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Scenario development for water resources planning and management

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Abstract We report progress on a novel effort to develop a unified framework for constructing scenarios for water resource management. The framework comprises five iterative phases: scenario definition, scenario construction, scenario analysis, scenario assessment, and risk management. While the scenario framework can be applied to most water resource applications, we place particular emphasis on semiarid environments and forces not typically considered in the traditional water management process such as unforeseen changes in government institutions, or second-order effects of climate change on environmental systems. The main objective of scenario development for water resources is to inform policy-makers about the implications of various water management strategies. In addition, scenarios can consider the possible effects of external drivers, such as changes in political institutions, or large-scale environmental change that may be especially important in developing countries.

Key words modelling; planning; projections; scenarios; stakeholder; water resources; uncertainty

INTRODUCTION

Although there have been many studies conducted in the field of scenario analysis and development, very few formal studies have explicitly addressed the unique demands that water resource applications place on scenario development. Even more evident is the absence of an established formal approach to develop and apply scenarios to water resources applications. In the following, we suggest a framework that can be applied to the development of scenarios for integrated hydrological modelling purposes. Scenario development is a process that evaluates possible future states of the world by examining several feasible scenarios. Scenario analysis can be thought of as a planning exercise that examines the future without making an attempt to forecast what the future will look like. Traditional forecasting produces answers while scenario planning encourages planners to ask questions to make the planning process robust to whatever the future may hold (Van der Heijden *et al.*, 2005).

The field of scenario planning evolved from the RAND Corporation's use of scenarios to assist the US Air Force to foresee their opponents' actions during World War

II (Schwartz, 1996; Van der Heijden, 2005). Herman Kahn, a noted futurist and one of the original RAND scenario planners, adapted the scenario approach as a business planning tool in the 1960s. Concurrently, Gaston Berger, Pierre Masse, Bertrand de Jouvenel and Michel Godet advanced the use of scenarios for government planning in France (Van der Heijden *et al*., 2002). Scenarios were initially seen as a way to plan without predicting things that were unpredictable (Van der Heijden, 2005). One of the notable early successes of the use of scenarios in business was that of Pierre Wack and Royal Dutch/Shell who, in 1967 noted that increasing uncertainty in oil production, delivery, and prices was likely and that power could shift from oil companies to oil-producing nations (Ringland, 1998). In particular, Wack's work moved beyond analysing the technical aspects of supply and demand for oil, to consideration of political economy, which was not part of the traditional planning process at the time. While competitors took years to respond to the oil embargo of 1973–1974, Shell responded quickly and secured the company's position in the industry. The broad consideration of outcomes that *could* happen, rather than what is likely, is what makes scenario analysis especially useful for water resources planning, where much is unknown, or even unknowable regarding the effects of variable climate on water resources.

Although the scenario planning approach has been extensively used in business, few applications exist within the natural sciences (e.g. Hulse & Gregory, 2001; McCarthy *et al*., 2001; Hulse *et al*., 2004). Hence, there has been a lack of generic approaches to scenario planning for environmental decision making. However, one can imagine that strategic planning with respect to water in the 21st century may be just as important as planning for oil was in the 20th century.

The relevance of scenario planning

Scenarios are often used to test the effects of different assumptions about the way the future could unfold and the implications for the system being modelled. Scenarios take many forms but those used in the natural sciences tend to fall under the definition provided by the Intergovernmental Panel on Climate Change (IPCC):

"*A scenario is a coherent, internally consistent and plausible description of a possible future state of the world. It is not a forecast; rather, each scenario is one alternative image of how the future can unfold*."
(Source: http://ipcc-ddc.cru.uea.ac.uk/ddc_definitions.html)

According to this definition, scenarios are not forecasts, predictions, or projections of the future; instead, they provide a more robust way of thinking about the future through consideration of multiple feasible alternative futures (Fig. 1). Scenarios are typically used in the context of planning over long time horizons. Long-term planning is especially important when making decisions that involve interaction of multiple uncertain variables, such as climate change, demographic trends, and evolving institutions (Godet & Roubelat, 1996). "*One of the great values of scenario planning lies in its articulation of a common future view to enable more coordinated decision-making and action*" (Means *et al*., 2005). Rather than relying on predictions, scenarios enable a creative and flexible approach to prepare for an uncertain future (e.g. Schwartz, 1996; Van der Heijden, 2002; Means *et al*., 2005).

