Understanding the Complex System Dynamics of Managing Water Security

Sondoss El Sawah, Alan McLucas, Michael Ryan

THE UNIVERSITY OF
NEW SOUTH WALES

Introduction

- Australia is the driest inhibited continent with one of the highest per capita consumption in the world.
- Most Australian cities are under water restrictions.
- The Australian Capital Territory (ACT) is an inland territory with some 360,000 inhabitants.
- The ACT is rainfall dependent with 60% of water coming from one catchment.

Introduction

- Since 2000, the ACT has had the worst drought on record (25% reduction in inflows).
- Exacerbated in 2003 with widespread bushfires that burnt out the vast majority of catchments.
- The ACT has one of the highest per capita water consumptions in Australia (54% household, of which 44% is used for irrigation of lawns).

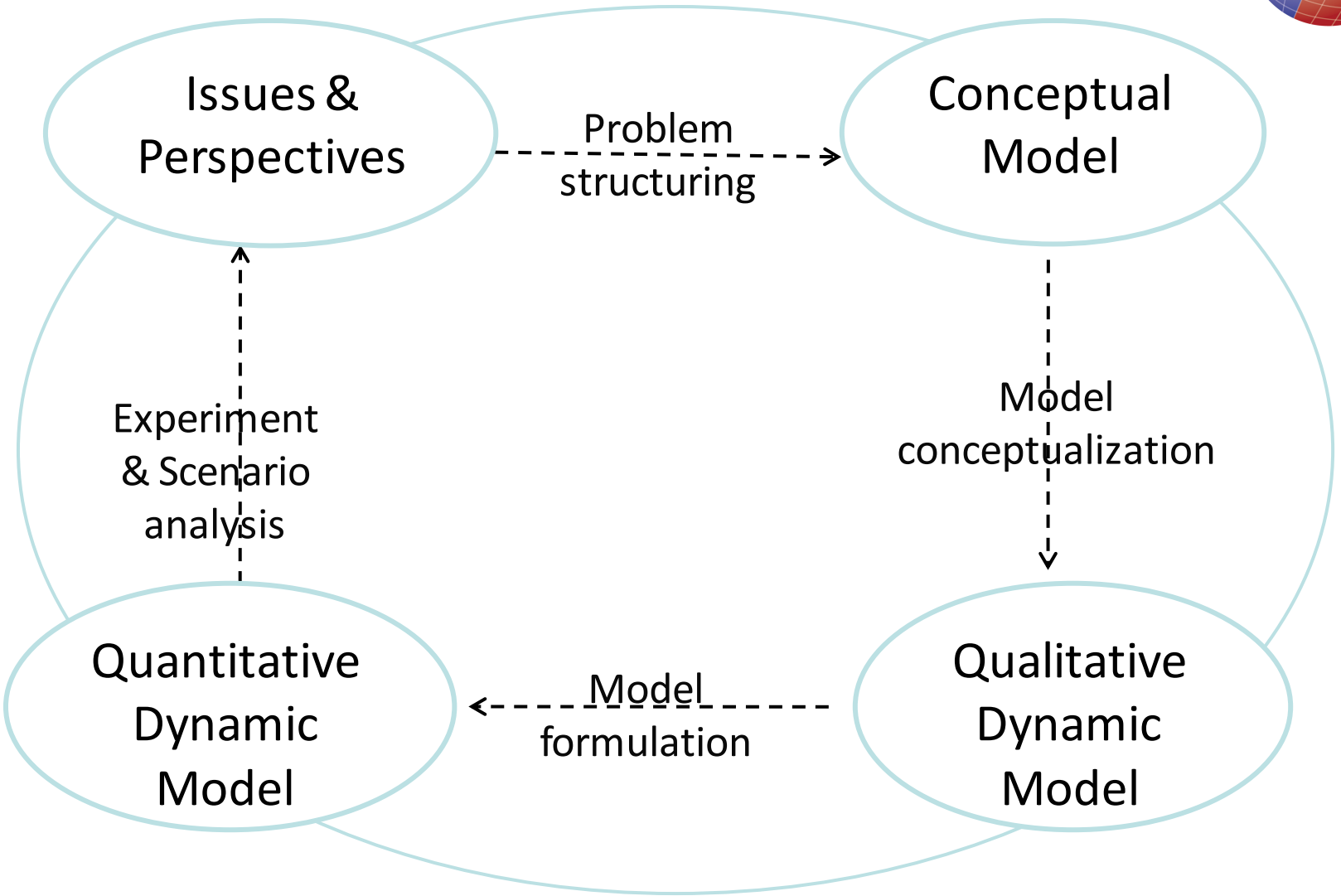
Why SD Modelling?

- SD provides a framework to facilitate learning about dynamic complexity.
  - Problem conceptualization involves eliciting, mapping and analyzing the cause-effect structure.
  - Simulating the model shows the delayed and systematic impacts of alternative strategies on system behavior.
- SD modelling and the simulation games derived from such models provide a great opportunity to be used as tools for enhancing communications about public policy.

