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Formal Scenario Development For Environmental Impact Assessment Studies.

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CHAPTER NINE

Formal Scenario Development for Environmental Impact Assessment Studies

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9.1. INTRODUCTION

Scenario analysis is the process of evaluating possible future events through the consideration of alternative plausible, though not equally likely, states (scenarios). The definition by the Intergovernmental Panel on Climate Change (IPCC) best represents scenarios considered in the natural sciences:

> "*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.*" (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 dynamic view of the future by exploring various trajectories of change that lead to a broadening range of plausible alternative futures as illustrated with the scenario funnel in Figure 9.1. Scenarios are typically used in the context of planning over long time horizons, offering many opportunities for unique and unanticipated conditions to occur. Long-term planning is especially important when making decisions regarding factors and trends of interactions and human consequences that may impact the future (Godet and 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 preparing for an uncertain future (e.g. Schwartz, 1991; Van der Heijden, 1996; Means et al., 2005). Most studies develop three to five scenarios that are subsequently analysed in detail.

Scenario planning originated in US Air Force planners' efforts to foresee their opponents' actions during World War II (Schwartz, 1991), which enabled them to prepare alternative plans to be used if a particular scenario occurred. One of these air force planners, Herman Kahn, later adapted the scenario approach as a business planning tool in the 1960s. Scenarios were initially used and applied in a broad commercial sense by businesses. Pierre Wack elevated the use of scenarios onto a new level in the 1970s by creating "alternative futures" for Royal Dutch/Shell's oil

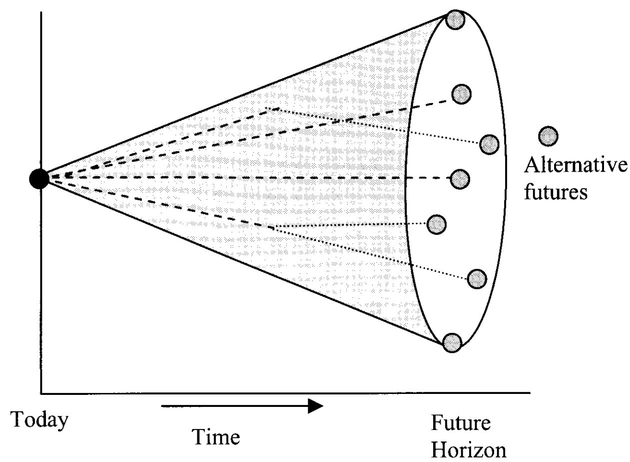

Figure 9.1 Conceptual diagram of a scenario funnel. Adapted from Timpe and Scheepers (2003).

enterprise. While conventional forecasting failed to predict the unexpected doubling of oil prices in the early 1970s, the Wack group presciently noted in 1967 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). This enabled Shell to respond quickly to the oil embargo of 1973–1974 and secured the company's position in the industry. In this sense, scenario planning can help companies to maintain stability in an unpredictable market (Leney et al., 2004). Peter Schwartz and colleagues later extended the use of scenario planning to governments when he and some of his colleagues formed the Global Business Network (Means et al., 2005).

Applications of the scenario planning approach are also emerging in environmental studies (e.g. Hulse and Gregory, 2001; Hulse et al., 2004; Kepner et al., 2004; Miller et al., 2007; Pallottino et al., 2005; Roetter et al., 2005; Steinitz et al., 1996). One example worth noting is the US EPA study on the Willamette River Basin in western Oregon, where detailed input from local stakeholders was used to create three alternative future landscapes for the year 2050 (Baker et al., 2004). These future scenarios were created and compared to the present-day and historical landscapes, in terms of water availability, stream conditions and terrestrial wildlife. It was found that a scenario projecting current policies and trends resulted in landscape changes and associated environmental effects that were surprisingly small. But a development-oriented scenario resulted in a noticeable loss of prime farmland and wildlife habitat, and a conservation-oriented scenario led to the recovery of 20–70% of historical losses in several ecological indicators. In all scenarios, water availability declined by 40–60%. Another study, for the agricultural watersheds in Iowa, developed and analysed scenarios to evaluate land use alternatives in terms of water quality, plant and animal biodiversity, and farm economics (Santelmann et al., 2001). And an analysis of Monroe County, Pennsylvania created six scenarios to address the stresses of recreational and residential developments (Steinitz and McDowell, 2001).

