 ABM IN THE THAMES CASE STUDY

## 5.1 Demand and Drought

In the past, the maintenance of public water supply has been focused predominantly on the securing of adequate supply to meet projections of increasing demand from households, agriculture and industry. However with increasing competition for available water resources (including the acknowledgement of the rights of the environment to adequate supply) and decreasing security of supply due to climate change, water managers are increasingly looking towards the planning and management of demand to meet the supply-demand balance.

In the Thames Region it can be seen that uncertainties related to water supply and demand are being increasingly recognised in water resources planning. In 2001, the Environment Agency (EA) in England and Wales published 'Water resources for the future: A strategy for England and Wales' (EA, 2001c) which introduced a detailed scenario approach to demand forecasting (see EA (2001a)) and proposed water management strategies in response to the projections. Strategies were produced regionally (see EA (2001d) for Thames Region) within the national framework.

In the EA scenarios, overall household demand is broken into micro-components, each micro-component represents a water consuming appliance or activity and is described in the household by its Ownership, Frequency and Volume (OFV). For each component, OFV describes how many (if any) are owned by the household, how much water is consumed per use and the frequency of that use. Trends in the potential change in OFV parameters under different socio-economic scenarios (defined by the UK Foresight Programme (see http://www.foresight.gov.uk/ and extended by the Environment Agency (EA, 2001a)) were assessed by experts. To deal with the potential impacts of climate change on demand, a further study 'Climate Change and the Demand for Water' (CC:DeW) was commissioned to adjust the EA scenarios considering expert opinion, water company data sets and dynamic models of water use (Downing et al., 2003).

Though the scenario process and outcomes provide a wealth of information on potential demand futures and provide a framework for strategy testing, they give little-to-no insight concerning how or why individual behaviours do, or do not, propagate certain scenario trends and therefore how these trends can best be managed or redirected. Also, the scenarios do not address the issue of drought and how changes in the frequency or severity of drought occurrence under climate change could impact public attitudes towards water use.

To address these further questions, a agent-based model was developed under the auspices of the CC:DeW project and the FIRMA project. The ABM approach is used to understand how and why households are using water, possible results of these water-demand behaviours in differing situations and the potential impacts of behavioural changes. While the scenarios look at possible water resources demand under imposed socio-economic conditions, the agent-based work looked more closely at individual household consumption and more personal adaptation measures to see how trends are generated and maintained.

In the model, agents, characterised by randomly distributed OFV parameters, follow rules for water consumption considering their characteristics and situation with respect to appliances and housing. Through communication with a user-generated number of similar agents and an overarching policy agent, an agent can learn about new situations or behaviours. Agents will evaluate their past consumption behaviour, the behaviour of their neighbours and the behaviour recommended by the policy agent to determine how they will, or will not, change their own consumption. To weigh the different influences, the agents are programmed with a bias towards the self, local or global sourcing of their consumption patterns. Agents with a bias towards global sourcing will give a greater endorsement to messages from the policy agent, automatically assuming that they are in the 'global' interest. Agents with a local bias will give greater endorsement to behaviours used by neighbouring agents (the number of agents that are 'neighbours' can be set by the user). Finally, agents with a self-sourcing bias will look mainly to their own consumption preferences. Endorsements will be tallied and consumption patterns altered in favour of the pattern with the highest endorsement rating. As agents change their consumption patterns they are observed by neighbouring agents and the process of adaptation continues. The 'copying' of behaviours 'endorsed' by other sources has been described by Cohen (1985) and has been previously implemented in agent-based approaches (Moss, 1998; Moss and Sent, 1999)to capture observed behaviour. These behaviours will then provide insights pertinent to demand planning and management.

The link between climate and water consumption in this model comes mainly from the policy agent's monitoring of climate impacts (in this case soil moisture) and the issuing of water saving messages in response to dry conditions. Soil moisture changes over time in line with the scenarios for temperature and precipitation provided by the UKCIP 2002 climate change scenarios for the UK (Hulme and Jenkins, 1998; Hulme et al., 2002a). Agents respond to the messages differently over time considering their bias, the actions of the surrounding agents, but also their ability to save water considering appliance ownership and characteristics.

Collectively, the agents build a pattern of aggregate water demand that can be compared to water company records of past demand and validated with stakeholders for plausibility. For this project, a steering group composed of decision makers from government and the water industry was canvassed for data concerning household demand behaviours against which findings could be validated, The stakeholder group was also used to validate behavioural rules and results with respect to their experience in the industry.