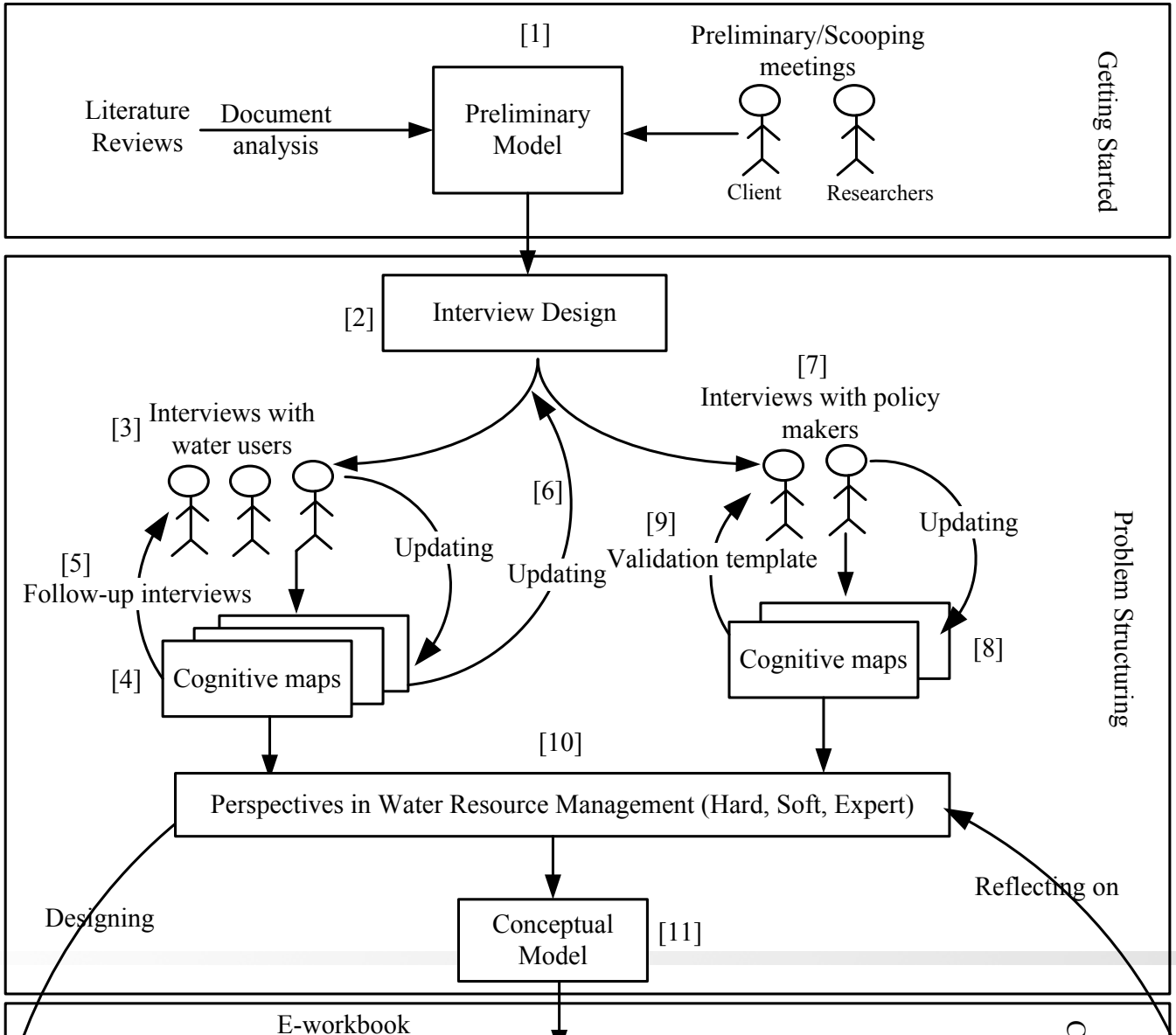
Objective

- Develop an integrated model that can be used to:
  - Understand the complex cause-effect relationships that generate the dynamics of supply and demand in the ACT.
  - Assess the effectiveness/robustness of various supply and demand management options.
  - Examine how the understanding of regulators and communities can be improved by the ability to use an interactive gaming interface