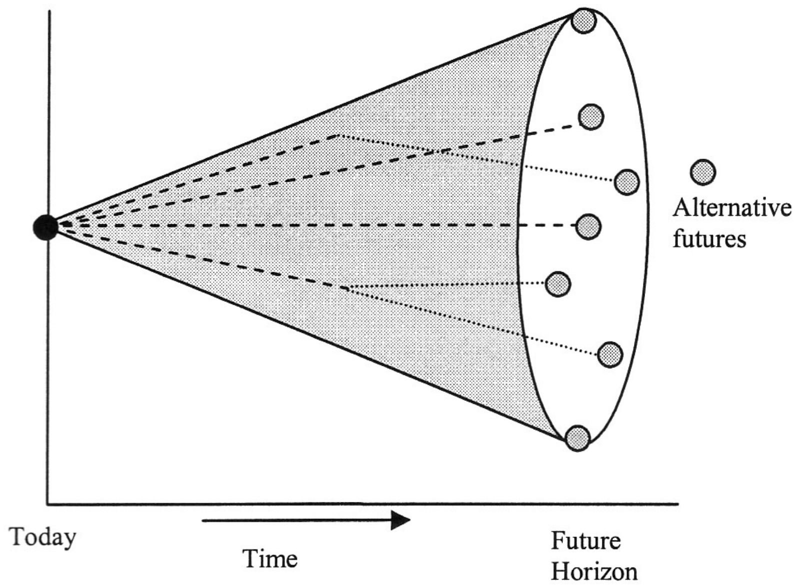

Fig. 1 Conceptual diagram of a scenario funnel. Adapted from Timpe & Scheepers (2003).

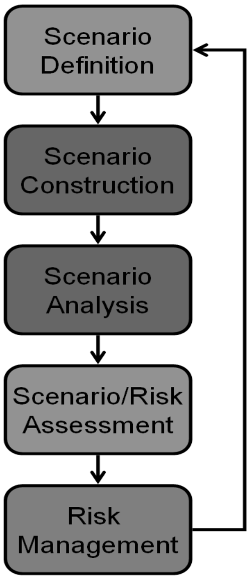

Fig. 2 The five phases of scenario development.

The five phases of scenario development

In what follows, we present a formal scenario development approach for use in water resources that comprises an iterative five-phase process: *scenario definition, scenario construction, scenario analysis, scenario assessment, and risk management* (Fig. 2).

The development of scenarios for natural resource problems should include both scientists and stakeholders contributing in complementary ways. In a general sense, scenario definition and assessment require extensive interactions and cooperation between scientists and stakeholders; scenario construction and analysis are primarily scientific efforts of researchers; and risk management is mainly the responsibility of stakeholders. However, in some cases, continuously involving stakeholders throughout the entire process might be important and desirable. It should be emphasized that feedbacks exist between each of the five stages.

Scenario definition

The scenario definition phase identifies the specific characteristics of scenarios that are of interest to decision makers. Such characteristics include the spatial and temporal scales of the scenario effort, whether the future is considered to be a trend of the present or has the potential for a paradigmatic shift in system behaviour, and most importantly, the critical forcings—the key variables that drive the system under study. Critical forcings of a system are those that are both somewhat predictable and drive change in the system. Some forcing estimates may be restricted by standard practice (such as specific rates of population growth used in economic development studies, or management rules for components of the system), while others are determined by predetermined events, boundary conditions, or end states. Effective scenario definition results from extensive discussions among stakeholders and researchers.

Important questions to address during the scenario-definition phase of an environmental study may include: What time horizon and intervals are important? What is the spatial extent of the problem? What system components will be considered in the scenarios? What factors exogenous to the system must be considered?

Scenario construction

Once the characteristics of the scenarios have been defined, the next step is to identify the detailed quantitative and/or qualitative information that reflects the logical implications of each scenario. Important questions to be asked during the construction phase may include:

– What are the causal relationships or external conditions that can be depended upon (e.g. predetermined elements)?
– What are the critical uncertainties in how the future might unfold?
– What are the assumptions about how different parts of the system work?
– What variables and situations are important and how should they be modelled?
– For a modelling-based approach, scenario construction will typically comprise three major steps: (1) conceptualization; (2) model selection or development; and (3) data collection and processing (Wagener *et al*., 2006; Liu *et al*., 2007).

Conceptualization involves working with stakeholders to capture key decision factors; understand the principles, hypotheses and assumptions related to system relationships, feedbacks, and flows; ensure that the key information needed to inform decisions is provided by models in a format useful to decision making; and provide a framework for monitoring (Wagener *et al*., 2006; Liu *et al*., 2007).