The agent-based model revealed that an increased frequency of drought could provide the catalyst for the adoption of water saving technologies and associated reductions in demand, or alternatively if the presumption of entitlement to a private good were to exceed the willingness to conserve water during periods of drought, increased frequency of drought could lead to consumers increasing their demand beyond the high reference scenarios. Critically the model identifies the importance of community interaction and particularly the mimicking of neighbour behaviour as a key determinant of the uptake of new water saving technologies. Neighbourly interaction also determines the extent to which households are influenced by policy agent exhortations to use less water in times of drought – closely knit communities appear to be less impressionable. The findings, although purely qualitative, suggest key social determinants of future water demand

## 5.2 Drought Planning

The Environment Agency has set out guidelines for developing Regional Drought Management plans in their Drought Manual (EA, 1997) and Drought Contingency Plans in the Drought Contingency Planning Guidelines (EA, 1999a). Guidelines and Manuals are then used by the different EA Regions and Water Companies to produce their plans. As stated above, in the Thames Region, 55% percent of water in the catchment is abstracted for domestic use. Therefore, household water use is a prime determinant of demand and influencing household water use could be an important aspect of drought response.

The Regional Drought Management Plans include: information on roles and responsibilities within Agency Drought Management Teams; financial resources; environmental monitoring; actions and mitigations; reporting arrangements; and reference materials (see Thames Regional Drought Plan (EA, 2001b)). Environmental monitoring includes the collection of baseline information against which the severity of drought impacts can be measured as well as the monitoring of environmental conditions during a drought. The drought management plans also set out the monitoring required to identify when drought situations are threatened or entered. As maintaining river flow in the Thames system is dependent upon aquifer storage (EA, 2001b), drought triggers in the region are associated with a review of winter recharge and a series of observation boreholes across the region.

What is not described in the drought planning documents are many of the behaviours associated with implementing the plans. Though options for managing supply and demand are listed, there is little-to-no guidance concerning why any particular option will be selected for implementation in a particular circumstance. There is also no description of what negotiations occur, and how they occur, when the different parties involved in drought management do not agree on the management strategy.

Some of the options put forward by the Environment Agency and Water Companies in the drought management and contingency plans involve the management of demand through voluntary or statutory exhortations. However, the mood of the public and their flexibility in water consumption (based on available appliances and lifestyles) changes over time. Changing climate can also impact the magnitude and composition of household demand as increases in climate could lead to increases in garden use, showering and/or clothes washing. The awareness of drought planners and the responsiveness of the drought planning system to these changes is unknown.

A common error in drought planning is to plan for droughts that have occurred in the past (U.S. Army Corps of Engineers, 1994). This could mean that current drought planning systems and options are unable to deal with droughts that are not within the bounds of the known record. Alternatively there could be surpluses in the system to deal with events that will not happen again in the foreseeable future.

A Virtual Drought approach (U.S. Army Corps of Engineers, 1994) will be used to explore these issues in a gaming environment. An improved understanding of the process, especially negotiation between stakeholders, can then be used to develop a drought management ABM that can be used to test alternative plans or strategies for drought management. In addition to providing information on option selection and negotiation, gaming is a chance for social learning between actors in drought management. Due to reorganisation and turnover of staff since the last drought, the game will enable new decision-makers to interact and understand the uncertainties, personalities and perspectives in management before a hazard event occurs.

Combining the drought management game with climate information from UKCIP 2002 (Hulme et al., 2002b) and household response patterns from the demand model, discussed in the previous section, will lead to a situation of complex uncertainty for drought management problem solving. The Thames case study focuses on drought management as an ongoing process of negotiated management to meet long-term goals and overcome short-term hazards.

# 6 DISCUSSION

## 6.1 Perspectives on Risk

In a comparison of the outputs from the scenario approach and the ABM approach, (see Figure 1) the most notable point is the pattern of demand over time. While the scenario approach generates a logical progression of demand changes, the ABM results fluctuate with changes in appliance ownership, climate and behaviour. The variations between the multiple runs of the ABM simulation are a result of randomisation in agent placement and attributes at the start of the simulation. The goal of the simulation is not to find a single answer but to identify patterns of behaviour that result from different situations. The relevance of this to risk is that systems of water supply-demand management will be tested not just by average changes in demand, which must, of course, be planned for, but also by the, more extreme, peaks and troughs of demand created through dynamic responses to new situations.

In the drought management game, the focus is not on optimum or projected solutions but the exploration of possible actions and their motivations. This provides a multi-agent framework for the re-examination of the hydro-illogical cycle (Tannehill, 1947) associated with drought risk management – exploring interactions between agents who may be at different stages of the rain-apathy-drought-awareness-concern-panic cycle at different moments in planning.