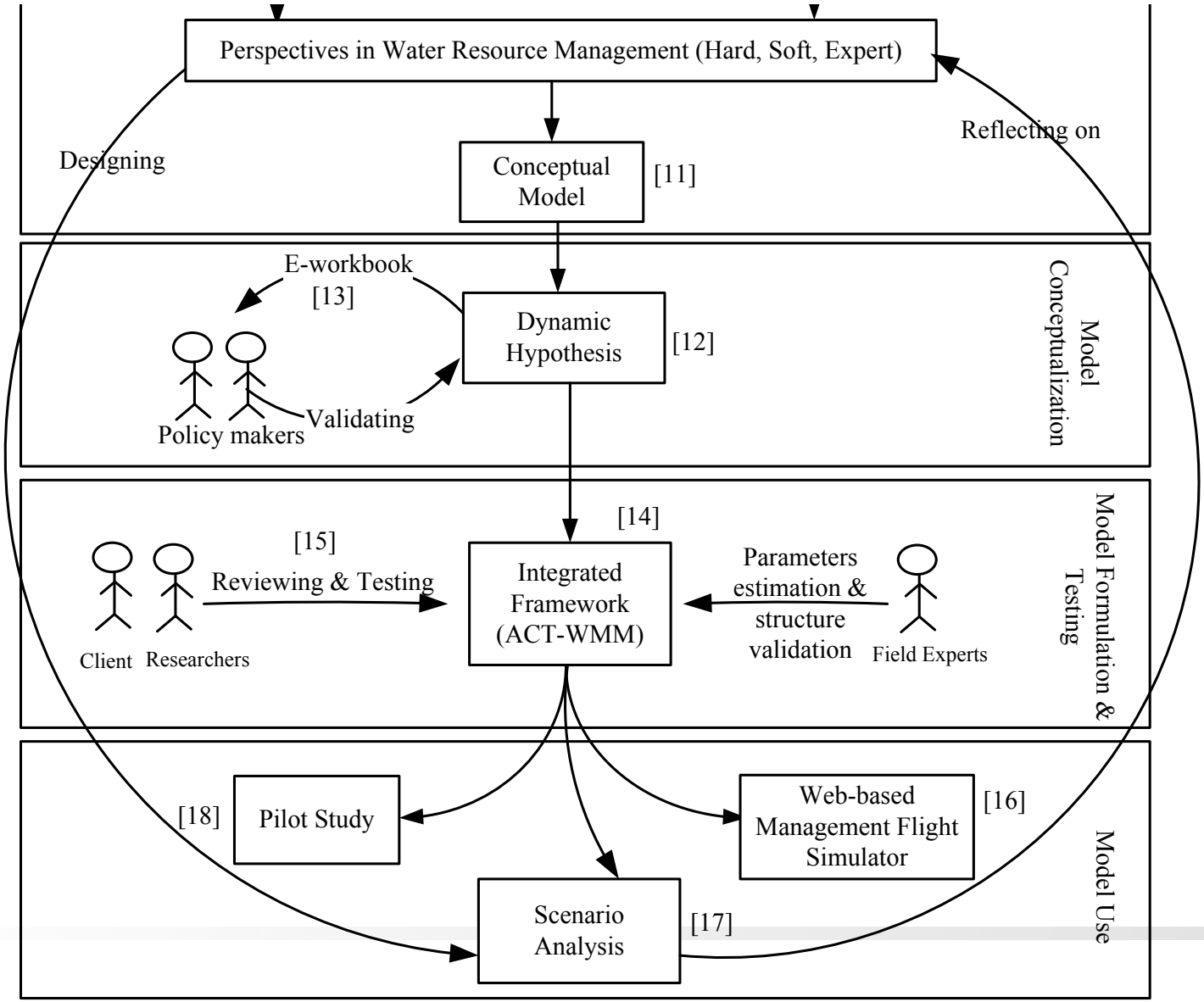
Modelling Approach



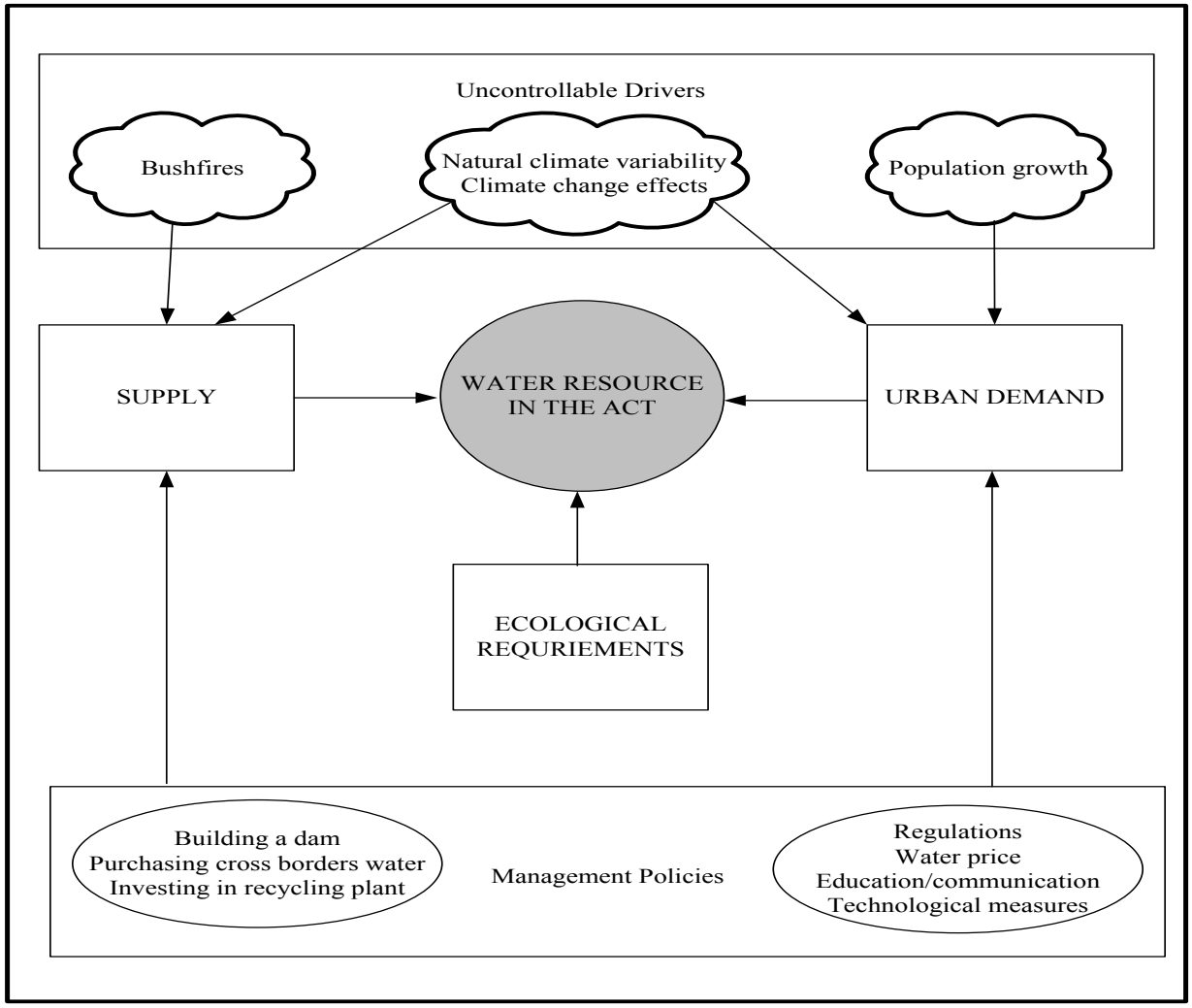
Modelling Approach



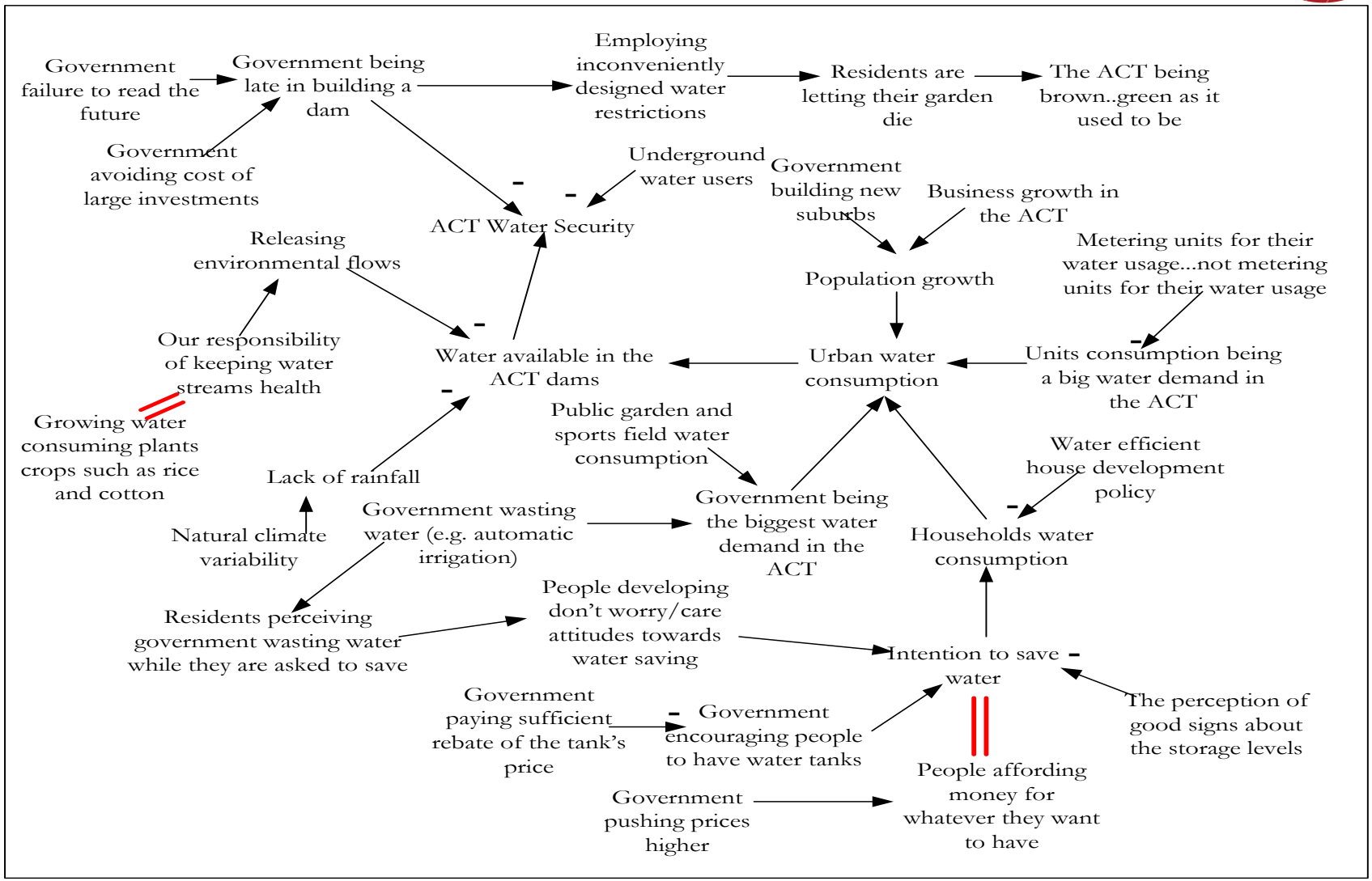
Modelling Approach



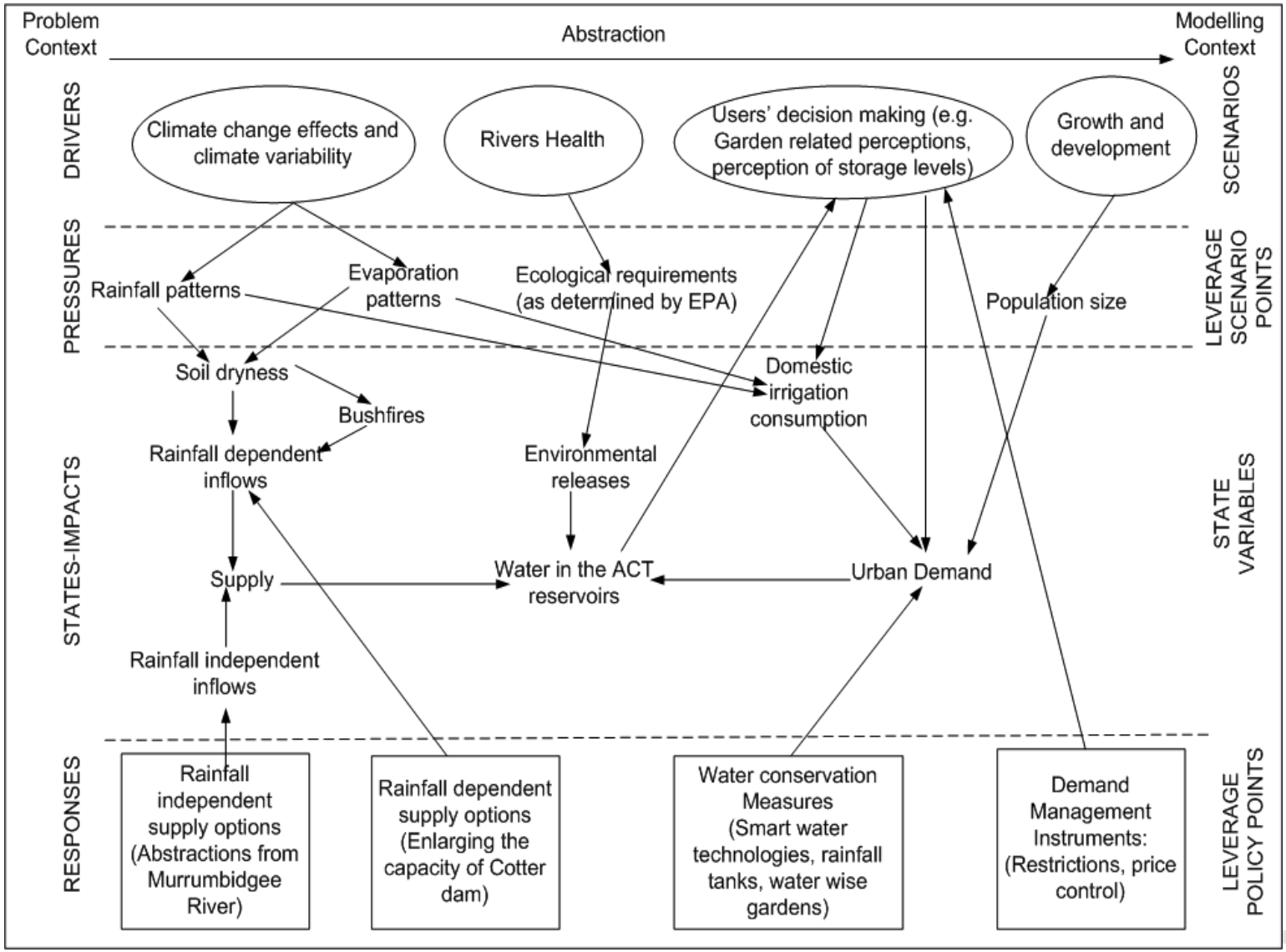
Preliminary Model



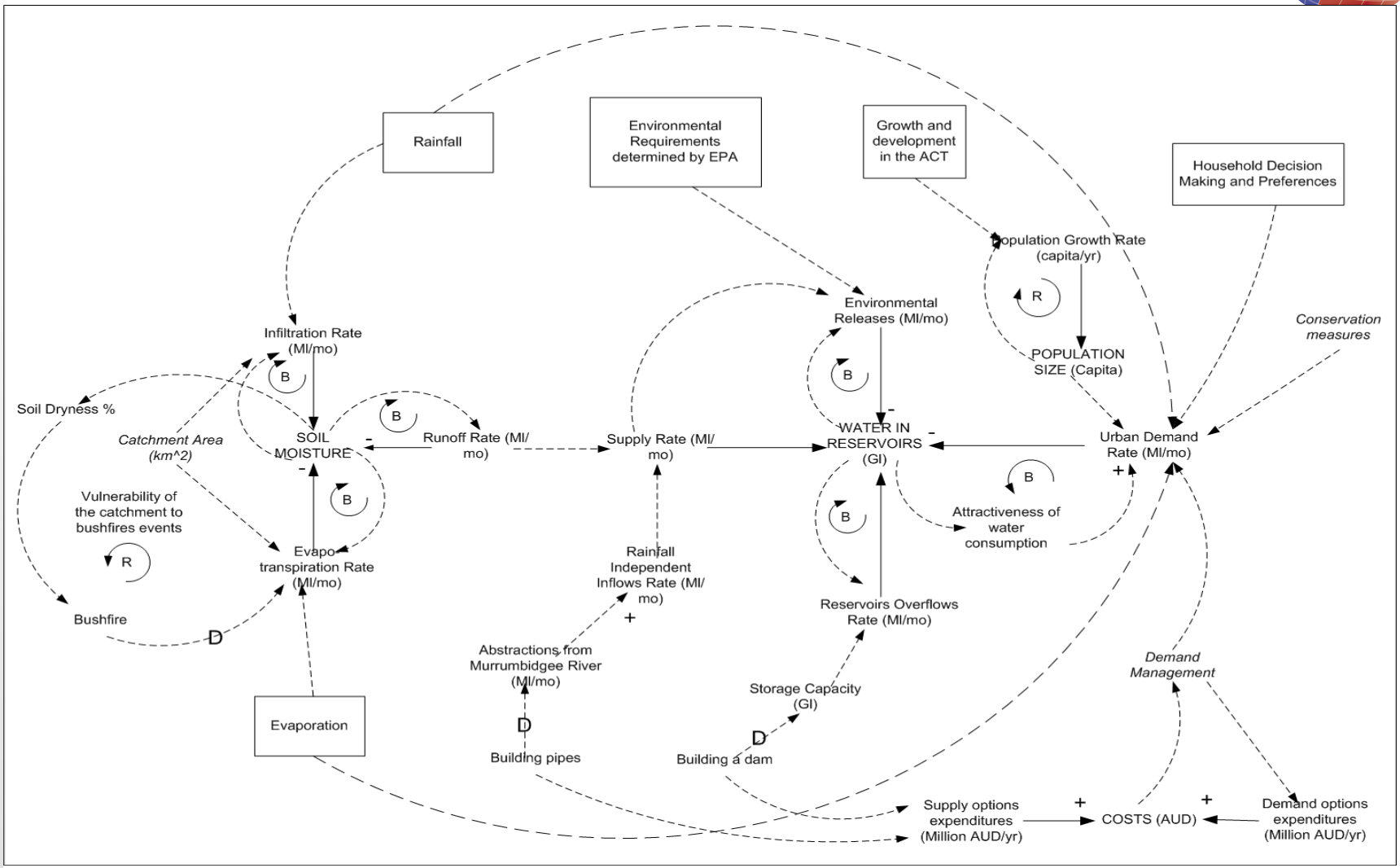
Cognitive Maps



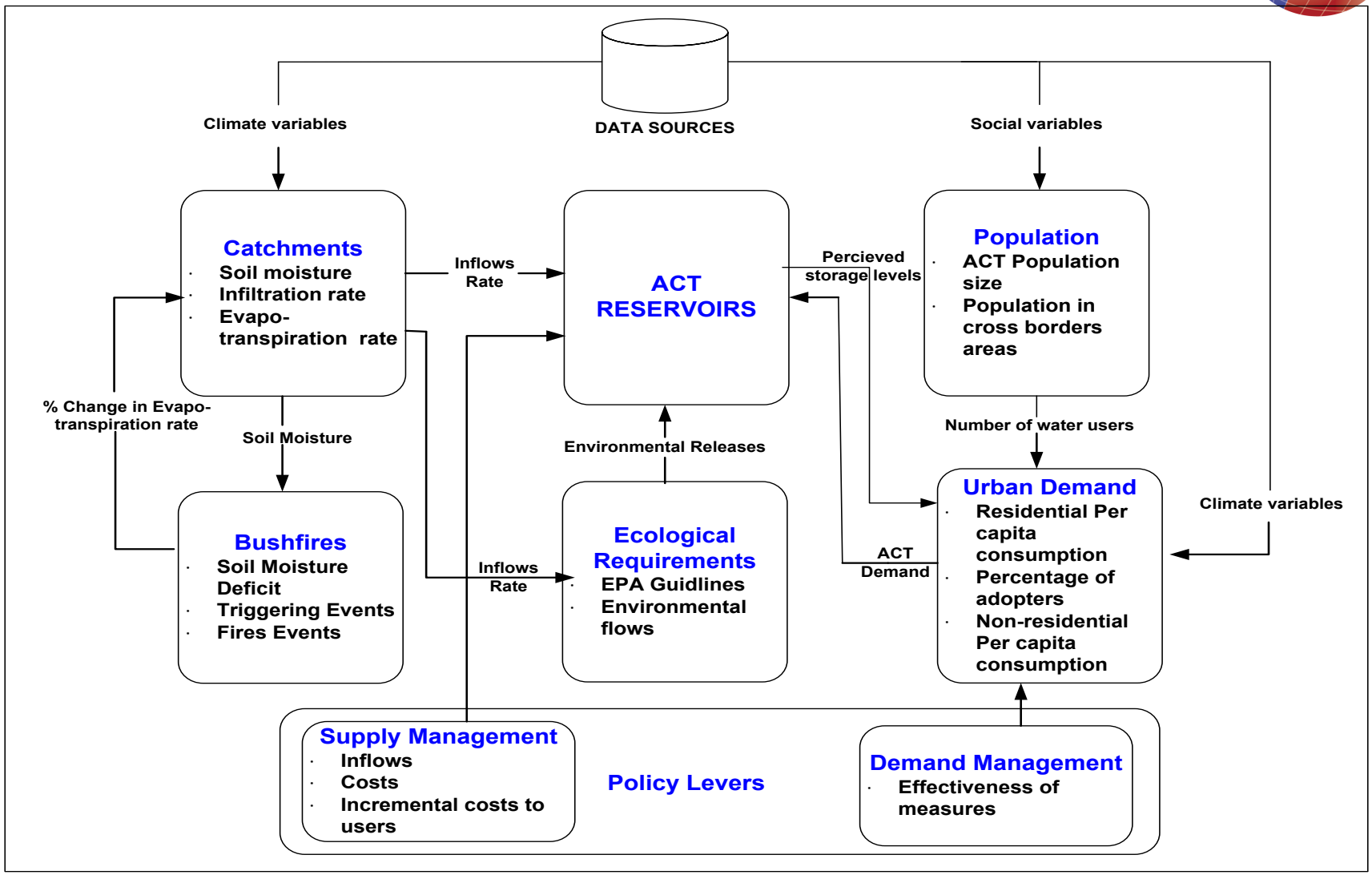
Conceptual Model



Qualitative Dynamic Model



Quantitative Dynamic Model



Observations – Getting Started Phase

- In some cases, managers are not aware of the potential of modelling (especially qualitative) in addressing the problems they face.