The next sections review the state of the art of scenario planning for environmental decision making, propose a formal approach to scenario development in environmental studies, discuss existing issues, and make some recommendations for future research in this area.

9.2. TERMINOLOGY AND BACKGROUND

9.2.1 Terminology

Most scenario development efforts involve a heterogeneous group of people from different disciplines and organisations. While this ensures a wide range of backgrounds it can also create a communication barrier due to the different languages used in different fields and organisations. For example, the terms scenario assessment, analysis, and development often have different meanings across the literature, or are used interchangeably. Our definition of some terms is provided below to improve clarity of the discussion presented in this chapter.

Alternative Futures: different representative "future worlds" that collectively illustrate the universe of the future.

Adaptive Capacity: ability of a system to successfully accommodate impacts of change.

Cascading Events: a consecutive set of events that occur as a result of specific triggers.

Conceptual Model: a high-level conceptual representation of important assumptions, inter-component flows, states, parameters, and uncertainties; may be used as a basis for numerical models.

Discontinuities: events or consequences that cannot be extrapolated from prior actions or events and are unpredictably new.

Model Structure: conceptualisation and mathematical implementation of a model.

Model: a particular combination of a model structure, parameters, and boundary and initial conditions.

Monitorable Indicators: variables that can be tracked through time to determine the occurrence of regimes, triggers, cascading events, discontinuities and wild cards.

Parameter: characteristic property of a system that remains constant over a time duration of interest.

Regimes: shift in the persistent status of a system.

Resilience: ability of a system to maintain its structure and function when external forces are acting on it.

Risk: a measure of the probability and severity of an adverse affect.

Sensitivity Analysis: assessment of how variations in specific factors (input, parameter, state, model structure etc.) affect the output (response) of a model.

Stakeholder: an individual or group who has an interest in the process and/or outcome of a specific project and can potentially benefit from that project.

Thresholds: conditions in time and space that produce notably different experiences in a system's state or response.

Trends: patterns of behaviour over time of the most critical and most uncertain variables.

Triggers: particular combination of conditions that lead to a change in a system's regime.

Uncertainty: inability to precisely determine the true magnitude or form of system/model variables or characteristics.

State Variables: variables that describe the time-varying characteristics of a system.

Wild Cards: major surprises that have high impacts.

9.2.2 Characteristics of scenarios

The future is not a static continuation of the past; scenarios recognise that several potential futures are possible from any particular point in time. Scenario studies commonly target issues to which stakeholders are most sensitive and they provide the means by which decision makers can anticipate coming change and prepare for it in a responsive and timely manner. Through exploration and evaluation of feasible future conditions, scenario studies enable assessment of system vulnerabilities and possibilities for adaptation measures. For example, decision makers can employ scenarios to guide control policies and implement strategic planning for impacts outlined by resultant alternative futures. Scenario planning can lead to better-informed decisions by bridging the gap between scientists and stakeholders and bringing to the forefront matters of immediate concern (Godet and Roubelat, 1996; Houghton, 2001; Maack, 2001; McCarthy et al., 2001; Schwartz, 2000; Santelmann et al., 2001; Steinitz, 2003).