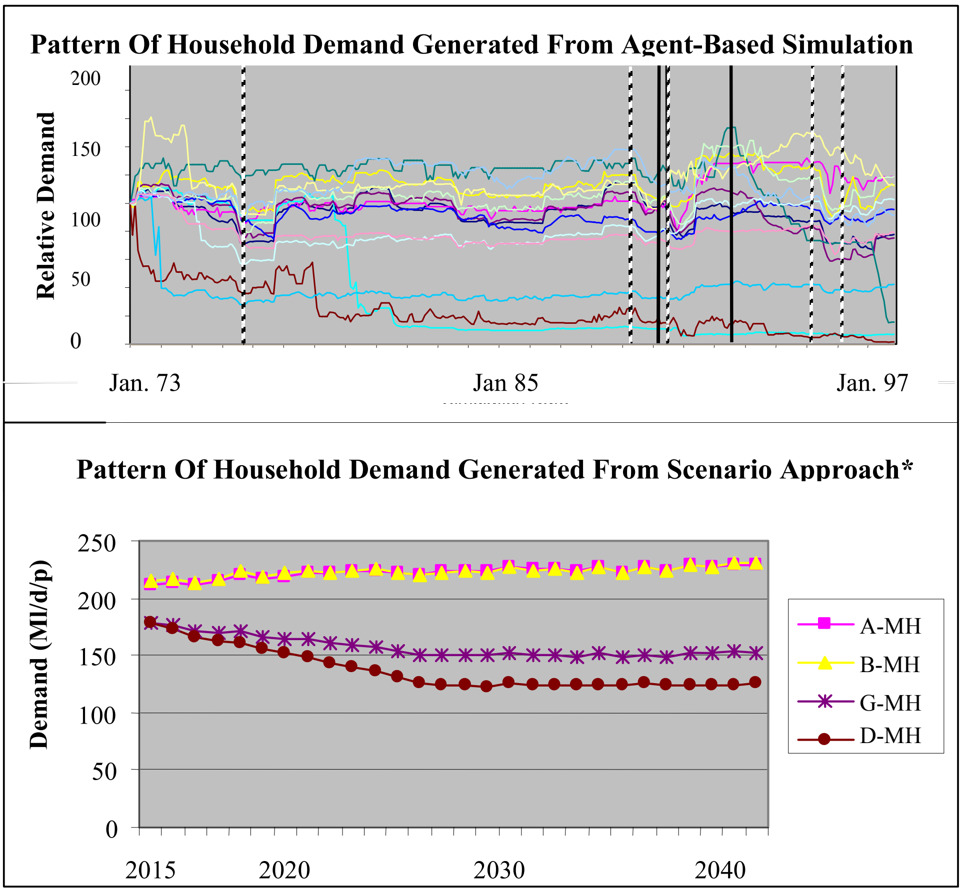



**Figure 1**: A comparison of demand patterns generated through agent-based and traditional scenario approaches (*scenario approach shows Environment Agency water resources strategies scenarios (EA 2001a &2001b), adjusted for climate change (Downing et al 2003)

## 6.2 Limitations to ABM Approaches

The case study highlighted the importance of working with stakeholders but also acknowledged that it was not always easy to convince stakeholders of the value of new research and participation methods. The size and scope of the project also proved difficult as the incorporation of many different types of agents usually meant that not all agent types could be represented in the stakeholder group. Where stakeholders did participate, the models provided an opportunity for social learning and served to educate stakeholders about behavioural issues relevant to planning.

The development and application of ABMs can also be limited by lack of validation data. In the case of water demand, there are no long-term records of daily or monthly water consumption demand for individual households. Full validation of the household behaviour would require this consumption data along with interview or survey data. The community interaction described in the model is also difficult to understand as the consumption surveys that do occur are usually spread over a large area, as opposed to focussing on a single neighbourhood. The outputs of the household consumption model were therefore validated using records of aggregate water demand for small areas. Validation was not based on exact results but on the identification of similar patterns of behaviour.

# 7 SUMMARY

In the case study applications discussed it can be seen that the AMB approach allowed researchers to look at the bottom-up detail of possible futures, as opposed to the broad planning perspectives and assumptions taken by government. ABM was used to question scenario assumptions about behavioural changes through an examination of behaviours in response to climate stress. The ABM approached flagged weaknesses in the conventional, top-down assessment of demand futures. The models highlight factors that will need to be considered or controlled in attempting to realise a planned future in water management.

Models that use statistical forecasts of event size and recurrence are an important part of hazard management. However, they do not tell us anything about how these risks, and the systems in which they are generated, are interpreted by the different stakeholders involved. Interpretations of risk and objectives in management will be the critical hinge in decision-making in any process that is not totally automated. Due to the many possible interpretations of risk and assessments of possible hazard impact to the system, risk cannot be taken as a well-defined subject for objective consideration and it must be represented subjectively from each stakeholder's perspective.

Stakeholder involvement was key to defining parameters in modelling and gaming and taking an agent-based approach allows representation of the different assumptions used by the different agents to identify solutions that can be suitable within various paradigms and most resilient to different system risks. In a good agent-based modelling process, learning is not restricted to the research team but is a platform for stakeholders to consider their own objectives and to learn about the perspectives of other stakeholder in the system.

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