# Water: A critical resource in a dynamic world

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## Background and Significance

Water is considered a critical resource because the amount of freshwater on Earth is finite and unevenly distributed. Due to the critical role water plays in life, industry, and agriculture, its intensive exploitation is exerting tremendous pressure on available resources as well as social and political structures. Many conflicts on local and national levels in many regions of the world are direct consequences of water exploitation. Adding climate change including extreme floods and intensive droughts as well as demographic, economic and social drivers for water supply and demand, technological innovation, policies, different laws and finance with different perspectives the management of the critical resource freshwater is a great challenge of the society (World Water Assessment Programme, 2009).

Water is at the heart of many social and political conflicts. In the Middle East where water has historically been a scarce resource, disproportionate exploitation of surface and groundwater has fuelled many long lasting conflicts like the tragic Israeli-Palestinian problem. Israelis use nearly nine times as much water per person as Palestinians, primarily for the irrigation in agricultural business (United Nations Development Programme, 2006). Conflicts between farmers, municipalities and industry in water-stressed areas are spurring many alarming conflicts in India, Thailand, China, and the USA (United Nations Development Programme, 2006). The limits of private water markets, unsolved problems in water rights and competitions between large-scale producers (commercials farms) and small-scale producers (family framing) cause many conflicts in Asia and Africa (United Nations Development Programme, 2006).

In the Southwestern United States, water usage and distribution is a key topic of political debate. According to the United Nations Development Programme (2006, p. 180) the Western United States has some of the most in depth institutional rules and norms for water transfer and trade in water rights, and is seen as a model for other countries. However, despite the depth of the institutional rules and norms around water rights, the US has still been unsuccessful in achieving equitable distribution and this problem continues to be largely contested and litigated. In fact, water shortage and rights in this part of the States have becoming an increasingly volatile issue.

As the global population continues to grow exponentially, paralleled with the dramatic rise in urbanization, effective water management and distribution is of paramount importance to avoid future conflict. Unfortunately, the problem of water is not simply a problem of supply and demand, it is a problem of governance that includes a complex network of agents namely social, legal, economical, political, and historical (Meszoely, 2006).

**Complexity of the Problem**

Water distribution is a complex problem for many reasons, in particular because of the multiplicity of the interdependent and dynamic network of agents. There are many levels to the water problem, with interdependent factors both within and across levels, or subsystems. For example, there is a coupling between the water and the human system. Figure 1 shows a complex coupled human-water/environmental system. The problem is also complex because of the non-linearity and dynamic nature of the system.

In the Southwestern USA, there exists many factors that add to the complexity of this issue. For example, one factors is that water rights and land rights are separated (United Nations Development Programme (2006, p. 180). Another factor is that there exists differences across states in how and by whom water issues are governed, as well as differences across states in how water rights can be appropriated (Meinzen-Dick and Ringler 2006; NNMLS 2000). This problem is difficult to address also in part because of the opposing interests and relative nature of the outcomes. In addition, the non-linearity of the system makes it difficult, if not impossible, to connect policy initiatives with measureable outcomes. Furthermore, changes in one part of the system create changes in other parts of the system, making it difficult to determine the best course of action at any given point in time.

The human system consists of heterogeneous groups with different interests regarding water distribution. Social and economic dynamics can create also 'economic' and/or 'political' water shortage without any changes in the 'natural' systems. However, any shortage of water will put stress on the human systems and therefore re-organisation is necessary (i.e. equal distribution or 'the winner takes it all' approach).

There are also many interdependent and dynamic relationships aside from the human system that must be considered. Climate change for example, has an influence on the amount, pattern and intensity of precipitation as well as the atmospheric and water temperature. Thus affecting hydrological processes such as runoff and storage of groundwater. In California, as a result of human impact such as dams and irrigation techniques, the Colorado river no longer drains to the Guld of California. And according to the National Resources Defense Council, the Colorado Basin will continue to get warmer and more arid (http://www.nrdc.org/globalwarming/west/fwest.pdf). The micro-climate is also heavily influenced which in turn increases the rate of evaporation from large water surfaces (including reservoirs, wetlands, swimming pools).

Another factor to consider is the quality of water that is being distributed to the people, especially for consumption purposes. Many times, the quality of water is strongly affected by anthropogenic sources (human activities). It may be necessary to sanitize and treat the water before allowing humans to drink it through procedures such as filtration, disinfection and deionization. Depending on the degree of treatment, the price of producing clean water increases thereby also increasing the amount of stress on policy makers and consumers.