One of the most important characteristics of a scenario is that it be physically and politically plausible (Houghton, 2001; Hulse et al., 2004). Plausible scenarios provide logical descriptions and explanations of possible happenings; this adds credibility to the body of work that scenarios are meant to supplement (Maack, 2001). To add further credibility, a plausible scenario should also be internally consistent with the driving forces that are critical to the development of the scenario trajectory (Houghton, 2001; Maack, 2001). To eliminate redundancy, scenarios should be distinct by focusing on different driving forces and/or scenario objectives, yet still retain a set of common variable inputs so that results from different scenarios can be compared. Useful scenarios should also be creative and test limits in exploring the unknown future (Maack, 2001), while remaining connected to the purpose of

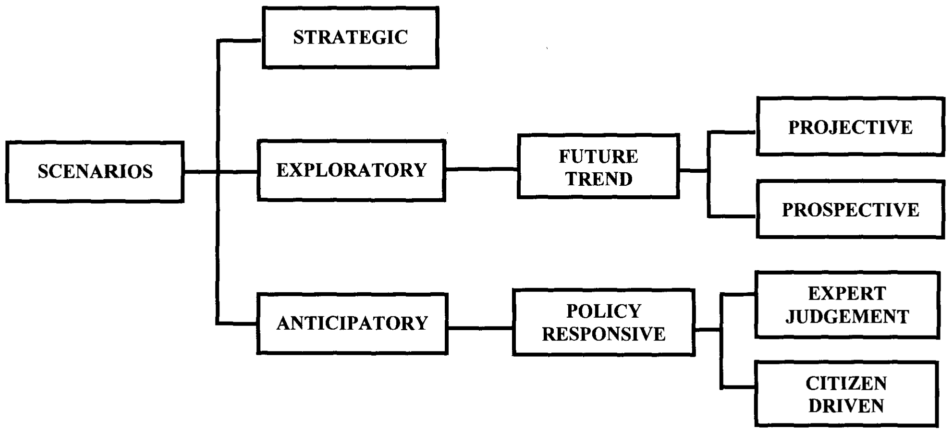

Figure 9.2 Scenario types.

their use and being fully defined quantitatively and qualitatively (Hulse et al., 2004; Maack, 2001). The simplest baseline scenario is that of the "official future," a "business-as-usual" scenario of a widely accepted view of the state of the future. Most decision makers will not accept future alternatives unless the official future is questioned (Schwartz, 2000).

9.2.2.1 Scenario types

Different basic types of scenarios can be found in the literature. Some of the main types are shown in Figure 9.2 and their major characteristics are briefly explained below.

- *Strategic scenarios* are primarily of interest to modellers and researchers. They are aimed at identifying inconsistencies in the approaches used by different disciplines to describe components of a complex system. The emphasis of strategic scenarios is on making explicit the assumptions, patterns and data selected by each discipline.
- *Exploratory scenarios* describe the future according to known processes of change and extrapolations from the past (McCarthy et al., 2001).
- *Anticipatory scenarios* are based on different desired or feared visions of the future that may be achievable or avoidable if certain events or actions take place; they make use of past and possible future conditions in their construction with high subjectivity (Godet and Roubelat, 1996; McCarthy et al., 2001).
- *Future trend-based scenarios* are exploratory in nature and are based on extrapolation of trends, projections and patterns. Although they are simple to apply, their simplicity does not permit the identification of all relevant policies that can affect the future (Godet and Roubelat, 1996; Steinitz, 2003). Commonly used in historical planning studies, future trend-based scenarios can be either projective or prospective. *Projective scenarios* project forward in time using trends experienced over some past period, while *prospective scenarios* anticipate upcoming change that significantly varies from the past (Hulse and Gregory, 2001).