Scenario construction processes use models to project potential future alternatives and to generate the scenario outcomes. Two common examples of this process include the emission scenarios used to drive Global Circulation Models to predict climate change and the socio-economic scenarios and stakeholder input used to drive land-use models to predict the amount and spatial distribution of anticipated land-use change (Schneider, 2002; Steinitz *et al*., 2003).

Issues to be considered in selecting or developing models and procedures may include: whether the model can adequately represent important behaviour of the system. Is the model feasible at the scales and resolutions specified? Can dominant uncertainties be sufficiently taken into account? Is a single model applicable to all the scenarios defined or are different models needed for different scenarios?

The data collection/processing component of construction ensures that scenarios are ultimately linked to real data sets. For a model-based approach, this step requires gathering and processing model input data, running the model for each scenario, and processing model output data. Primary model input and output variables are driven by scenario definitions and should have been identified in the conceptualization step, along with appropriate spatial and temporal resolutions and scales.

Model input data can be derived from any combination of projections, field observations, or outputs from other models. The key issue here is to ensure that the input data sets are at appropriate time/spatial scales and resolutions and are internally consistent. Model output data (i.e. scenario outcomes) are obtained by running the models and can be evaluated or validated against projections from other sources.

Scenario analysis

Scenario analysis focuses on identifying the consequences of interactions among the boundary conditions, driving forces, and system components. Scenario analysis is primarily a scientific effort, employing a variety of statistical and other analytical techniques to examine the scenarios constructed in the prior phase. Activities include: examination of model outputs, inspection for data consistency, and the quantification of uncertainties associated with the scenarios. Model outputs are converted into the desired form identified in the scenario definition phase and adjusted to different time and space scales as required. Scenario analysis also identifies notable system conditions or behaviours, including trends, regimes, thresholds and triggers, discontinuities, and cascading effects.

Scenario assessment

Scenario assessment includes identifying risks, mitigation opportunities and trade-offs; presenting results to stakeholders; and devising plans to monitor and audit scenario plans and resulting management strategies. This phase extracts a set of narratives describing scenario results from the outcomes of the scenario analysis phase, and examines the implications for resource management and other decisions in different dimensions. For example, for an integrated assessment of climate change impacts on water resources, this may involve environmental, institutional, and socio-economic dimensions of the problem. Attention should be focused on the patterns identified in the scenario analysis rather than specific numbers or end states, and on factors (e.g. cognitive filters) that may bias assessment results. Crossing into the realm of risk assessment, scenario assessment uses techniques from that field, including influence diagrams, event trees, outcome matrices, contingency planning, cost/benefit analysis, Delphi techniques, normative tables, and vulnerability assessment, among others. Scenario assessment relies on extensive discussion among stakeholders and researchers, although finding effective ways of presenting information remains a challenge.

Risk management

Risk management is primarily the responsibility of stakeholders rather than scientists. Risk management includes implementation of strategies for reducing vulnerabilities to risk, increasing resilience to problematic conditions, and positioning resources to exploit opportunities. While many risk management techniques exist, not all may be practical in a specific situation. The risk management options that are available set limits on subsequent scenario definitions. Furthermore, not all risk can be eliminated and some residual risk will remain regardless of management practices.

OUTLOOK FOR SCENARIO DEVELOPMENT IN WATER RESOURCES

While scenario approaches have been used in the past to address water-resource issues, these scenarios are typically done one at a time by consulting firms or extension agencies for particular clients. Because many agencies are faced with similar issues, e.g. water resources management in the context of changing climate and explosive population growth in the American Southwest, independent efforts may involve needless duplication of scenario development efforts. Additionally, most of these scenario efforts and their production processes have been poorly documented and have received little, if any peer review. Consequently, there is little guidance on the process available to natural scientists interested in developing quality scenarios to drive models. The process detailed above represents an attempt to provide the water–resource community with a formalized framework for the development of scenarios to inform decision-making and drive integrated models.

Recognizing that the extant literature on scenario development focuses on business planning problems and that scenario activities within the natural sciences community are often poorly documented, SAHRA (Sustainability of semi-Arid Hydrology and Riparian Areas) at the University of Arizona, has created a web community where natural scientists interested in the scenario development process can find and share information and experiences (http://sahra.arizona.edu/scenarios/). This interactive community website seeks to engage and educate potential scenario developers about the scenario development process, share and exchange information and resources on scenarios to foster a multidisciplinary community of scenario developers, and establish a unified framework for scenario development. The website provides information on scenario development, current scenario-related activities, key water-resources scenario studies, links to other scenario studies, a forum for discussion on scenarios, a depository on scenario development publications, and a glossary of scenario terms.

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