- To create a point of entry and gain client's commitment, the researcher has to formulate research questions that are closely linked to management questions and issues of concern.
- The use of a preliminary model is useful in broadly characterizing the issues for investigation, which facilitates communication with the client at the early stages of the analysis.
- In this early stage, it is useful to avoid drawing speculative or premature causal assertions.

Observations – Cognitive Mapping Phase

- Cognitive mapping is highly effective technique in:
  - building a rich and multi-perspective understanding of the problem,
  - framing the ‘nub of issues’ that define the situation,
  - empirically validating the initial argument about the perceived limitations of the employed policies for communicating about water resource;
  - eliciting the salient decision rules that govern decision making of users and policy makers;
  - identifying barriers to engaging in water saving, and hence, communication targets, and
  - eliciting modelling requirements.
- …

Observations – Cognitive Mapping Phase

- Constructing perspectives is a quite challenging process:
  - Difficult to distinguish between the rules that actually govern interviewees' decisions (i.e. theories in-use) and what they say/ think about the rules that influence their decisions (i.e. espoused theories). Semi-structured interviews are useful in investigating salient factors that influence decision making.
  - It is cognitively demanding task to make sense of such large set of data to synthesize higher-level perspectives.
  - The mental models included aspects of more than one perspective, which can be interpreted as internal conflict. In such case, it became difficult to distinguish between conflicts within one frame and conflicts that cut across multiple frames.
  - ….

Observations – Cognitive Mapping Phase

- Constructing perspectives is a quite challenging process:
  - ….
  - Despite significant effort, researcher biases and preferences inevitably influence the process of constructing frames.
  - The use of an electronic template, like the one designed in this research, provide an effective tool to validate large-size cognitive maps, for time-stressed participants. However, it allows only for validating relationships that are already identified rather indicates if there are relationships which are missed out.