- *Policy-responsive scenarios* follow the anticipatory approach, where policy decisions are outlined based on critical issues, and scenarios are then constructed with the desired policy as the targeted future outcome. This type of scenario is frequently found in governmental and organisational decision making in the context of attempting to better understand and manage risks (Schwartz, 2000; Steinitz, 2003; Baker et al., 2004). Policy-responsive scenarios can either be based on expert judgment or driven by stakeholders.
- *Expert judgment-driven scenarios* model future conditions by means of scientific knowledge derived from decisions, rules, objectives and criteria established by science investigators and field experts. Advantages of this type of scenarios include the integration of current thinking towards future change, the incorporation of a wide range of pertinent information, and the ability to build a scientific-based consensus. Major disadvantages of scenarios governed by expert judgment are introduction of bias through subjectivity and lack of political plausibility (Houghton, 2001; Hulse et al., 2004; McCarthy et al., 2001).
- *Citizen-driven scenarios* involve stakeholders in defining the assumptions about the future that are to be incorporated into scenarios. They usually have greater political plausibility and public acceptance than expert-driven scenarios, for stakeholders are actively engaged in the scenario planning and development processes (Hulse et al., 2004). However, they potentially contain biases because only the most active citizens are typically involved.

9.2.2.2 Scenario themes

When scenarios involve complex interactions between natural and human systems, the identification of scenario themes, as plot lines within a story-like narrative, can facilitate discussion about different issues. Scenario themes are typically suggested by the cause and effect relationships between those most critical and most uncertain variables. Themes may include those that describe the future in terms of growing or declining forces (e.g. enhanced vs. declined environmental monitoring networks), good news and bad news (e.g. sustained drought vs. highly variable climate), or winners and losers (e.g. ranchette vs. city-infill patterns of population distribution). Themes can also be represented in the form of cycles of periodic change or states of change, representing a sequence of events that feed off each other to cause a movement towards a certain state (e.g. a series of innovations leading to improvement, or a series of mistakes leading to stagnation). Additionally, extreme wild card scenarios can involve themes to portray developments that could completely reshape society (Maack, 2001).

9.2.2.3 Scenario likelihoods

There are no "true" likelihoods associated with scenarios in the sense that scenarios are not forecasts/predictions but descriptions of plausible alternative futures. However, for the purpose of risk assessment, scenarios can be categorised according to whether they are possible, realisable, or merely desirable (Figure 9.3). Possible scenarios encompass all that are feasible; realisable scenarios are feasible scenarios operating under a set of defined and specified constraints; and desirable scenarios are possible scenarios that may not necessarily be feasible or realisable (Godet and

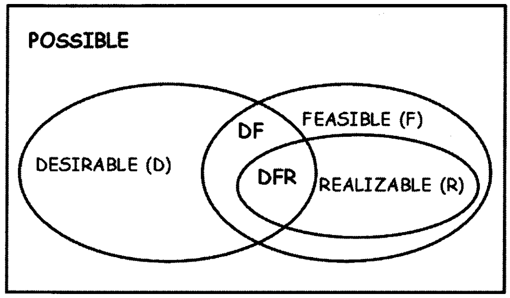

Figure 9.3 Likelihoods of scenarios.

Roubelat, 1996). In risk management, pair-wise comparison of these relative "likelihoods" of the scenarios can be used to determine the priority of scenarios, for risks generally increase with scenario likelihoods and the undesirability or severity of consequences of scenarios.

9.2.2.4 Scenario categories

Scenario planning is most commonly driven by decision makers or their advisors with a particular set of concerns and objectives in mind. As a result, scenario-planning efforts have commonly focused on a particular category of future conditions to narrow the scope of the process. Common scenario categories are those of climate, socioeconomics, environment and water resources.

- *Climate scenarios* are based on climate projections and are designed to represent future climate such that potential impacts of anthropogenic climate change are investigated. The Intergovernmental Panel on Climate Change (IPCC) focuses heavily, and almost exclusively, on climate change scenarios in which scientific, technical, and socioeconomic information is assessed to understand the risks, impacts and mitigation options for human-induced climate change (Houghton, 2001).
- *Socioeconomic scenarios* characterise demographic driving forces, and the sensitivity, adaptability, and vulnerability of socioeconomic systems. These scenarios are inherently complex since they require the careful blending of extrapolation and expert judgment to produce plausibly coherent scenarios that combine disparate elements (McCarthy et al., 2001).
- *Environmental scenarios* encompass future environmental factors and conditions that consist of threats to natural ecosystems and environmental consequences of land use as well as other applicable practices (McCarthy et al., 2001).
- *Water resources scenarios* represent water's importance in human survival, ecosystems management, economic activities, agriculture, power generation, and various other industries. The quantity and quality of water are equally important in assessing present and future demands for the resource (McCarthy et al., 2001).

For most environmental studies, it is obvious that all of these categories are closely interrelated with potential feedbacks and consideration of any one in isolation can potentially lead to flawed scenario outcomes. Consequently, successful en-

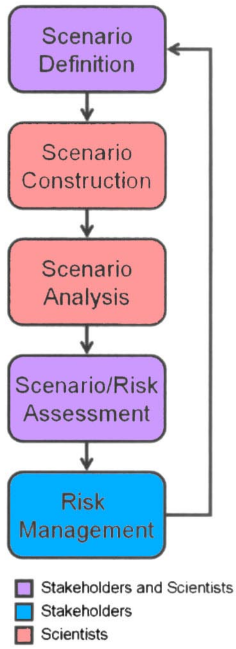

Figure 9.4 The five progressive steps of scenario development.

vironmental scenario studies usually combine elements of climate, socioeconomic, environment, and water-resource scenario categories (e.g. Steinitz and McDowell, 2001; Steinitz, 2003; Baker et al., 2004).

9.3. A Formal Approach to Scenario Development

The development of scenarios is a complex process and inherently involves substantial researcher-stakeholder interactions and/or expert judgments. While there are plentiful resources available about scenario development in business and the information sciences, fewer resources are specific to the unique problems of developing scenarios for natural sciences and environmental assessment (e.g. Steinitz, 1993). Here we propose a formal scenario development approach for use in environmental studies, by describing scenario development as an iterative process with five progressive phases: *scenario definition, scenario construction, scenario analysis, scenario assessment, and risk management* (Figure 9.4). 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. Further, it is useful to have some feedback among all phases of scenario development.

9.3.1 Scenario definition

The *scenario definition* phase identifies the specific characteristics of scenarios that are of interest to stakeholders such as the spatial and temporal scales of the scenario development effort, whether the future is considered to be merely a trend of the present or has the potential for a paradigmatic shift in system behaviour, and most importantly, identifies the critical forcings – the key variables that drive the system under study. The driving forces most aligned with a scenario are those to which a system is responsive, and that have a certain degree of predictability. Some aspects may be restricted by standard practice (such as specific rates of population growth used in economic development studies), 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 regional extent and subdivisions should be considered?
- What system components should be considered in the scenarios? Should the scenarios include climate variability, agricultural practices, or water resources regulations and policies? Should they include changes in socioeconomic development patterns or behaviour?

9.3.2 Scenario construction

Once the scenarios have been defined, the next step is to flesh out the scenarios with detailed quantitative and/or qualitative information that reflect the ultimate outcomes of scenario characteristics. 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 key 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 may consist of three major steps: (1) system conceptualisation; (2) model selection or development; and (3) data collection and processing. Similar strategies for scenario construction using environmental models can be found in Jakeman et al. (2006) and Scholten et al. (2007).

9.3.2.1 System conceptualisation

The first step of scenario construction is to identify the concepts and rationale behind the current system and the proposed changes resulting from the scenario definition process. If a model-based approach is adopted for scenario construction, as is typically the case for environmental assessment, a conceptual model needs to be built to identify key assumptions and decision factors and establish an explicit connection between the scenario definitions and the models to be used. The purpose of conceptualisation is fourfold:

- *To enhance understandability and facilitate communication with stakeholders.*
  A model used for scenario planning needs to be sufficiently realistic to achieve credible results; it, however, should also be at an appropriate level of complexity that the stakeholders can comprehend. Conceptualisation can be used to identify the appropriate level of model complexity that is both understandable and credible among the stakeholders.
- *To capture key decision factors.*
  Conceptualisation helps ensure that the specific issues, identified in the scenario definition phase as strategically relevant to decision making, are contained by or connected to prospective models.
- *To define scenario logic.*
  Here, conceptualisation involves identifying principles, hypotheses and assumptions related to system relationships, feedbacks, and flows that provide, from a modelling perspective, each scenario with a coherent, consistent and plausible logical underpinning.
- *To provide an anchor for monitoring/validation/review.*
  Conceptualisation helps to identify key variables/processes that represent changes in the environment, thus providing an anchor for monitoring and post-audits.

9.3.2.2 Selection or development of models

Typical scenario construction processes use models to project potential future alternatives and to generate the scenario outcomes. Two common examples of this process include:

1. Emission scenarios used to drive Global Circulation Models (GCM) to predict the impact of increasing concentrations of greenhouse gases in the atmosphere on the change of global temperature (Schneider, 2002).
2. Socioeconomic scenarios and stakeholder input used to drive land-use models to predict the impact of anticipated land-use change (Steinitz, 2003).

Models or procedures used for data generation need to be consistent with the conceptual model in terms of underlying assumptions and hypotheses, intercomponent flows, control variables, and parameters etc. Issues to be considered in selecting or developing models and procedures may include: can the model adequately represent the important behaviours of the system? Is the model feasible at the scales and resolutions specified? Is a single model applicable to all the scenarios defined or are different models needed for different scenarios within the spectrum?

In some instances, such as for small areas and projects with a more limited scope or less anticipated change, simple scenarios can be prescribed rather than modelled. For example, a group may be interested in exploring the consequences of land-management strategies and climate on local water resource conditions. Scenarios can be constructed for this task using available data: land-use/cover grids can be modified to reflect management strategies; and wet, dry and average periods can be selected from past climatic observations to represent different climatic regimes.

9.3.2.3 Data collection/processing

Realistically plausible scenarios ultimately are linked to real datasets that should be evaluated prior to their use in resources planning and decision making. For a model-based approach, this step refers to gathering and processing model input data, running the model(s) for each scenario, and processing model output data. Primary model input and output variables are driven by the scenario definitions and should have been identified in the conceptualisation 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 datasets are at appropriate time/spatial scales and resolutions and are internally consistent. A data processing procedure is usually used to achieve this. For example, precipitation data from a GCM can be down-scaled or up-scaled using a scaling approach and be combined, numerically and statistically, with rainfall observations from other available sources (e.g. radar and satellite measurements) using a data fusion/assimilation procedure. Model output data (i.e. scenario outcomes) are obtained by running the models and can be evaluated or validated against projections from other sources.

9.3.3 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 (discussed in more detail in Section 9.5). Model outputs are converted into the desired form (such as peak daily stream flows) identified in the scenario definition phase, and adjusted to different time and space scales if required. Scenario analysis also identifies notable system conditions or behaviours, including trends, regimes, thresholds and triggers, discontinuities and cascading effects.

9.3.4 Scenario assessment

Scenario assessment includes: identifying risks, rewards, mitigation opportunities and tradeoffs; 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 management, this may involve environmental, institutional, and socioeconomic dimensions of the problem (Figure 9.5). The proper focus is 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

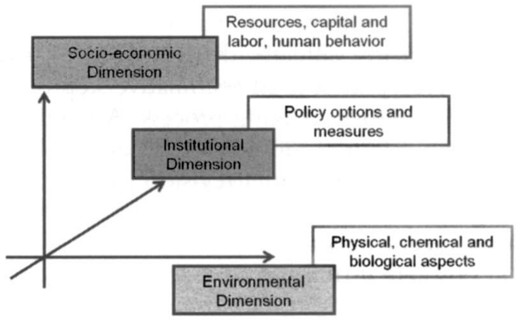

Figure 9.5 Dimensions of integrated assessment for water resources management.

techniques such as 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.

9.3.5 Risk management

Risk management is primarily the responsibility of decision makers, not the scientists involved in a scenario development study. Risk management encompasses the 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. Modellers may be helpful by modifying scenarios in response to risk management considerations and returning to the scenario definition phase of the process. Furthermore, not all risk can be eliminated and some residual risk will remain regardless of management practices.

9.4. Monitoring and Post-audits

The environment is constantly changing and no one is able to both consistently and correctly forecast the future. Hence, continuous reviews and corrections of scenarios are usually necessary in a formal scenario development process. As noted by Schwartz (1991), "it is important to know as soon as possible which of several scenarios is closest to the course of history as it unfolds." As the future unfolds, scenarios should be reviewed and evaluated to determine whether the current plans should be modified or if new scenarios are needed. While the value of good scenarios includes their ability to help decision makers avoid dangers and achieve desired objectives (Godet and Roubelat, 1996), these attributes can only be tested at the conclusion of scenario development through scenario monitoring and post-audits, a process that is also widely referred to as adaptive management.

Scenario post-audits highlight the flexible nature of scenarios, as the continuous use and refinement of scenarios validates their application (Maack, 2001). Post-auditing scenarios after development is an assimilative step of integrating scenarios into a stakeholder-defined decision-making process. A continuous re-examination of conditions and strategies requires a review of major problems, an adjustment of objectives based on observed results, and a revision of priorities. It is then wise to rethink scenarios in light of new developments and adjust them so that they may correspond to the most recent information. This renders scenarios as innovatively connected rather than obsolete if findings are contrary to their application (Maack, 2001).

Post-scenario investigation requires *monitoring* of scenario progress by establishing clear and measurable indicators that help determine which scenarios are converging or diverging from the actual evolving future. These indicators represent key factors that signal the success of the intended scenario development goal. Indicators can be based on fixed events, observable trends, or ongoing external processes; they are tracked throughout a project's lifetime and allow for the assessment of a scenario's progress towards the future with respect to reality. The setting up of these indicators is an effort by scenario developers to adapt to change; they are necessary for sustainable development. To be beneficial for planning, indicators must be intrinsically linked with strategy changes (Maack, 2001). Monitoring efforts can also improve the consistency and quality of observed and comparable scenario data in an ongoing scenario development process (McCarthy et al., 2001).

9.5. DISCUSSIONS AND FUTURE DIRECTIONS

In this chapter, we have reviewed the state of the art in scenario development. Feedbacks from an international workshop on scenario development held in July 2006 (at the Third Biennial Meeting of the International Environmental Modeling and Software Society) indicate that there exists a general agreement in the environmental modelling community that scenario planning is a practical, effective way to put environmental models into more beneficial use for long-term real-world decision making. Although scenario approaches represent common and popular practices in the business world, there exist far fewer examples for environmental studies. Moreover, the lack of general guidance on how to approach formal scenario planning has discouraged some environmental scientists and stakeholders from using scenarios to inform their decision making. Motivated by this problem, we propose in this chapter a formal scenario approach that is expected to be applicable to most environmental impact assessment studies. There remain, however, some outstanding issues that deserve particular attention when pursuing scenario planning for environmental studies.

9.5.1 Uncertainty issues

Uncertainty is the inability to determine the true magnitude or form of certain variables or characteristics of a system. It has been a pervasive theme throughout the chapters of this book. Uncertainties are inherent in scenario development, even though some of them can be reduced while the future unfolds. Hence, taking into account various uncertainties is a necessity for fully understanding the implications of scenarios. In general, scenario uncertainty mainly arises from the *scenario definition* and *scenario construction* phases and can be attributable to either the scenario definition itself or the model(s) and data used to construct the actual scenario. As also covered in Chapters 2 to 6, specific causes of uncertainty may include lack of basic knowledge, data errors, model structure and parameter errors, variability in condition approximations, subjective judgment, inappropriate assumptions, ambiguously defined concepts, and errors in projections of human behaviour, among others. How to treat various uncertainties associated with scenarios deserves extensive research by itself and detailed discussions on this topic are beyond the scope of this chapter. In brief, three essential aspects should be considered when handling scenario uncertainty:

- *Understanding uncertainty* – what are the sources of uncertainty to be considered?
- *Estimating uncertainty* – what are the magnitudes of these uncertainties and how do they propagate from one phase of a scenario development process into another?
- *Communicating uncertainty* – how can this uncertainty be communicated to stakeholders and decision makers?

There exists an extensive literature on understanding and estimating uncertainties in environmental studies (Morgan and Henrion, 1990; Beven and Freer, 2001; Wagener and Gupta, 2005). However, communicating scenario uncertainties to stakeholders continues to be one of the most challenging aspects of scenario applications. To ensure successful communication of uncertainty, it is necessary to establish credibility and trust of the scenarios to relevant stakeholders. In addition, it has been a pervasive theme of this book that continuously involving stakeholders in the scenario development process and being transparent about various uncertainty sources are critical.

9.5.2 Potential obstacles to formal scenario development

Whether formally stated or not, scenario development is at some level inherently used in many decision-making activities. However, the adoption of formal scenario development and the alignment of involved parties into a structure such as Figure 9.4 can depend on the scale of the issue, resources available, and willingness to invest in such a structured investigation. The larger the scenario scale (e.g. global warming), the greater the necessity for formalised systems of data storage, models, visualisation tools, and structured decision paths that directly address specific points of concern. Smaller scale evaluations (e.g. small contaminated site, watershed level) may have fewer data or modelling requirements and may be based on expert judgment. The efficiency of a formal scenario approach in terms of adaptability and interpretability of results is critical.

The willingness of participants to invest in plausibility studies can depend on how a future reward or penalty is perceived. If there is a high cost of failure or a high reward in correctly anticipating a future condition, the incentive to expend available resources increases. It must be convincing that the added value of tracking down plausible scenarios exceeds the "business-as-usual" baseline. This can be subjective, open to debate, and conclusions may vary among participants depending on their individual objectives. In fact, the varying personalities, position, and viewpoints of participants may determine whether a formal framework is adopted at all. Proponents for the development and exploration of plausible scenarios must provide a clear incentive for doing so to the group of participants. It must demonstrate an advantage over the strong tendency to go about business as usual. In doing so, one must assess the cost, the rewards, the penalties, the reliability and data requirements of any supporting tools, and the ability to understand both the process and results.

9.5.3 Future recommendations

Like environmental predictions, scenario results are of limited value if the involved uncertainty is not properly considered. Hence, understanding scenario uncertainty and communicating it to stakeholders in an appropriate way represents a particular area that deserves extensive further discussions and research efforts. In addition, scenarios of a more variable nature can provide more constructive information than simply relying on broad-scale, long-term global change scenarios that are widely available (as has typically been the case). Several directions can be taken to respond to this, including: (1) development of approaches that can effectively combine expert- and citizen-driven scenarios, and research-based strategic scenarios; (2) construction of other non-climate scenarios from the knowledge of experts and citizens that is largely untapped in current scenario studies; and (3) use of *policy-responsive* scenarios that are inherently connected to the direction future conditions might take (McCarthy et al., 2001) and are capable of physically manifesting environmental management at a variety of scales. And finally, extensive and active dialogue among researchers working on scenario-related environmental studies should always be encouraged to enable sharing of relevant resources, information and ideas. For example, the availability of generic tools for the development of prescribed scenarios (e.g. climate, land-use and socioeconomic scenarios) can greatly facilitate the scenario construction process and result in cost savings that could make formal scenario development a much more affordable, thus more appreciated, means of environmental planning and integrated assessment.

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