Water distribution is clearly a complex problem, and as such simplistic solutions that do not consider the interdependent and dynamic nature of the problem will not work. Unfortunately, applying a complex systems lens, or approaching the problem from a complex science paradigm can be overwhelming. The purpose of this project is to begin to address the issue of water distribution specifically in California via a complexity science paradigm. This project attempts to apply tools appropriate to complex systems to begin to elucidate some of the key agents and relationships central to the issue and to successful problem solving. A better understanding of the complexity of water distribution, as well as increased ability of researchers and policy makers in this field to use appropriate systems tools, is paramount to developing successful solutions.

**Project Overview**
Research question: How can water distribution be improved in California?

**Objective 1:** to model the coupled human-water systems using heterogeneous agents employing prediction models;

**Objective 2:** to determine actions to represent the non-linear behaviour of economic, political, and social systems in water resources management; and

**Objective 3:** to observe the behavior of the model, by tracing the utility measures, in response to policy changes.

## Methods

### Approach
The initial plan for this project was to use a combination of both Agent-Based Modeling (ABM) and network analysis to address the research question. However, due to time constraints only the ABM has been worked on thus far. The model was intended to be a dynamical agent-based-model focusing on interactions and feedback loops of hydrologic and human systems to gain more insight of the dynamic of this coupled system.

To construct the model, the team began with a brainstorming session to identify the agents to include. The first version of the ABM contained numerous agents in the model, including damns, wells, and farmers, which proved to be too much, and was simplified into a model with less agents. The variables and agents were identified based on a literature review and group discussion. The model construction occurred through an iterative process of running and simplifying the model. The project did not get to the point of model testing yet.

### ABM Model
The final ABM water model captures some key basic elements of water resources management. The variables are divided into 5 categories: externalities, utility, policy, internalities, and agents (table 1).

Table 1. Working table describing model variables and definitions.

| Category | Variable Name | Definition |
|---|---|---|
| Externality | | these will randomly fluctuate around some predefined value as a basic model. |
| | Rainfall | a number that represents total allocated water to the state |
| | Economy | a number that represents total allocated capital to the state |
| | Energy cost | |
| | | |
| Utility | Environmental sustainability | a number that represents the health of the environment = total energy use – dam energy production + r*dam size. r is a constant that represents the damage that dams do to the environment |
| | Economic wellbeing of all citizens | number of citizens that fall below poverty line |
| | Peace with neighbors | a number that measures neighbor satisfaction, = total allocated water – total consumed water* |
| | | |
| Policy | Ratio of water extracted from dams vs. wells | dam ratio and well ratio |
| | Price of water | |
| | | |
| Internalities | Water use level attitude | = average of Consumer consumption * Consumer influence factor (influential consumers will have a bigger impact on policy. This will capture the effect of elections, general behavior, etc.) |
| | Environment protection attitude | = average of Consumer sensitivity to environment * influence factor |
| | | |
| Agents | Consumer | |
| | Farmer | |
| | Dam | |
| | Well | |
| | | |

*This means that if the sates consumes above its allocated amount, then it must be taking water away from neighbors

## **Discussion**

Overall, the project was deemed to be both interesting and educational. There were many 'lessons learned' derived from the project, that can be carried-over to future ABM activities and work in complex systems in all of the team members diverse fields. One of the key lessons learned, was that it is best to start with a relatively simple model, test it, and then continue to build it into a more complex model if appropriate.

Our project team was interdisciplinary, which provided valuable insights, as well as challenges. It was clear that interdisciplinary work requires extra attention to communication and constant goal clarification, as there is much opportunity for divergence to ones own discipline and familiar perspectives. Future work on this project would include further refinement of the ABM model, and the addition of the network overlay.

## References

Meszoely, G. Water Resources Management in a Saharan Oasis. Ph.D. Dissertation, Northeastern University. greta.obrahim.com, 2006

http://www.unesco.org/water/wwap/wwdr/wwdr3/

http://www.scitopics.com/Agent_Based_Spatial_Models_for_Agriculture_Land_Use_and_Water_Management.html

http://dspace.mit.edu/handle/1721.1/44199

http://cfpm.org/cpmrep163.html

http://sim.sagepub.com/cgi/content/refs/81/3/175

http://www3.interscience.wiley.com/journal/114286455/abstract?CRETRY=1&SRETRY=0 <http://www3.interscience.wiley.com/journal/114286455/abstract?CRETRY=1&SRETRY=0>

http://www.sciencemag.org/cgi/content/full/310/5750/987?ck=nck

http://en.wikipedia.org/wiki/Water_cycle)

(http://www.nrdc.org/globalwarming/west/fwest.pdf).
(http://en.wikipedia.org/wiki/Colorado_River). Lager water

World Water Assessment Programme. 2009. The United Nations World Water Development Report 3: Water in a Changing World. Paris: UNESCO, and London: Earthscan.

United Nations Development Programme. 2006. Human Development Report 2006: Beyond scarcity - Power, poverty and the global water crisis. Palgrave Macmillan, New York.