Observations – Modelling Phases

- The flow from the conceptual model to influence diagram is not a smooth linear transition. Some feedback loops are not directly inferred from cognitive maps and must be identified by the modeller, which is time consuming. This process can be substantially facilitated by the use of Group Model Building sessions where participants directly contribute to building the dynamic hypothesis.
- Modellers need to master different causal mapping techniques to translate the dynamic hypothesis from one form to another dependent upon the purpose. For example, influence diagrams are not easy to communicate, and are better kept with modellers while causal loop diagrams are used as a client interface.
- …

Observations – Modelling Phases

- …
- It is useful not to wait till the dynamic hypothesis is completely finished to start building the stock-and-flow diagrams. The transitions back and forth between influence diagrams:
  - provide an early test for the logic of the dynamic hypotheses;
  - identify vague concepts, contradictions and inconsistencies;
  - improve understanding about causal links and their mathematical representation;
  - provide insights into missing variables that were necessary for the inner working of the quantitative model; and
  - spotlight quantitative data requirements.

Observations – Water Security in the ACT

- Many cause and effect relationships are poorly understood, and that modelling is highly valuable to inform integrated water management:
  - Observed increases in evaporation rates, a consequence of warmer temperatures and lower humidity near the surface of the Earth in this region, have substantial impacts on the recent rapid decline in inflows into the water catchments. Whilst average rainfall has reduced only somewhat, the main problem is that it is now warmer throughout the whole year, particularly during the usually cooler and wetter seasons, autumn through winter and into early spring, which produces significantly higher total annual evaporation resulting in a marked increase in loss of rainwater both before it can be captured in the dams and loss from the dams. As little as 12-15% of water falling as rain is ultimately deliverable to ACT consumers as potable water.
  - …

Observations – Water Security in the ACT

- Modelling is highly valuable:
  - …
  - Bushfire rates are higher as a consequence of climate change. Whilst fires consume enormous amounts energy (2003 fires consumed an amount of energy equivalent to 340 Mega tonnes of TNT), fires cause incredible loss of moisture. After the fires have died down and trees and undergrowth regenerate, there is a consequent and dramatic impact on transpiration and evaporation.
  - Evapo-transpiration rates are particularly high when forests are experiencing re-growth. Juvenile trees and trees and undergrowth regenerating after bushfires take up water at very high rates compared to old-growth forests. Further, trees and undergrowth take up more water from the soil when humidity levels are lower.
  - …

Observations – Water Security in the ACT

- Modelling is highly valuable:
  - …
  - Further, bushfires pose a substantial threat to future water supply for this reason and because each bushfire event degrades water quality for periods of months to years.
  - Rates at which trees and undergrowth take up water have an effect on the amount of water that can find its way into subterranean aquifers. That is, the dryer the soil becomes as a consequence of trees and undergrowth taking up water, the less water is available to infiltrate the aquifers. These mechanisms require further study beyond that undertaken in this research.
  - Uncertainty about climate change is an important determinant of consumers' perceptions. Even when it is explained, many remain convinced that current trends towards high evaporation rates, and therefore less water, are only temporary.
  - …

Observations – Water Security in the ACT

- Modelling is highly valuable:
  - …
  - Further, humans are poorly equipped to deal with changes that are slow and relatively imperceptible, even when the changes described here have been observed consistently over 40-150 years. Projections of recent trends could have dire consequences. Despite this, most consumers consider the current situation as part of 'normal' variability of the climate.
  - Simulations based on this research suggest that without careful water resource management and substantial enlargement of the main (Cotter) catchment it is highly likely that the ACT region could run out of water at least twice in the next 40 years. Here, running out of water means that the catchments have less than 10% of their maximum capacity.
  - …

Observations – Water Security in the ACT

- Modelling is highly valuable:
  - …
  - Because the ACT water catchments are part of the much larger Murray-Darling river system, it is essential that the ACT continually releases water to sustain downstream catchments. Most consumers do not consider the impacts that environmental releases have on available water. Simply put, their mental model are simplistic: when it rains, more water is captured and hence more is available for consumption. For most consumers, issues such as evaporation, transpiration, bushfire effects and environmental releases are not part of the equation.

Management Flight Simulator

- While the modeling described here has been used to examine the dynamics of water supply and to examine policy options, SD modelling and the simulation games derived from such models are yet to be fully exploited as tools for enhancing communications about public policy.
- Rarely do members of the public, who can be either the unwitting beneficiaries or victims of public policy decisions, have an opportunity to test for themselves the likely efficacy of alternate management policies. Experience gained through this research suggests that the problems faced jointly by both regulators and communities can be readily misunderstood and, as a consequence, the formulation of policies can be flawed.

Understanding the Complex System Dynamics of Managing Water Security

Sondoss El Sawah, Alan McLucas, Michael Ryan

THE UNIVERSITY OF
NEW SOUTH WALES