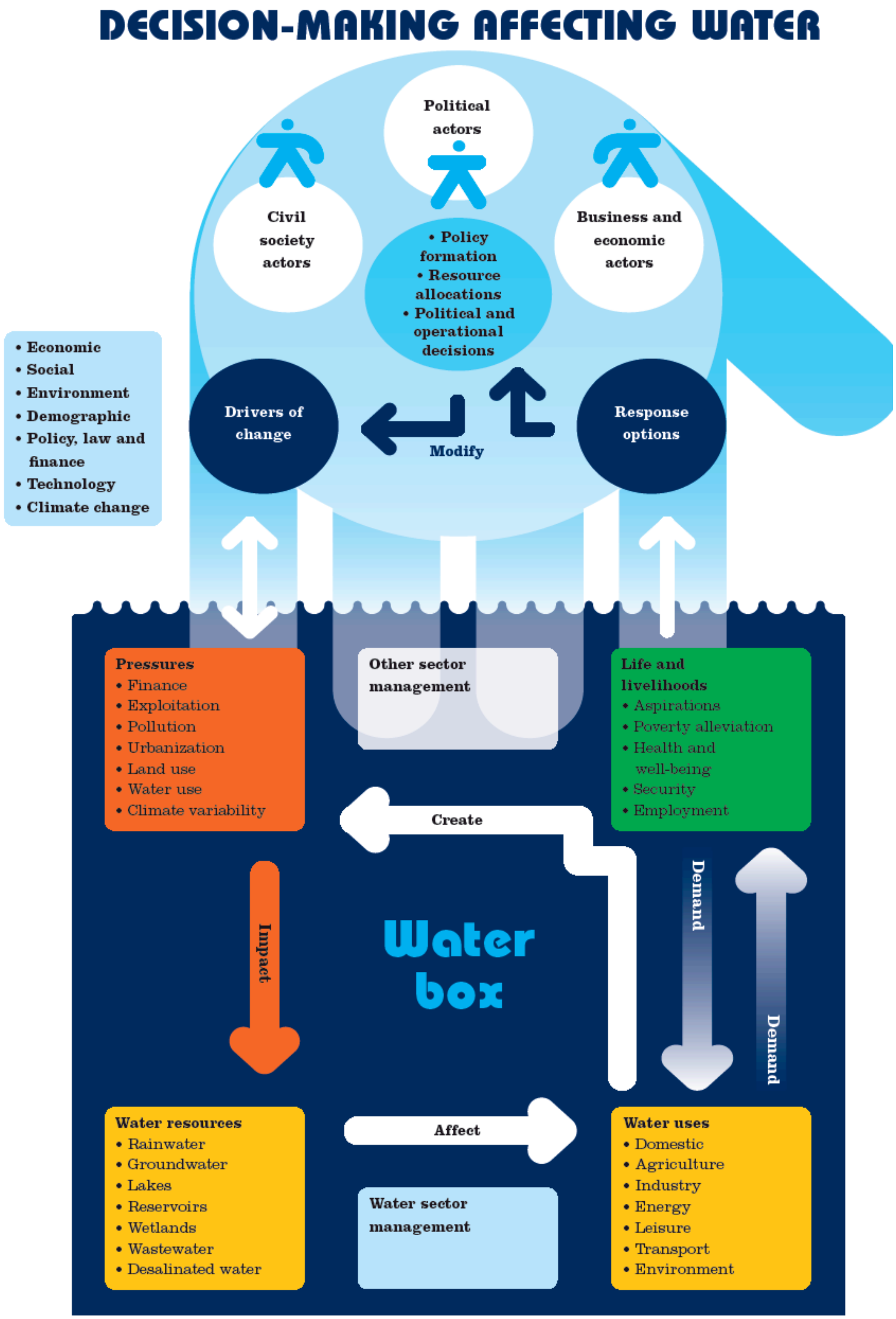
DECISION-MAKING AFFECTING WATER
Political actors
Civil society actors
Business and economic actors
• Policy formation
• Resource allocations
• Political and operational decisions
• Economic
• Social
• Environment
• Demographic
• Policy, law and finance
• Technology
• Climate change
Drivers of change
Modify
Response options
Pressures
• Finance
• Exploitation
• Pollution
• Urbanization
• Land use
• Water use
• Climate variability
Other sector management
Life and livelihoods
• Aspirations
• Poverty alleviation
• Health and well-being
• Security
• Employment
Create
Impact
Water box
Demand
Demand
Water resources
• Rainwater
• Groundwater
• Lakes
• Reservoirs
• Wetlands
• Wastewater
• Desalinated water
Affect
Water sector management
Water uses
• Domestic
• Agriculture
• Industry
• Energy
• Leisure
• Transport
• Environment

Figure 1: