CHAPTER EIGHT

Dealing with Surprises in Environmental Scenarios

Ferenc L. Toth *

Contents

* IIASA, Laxenburg, Austria

Environmental Futures: The Practice of Environmental Scenario Analysis
1574-101X.

There are more things in heaven and earth, Horatio, than are dreamt of in your philosophy – Shakespeare, Hamlet (I, v, 166–167)

1. Introduction

Over the past few decades, the use of scenarios to study problems involving uncertainties of various kinds has been steadily increasing. Uncertainties arise due to insufficient knowledge about the constituents and the boundary conditions of the problem or system at hand, about the relationships among those components, about the relations to the external environment, and about the future evolution of the external forcing. Scenarios offer a convenient form to tally knowns and unknowns and to organize the latter into a suitable form for systematic study. Surprises constitute a special and extreme form of uncertainty. The exploration and the integration of surprises into scenarios are therefore a special challenge.

Environmental scenarios have recently become a fast growing area in the realm of scenarios. By definition, they are developed and used for environment-related studies, primarily for assessment, policy, management, awareness raising and education (see the review of scenarios by Rothman in Chapter 3). With local and largely short-term problems dominating the environmental agendas throughout the 1960s, scenarios played a limited role in the environmental domain. Increasing concerns over multifaceted, continental- to global-scale, and especially long-term problems require the escalating use of scenarios. Milestones in the evolution of developing and using environmental scenarios in the past four decades include the first report to the Club of Rome (Meadows et al., 1972), the Global 2000 Report to the President of the United States (Barney, 1980), and more recently the scenarios developed by the Intergovernmental Panel on Climate Change (IPCC, 1992, 2000), by the Global Scenario Group (Raskin et al., 1998) and by UNEP (2002). While these scenarios have many different virtues and they successfully served a diversity of objectives, one common deficiency characterizes all of them at least to some degree: they are void of major shocks and structural changes that are plausible but would strike at least part of the targeted audience as a major surprise. This is in sharp contrast with one of the key lessons from ecosystems research and environmental management: we do not know enough and we will unlikely ever know enough about ecosystems functions and their responses to anthropogenic forcing. "Expect the unexpected" is therefore the main directive in environmental management (Bazykin et al., 1979). If scenarios are to be of any benefit to decision makers, they need to include plausible trends and events that are far beyond the current range of expectations or even imagination of the intended users.

This chapter offers guidance for defining and exploring various kinds of surprises in environmental scenarios. Given the large uncertainties and, in many cases, outright ignorance about the complex interactions between human societies and the natural environment, potential surprises are looming in virtually every area of environmental management. Thus an improved treatment of surprises is necessary for a better environmental management.

The chapter starts with a short review of recently proposed definitions and typologies of surprises in the environmental domain. Section 3 defines some basic concepts for the purposes of this chapter. Section 4 offers a new typology that is more relevant for generating and incorporating surprises into environmental scenarios. Section 5 lists a number of purposes for which environmental scenarios are developed and used. The relevance and usefulness of different types of surprises are also discussed. Section 6 then briefly reviews well-established and widely used methods in futures studies that might be considered by scenario developers to generate surprises of various types for their own scenarios. The final section summarizes the main points and provides general guidance for the treatment of surprises in the process of developing environmental scenarios.

2. Concepts and Typologies of Surprises

Many approaches to categorizing uncertainties are proposed in the literature. In their seminal book, Morgan and Henrion (1990, p. 56) classify uncertainties according to their sources and list the following categories: statistical variation, subjective judgment, linguistic imprecision, variability, inherent randomness, disagreement, approximation. In this context it is worth pointing out to what was eloquently formulated by Kant (1790 [2004]) that an increase in knowledge also leads to an increase of non-knowledge, open questions, and thus uncertainties. The scope of this chapter is limited to exploring one specific form of uncertainty (surprise) in the context of environmental scenarios.

Several disciplines analyze surprises from different perspectives and in different contexts. Psychology, sociology, and especially the science of social psychology offer valuable insights concerning the question: to what extent are surprises absolute (no one ever expected the event) or relative from the perspective of the scenario writer or user (an event would not have been a surprise if people had paid more attention to the situation or if they had considered other information sources). This literature emphasizes that many surprises originate in social or personal limits to perceptions (for a diverse sample see Choi and Nisbett, 2000; Reisenzein, 2000; Gendolla and Koller, 2001, and Olson and Janes, 2002). This raises the key question: surprise to whom? Smith (2003) suggests that the wave of power cuts in Western Europe and North America in 2003 took the general public by surprise although experts had been issuing warnings about this risk for years before. Schwartz (2004) discusses a large collection of demographic, economic, political, technological, and environmental trends and events that came as a surprise to many although "in hindsight were obviously inevitable, and equally important, foreseeable." An in-depth discussion of these aspects is beyond the scope of this chapter. The main implication for our discussion is that scenario analysis can help overcome these limits by adopting carefully chosen and properly implemented methods.

Before turning to our specific task of elaborating on surprises in environmental scenarios, it is useful to recall results from a series of earlier attempts to address surprises in society-environment interactions. Clark (1986) emphasizes the importance of considering surprises in managing development-environment interactions as well as the need for methods and models to deal with them. The volume edited by Clark and Munn (1986) contains important contributions to the topic: Holling (1986) introduces surprise as the key concept for relating the understanding of ecosystem behavior to the way societies perceive and manage them. His definition emphasizes the qualitative difference between expectation and reality. "Surprises occur when causes turn out to be sharply different than was conceived, when behaviors are profoundly unexpected, and when action produces a result opposite to that intended – in short, when perceived reality departs qualitatively from expectation" (Holling, 1986, p. 294). Holling frames the concept of surprise in the dynamic, qualitative, and discontinuous process of learning: knowledge about ecosystems accumulates, but incomplete understanding leads to surprises, and surprises, in turn, generate new concepts and result in better understanding.

Holling looks at the prevalence of discontinuous changes in ecological systems and finds their origins in specific non-linear processes interacting on multiple time and space scales. His central concept is the distinction between resilience and stability based on the recognition that there exist different stability structures. He emphasizes four main points:

- more than one stability region or domain can exist, i.e., multi-equilibrium structures are possible;
- discontinuous behavior occurs when variables (i.e., elements of an ecosystem) move from one domain to another because they become attracted to a different equilibrium condition;
- the precise characteristics of the equilibrium (steady state or stable oscillation) are less important than the fact of equilibrium;
- the existence, shape, and size of the stability domains are defined by systems parameters that depend on a balance of forces that may shift if variability patterns in space and time change; reduced variability may lead to smaller stability regions, thus sharp changes triggered by stability boundaries crossing the variable rather than the other way around.

In Holling's surprise theory, stability is defined as the propensity of a system to attain or retain an equilibrium condition of steady state or stable oscillation. Highly stable systems tend to resist any departure from equilibrium and show a rapid return after perturbation. This classic equilibrium-centered definition of stability emphasizes the equilibrium, the low variability, and the resistance to and absorption of change. In contrast, resilience means the ability of the system to maintain its structure and patterns of behavior in the face of disturbance. The size of the stability domain of residence, the strength of the repulsive forces at the boundary, and the resistance of the domain to contraction are all distinct measures of resilience. This conception emphasizes the boundary of the stability domain and events far from equilibrium, high variability, and adaptation to change.

Brooks (1986) focuses on surprises in technology, institutions, and development. He notes the dominance of the evolutionary paradigm that implies a gradual, incremental unfolding of the world system as described by surprise-free models, parameters derived from time-series and cross-sectional analyses of existing systems.

This is partly caused by the lack of usable methodology to deal with discontinuities and random events. The implicit hope of the analysts is that short-term discontinuities average out; therefore smooth long-term trends are acceptable characterizations. Brooks offers a typology of surprises consisting of three general types:

- unexpected discrete events (oil shock, the Three Mile Island nuclear accident, political coup, natural catastrophe),
- discontinuities in long-term trends (stagflation in the 1970s, decoupling of energy consumption and economic growth),
- sudden emergence of new information (linkages between chlorofluorocarbons and stratospheric ozone, between air pollution and forest decline) into the political realm.

Brooks notes that these three types of surprises are interrelated: discrete events may trigger a permanent change in long-term trends, for example. The most important thing is to understand how long-term trends predispose systems toward surprises and discontinuities. Smooth development is the exception rather than the rule: non-linearities, perception thresholds, effects of scale shape the future. Brooks points out that technology-related benefits increase in proportion to its scale of application, but the environmental and social implications of the application increase highly non-linearly with the increasing scale. At some threshold systemic change occurs.

Timmerman (1986) suggests that when surprises are explored, emphasis should be on the interactions between an event, the perceptions of that event, and the basic frame of the interpretative reference which may accept or reject the implications of any particular surprise. He also offers a taxonomy according to which surprises can appear in four basic ways. They can erupt from a system, irrupt into a system from outside, bypass a system, or result from the system and its context mutually creating an interactive surprise. Moreover, Timmerman proposes a scale of increasing intensity of surprises according to their ability to provide usable information for the observer and manager. On this scale, surprises are classified into four grades:

- anomalies: marginal, puzzling, but not enough to alter perception;
- shocks: extensive and intensive, freeze the system or cause it to act inappropriately;
- epiphanies: central, reveal essential characteristics of the system dynamics;
- catastrophes: destroy the system.

Kates and Clark (1996) revisit the issue of environmental surprises in the context of sustainable environmental management. Taking three major incidences (Legionnaire's Disease outbreak at a convention in Philadelphia, the chemical plant accident in Bhopal, and the depletion of the stratospheric ozone by chlorofluorocarbons) as a starting point, they also emphasize "unexpectedness" as the key concept in defining surprise. The three cases also serve as examples of archetypes in a typology tallying surprises and social responses. The Kates and Clark (1996, p. 29) surprise typology distinguishes surprising events (rare events with serious consequences and common events that elude detection/prevention) and surprising consequences/causation (unexpected consequences and expected but mistakenly attributed consequences). The authors also cite techniques that might help anticipate surprises.

A session convened by Schneider and Turner (1995) at the 1994 Aspen Global Change Institute (AGCI) was explicitly devoted to surprises in the domain of global environmental change. Originating in the seminal work by Luce and Raiffa (1957) and extended by Faber et al. (1992) to a taxonomy of surprise and ignorance, AGCI participants produced the Aspen Map of Surprises (Schneider and Turner, 1994). They use the following definitions: "risk – the condition in which the event, process or outcome, and the probability that each will occur, is known; . . . uncertainty – the condition in which the event, process, or outcome is known (factually or hypothetically), but the probabilities that it will occur are not known or are highly subjective estimates; . . . surprise – the condition in which the event, process or outcome is not known or expected" (Schneider et al., 1998, pp. 172–173). Contemplating that surprise in the strict sense is impractical for policy making, the authors introduce the term "imaginable surprise" and define it as "the event, process, or outcome depart from the expectations of the observing community or those affected by the event or process" (p. 173). This definition emphasizes important features of the surprise concept: surprise to whom, surprise when, therefore it has important implications for the methods one would use for systematically searching for surprises.

Myers (1995) defines two categories of "anticipatable surprise": the first category is associated with unforeseen discontinuities in ecosystems or human-environment interactions while the second category involves synergisms in which the outcome of the interactions of two or more environmental processes is multiplicative. The examples cited by Myers indicate that discontinuities can occur when cumulative processes reach a saturation point and overflow or when gradual forcing of a system reaches a threshold at which its present structure breaks down. Synergistic surprises are particularly relevant for environmental scenarios because they arise from multiple stresses. These surprises are anticipatable in the sense that a rigorous investigation of the underlying systems together with the external forcing might provide at least some indication that a limit would be reached at one point.

We conclude from this short overview that the surprise concept can be approached from different angles, and classifications of surprises differ according to the framing and objectives of the surprise studies. Both the exploration of basic science-philosophy issues (Faber et al., 1992) and the policy-oriented efforts pursuing the identification of specific surprises and their sources (Schneider et al., 1998) provide useful guidance for generating and incorporating surprises into environmental scenarios.

3. Defining Basic Terms and Concepts

In everyday language, the word surprise is used to characterize events or outcomes outside the range of expectations. Many events and outcomes in life are uncertain. The probabilities of certain outcomes can be objective (like the probability of getting a four by rolling the dice) or subjective (like judgments regarding the outcome of a soccer game). The former is based on systematic observations consolidated in the form of theories and is usually referred to as frequentist or classical

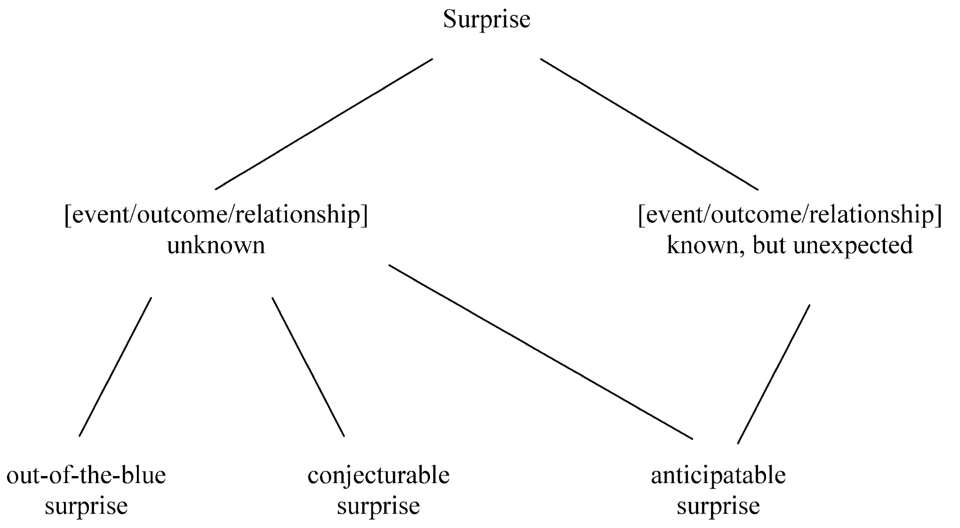

Figure 8.1 A general typology of surprises.

probability, while the latter is based on previous personal experience, information and subjective judgment and it is called subjective or Bayesian probability.

We follow the AGCI definitions and characterize risks as a combination of a certain known outcome or consequence and a known probability. The situation in which the outcome or consequence is known but the probability of its occurrence is unknown or highly subjective is defined as uncertainty. Surprise in the strict sense implies that not even the outcome or the consequence is known. Accordingly, in this strict sense, surprise cannot be anticipated as it is an unexpected event or outcome by definition. Once we know about or just suspect a possible event or outcome, it is not a surprise anymore. If it is not a surprise, we cannot integrate it as surprise into environmental scenarios. So shall we finish the chapter here? Perhaps not.

Instead, we propose a more flexible definition of surprise that combines the two crucial dimensions, the unknown and the unexpected features (see Figure 8.1). When the outcome is unknown, it is by definition totally beyond expectation; this means there is a clear link between unknown and unexpected in this case. Thus "unknown outcomes" embrace the first set of surprises. The second set contains outcomes that are "known but unexpected." An individual or a community may well be aware of the existence of certain possible outcomes but they attach a very low probability to it, often as low as zero – see the many "it is impossible" assertions people make daily about events or outcomes that they themselves consider perfectly plausible. It is then a surprise when such an unexpected event or outcome really happens despite the extremely low subjective probability attached to it. This second set of surprises corresponds to what Schneider et al. (1998) call "imaginable surprises."

The set of "known but unexpected" events/outcomes contains also the so-called "relative" surprises, i.e., cases in which the existence or the bare possibility of certain processes or relationships were suspected or even demonstrated by some experts but they were ignored for long time periods, in some cases for decades, by policymakers and the public. The European Environmental Agency collected and documented twelve cases of ignored "early warnings" in environmental management over the past century (EEA, 2001). Learning the lessons from these cases is extremely important but it is beyond the scope of this paper. The focus here is on the first-time discovery of a surprise rather than on its propagation through the expert community and the rest of the society.

In the "known-but-unexpected" category, we can think of surprise in terms of quantity. In this case the trend or event is expected but the magnitude turns out to be far from the expectation. For example, with the accumulation of radiatively active trace gases in the atmosphere, an enhanced greenhouse effect and increasing surface temperature is expected. It would be a surprise, however, if the increase in equilibrium global mean annual surface temperature in a doubled CO_2-equivalent climate turned out to be 15 °C or more. The second type of surprise is qualitative. Qualitative surprise occurs when the nature of the outcome is different from what was expected or its direction is the opposite of the expectations. Qualitative changes can be described as structural change in the given system. They can involve changes in the character of the relationships among variables and/or in the stability domains of the parameters. A surprise then occurs when there is a qualitative change in system behavior, for example, when stability domains shift away from their earlier locations.

The main difference between the system proposed here and that of Schneider et al. (1998) is in the first set that is in the "unknown" category. Several examples cited by Holling (1986) and Myers (1995) indicate that many environmental surprises in the "unknown" set could have been "anticipated," had the right questions been asked. The availability of information for "anticipation" is an important criterion for delineating surprises in an operational context, such as their inclusion in environmental scenarios.

The bottom part of Figure 8.1 presents three categories of surprises delineated according to the difficulties involved in identifying them for inclusion in scientific and policy-oriented studies. "Anticipatable surprises" include the "known but unexpected" outcomes (surprises have already been detected). They also include a subset of "unknown" outcomes for which some clues are already directly available or could be derived indirectly from existing information about some driving forces or determining factors (surprises could be uncovered). For such "unknown outcomes," there are often indications or foreshadows of a looming surprise but a systematic identification and interpretation would be needed to find them. In other cases, there are dispersed signs and to casual observers unrelated clues but a well-targeted procedure could help arrange these pieces of the puzzle to get the full picture. Furthermore, there might be discernible single trends at work that will inevitably collapse one way or another but a thorough investigation would be needed to identify the preconditions for the trend break and the possible outcomes. Finally, dispersed and to casual observers, unrelated, trends might unavoidably clash at one point but, once again, a laborious effort would be required to combine the trends for detecting the clash and to explore the implications.

The next category of surprises comprises events, relationships, and outcomes that no one ever thought of, but that appear to be perfectly conceivable once they are brought to light. Such "conjecturable surprises" are defined as events or outcomes for which none of the above four foreshadows exists but they could be postulated in a concerted and well-targeted process by adopting appropriate methods. Such discoveries require a good mixture of expert knowledge, imagination, and luck. Section 6 will list some methods that could be considered to inspire imagination and thus reduce the role of luck in detecting conjecturable surprises.

The final category is called "out-of-the-blue surprises" because they defy detection even by the most advanced supercomputer-based search algorithms and by the most imaginative minds triggered by the most inspiring techniques. This category reflects the recognition that there will always be events and outcomes that are beyond any imagination and remain inconceivable until they happen.

There are many ways to characterize the sources of surprises. The main sources are usually listed as ignored relationships among system components (the relationship is known but not included in the analysis). The second case is when the relationship has been previously unknown: there was no clue about its existence, the relationship has never been observed or experienced.

If we define surprise as an event outside the range of expectations, its possible sources become more tractable. This context is also helpful to clarify some of the confusion noticeable in the literature. Discontinuities and non-linearities are often confused with surprise. We speak about a non-linear response when the relationship between a driving force and the outcome has a non-constant slope. A non-linear relationship is a surprise only if a linear response was expected or no relationship was assumed. Non-linearity is an immanent characteristic of complex systems and thus of many biogeochemical processes. Just one example: Qi et al. (2002) demonstrate that soil respiration responds non-linearly to changes in temperature. Once this non-linear relationship has been recognized and even estimated and quantified, there is no reason to consider it a surprise any more.

Discontinuity is somewhat more difficult because it involves a qualitative change in the system, a jump from one equilibrium to a different equilibrium state or a phase transition that will change the qualitative behavior of the system. Such changes are very often surprising to the observer because they are hard to detect until a system is actually forced to some threshold. Some analysts equate discontinuity with surprise; others propose to derive the characteristics of discontinuity from surprises. Van Notten et al. (2005, p. 191) define discontinuity as "a temporary or permanent, sometimes unexpected, break in a dominant condition in society." This is congruent with our proposition that not every discontinuity is a surprise and only a fraction of surprises originate in discontinuous behavior. Therefore, just as in the case of non-linearity, we argue that a discontinuity is a surprise only if continuous (not necessarily linear) behavior was expected. If a pencil is bent at both ends with increasing force, the pencil will break sooner or later. This represents a discontinuous change in the pencil's structure but it is by no means a surprise.

Another related term is irreversibility. A change is irreversible when we are not aware of any plausible way to reverse the direction of the change or to restore the system to its previous state. Here again, an irreversible event or outcome is not necessarily a surprise if there are some preliminary indications of its possibility. Moreover, irreversibility is often just a question of time scale. In large geophysical systems, a change considered to be irreversible on the scale of decades might reverse over thousands or millions of years.

The last notion to mention here is catastrophes. They are normally used to denote natural or human-made disasters, changes with extremely harmful outcomes. They could be the result of small linear changes as well as large and non-linear ones. Catastrophes are not necessarily surprises. Natural disasters are expected to happen in many regions of the world but their exact timing and magnitude are unknown.

To summarize: the three main sorts of surprises (anticipatable, conjecturable, out-of-the-blue) originate in uncertainties or in the complete lack of knowledge about the driving forces, actors, and relationships (linear, non-linear or discontinuous) and/or about the parameters (their magnitudes) of a given system. Some of them are relative (known to some people, unknown to others) and even if unknown, they might be anticipated from scattered but available information. Some surprises in the unknown category are conjecturable but their exploration requires a concerted effort of creative minds using effective techniques. Finally, some surprises remain impossible to detect.

4. Surprises in the Society-environment Interactions

The types of surprises, briefly explored in the previous section, and their classification into different typologies provide valuable insights into the difficulties of the concept and their practical implications. This section present a new typology explicitly oriented towards the action of developing and using environmental scenarios. The purpose is to delineate some archetypes of surprises that might be considered for different types of environmental scenarios according to their function and purpose. This new typology also helps guide the choice of methods in efforts aimed at discovering surprises.

Three main classes of surprises are defined. The ordering principle for defining these classes is based on the implication of the surprise for the relationship between society and the natural environment. Figure 8.2 presents an overview of this typology.

Class I surprises are defined as *isolated surprises*. They are unexpected events or new information in the social or environmental domain without any direct or immediate implication for the other. The discovery of a thirteen-legged worm in the Amazon region might come as an environmental surprise but probably without any noticeable direct social implication. Similarly, the invention of a new voice recording technology might appear to be a technological surprise in the socioeconomic domain but conceivably with no noticeable direct environmental effect.

Class II surprises are defined as *interactive surprises* and they include the core items of our typology. Four types of interactive surprises are distinguished in the society-nature relationship depending on the origin of the surprise and the implications for the other domain.

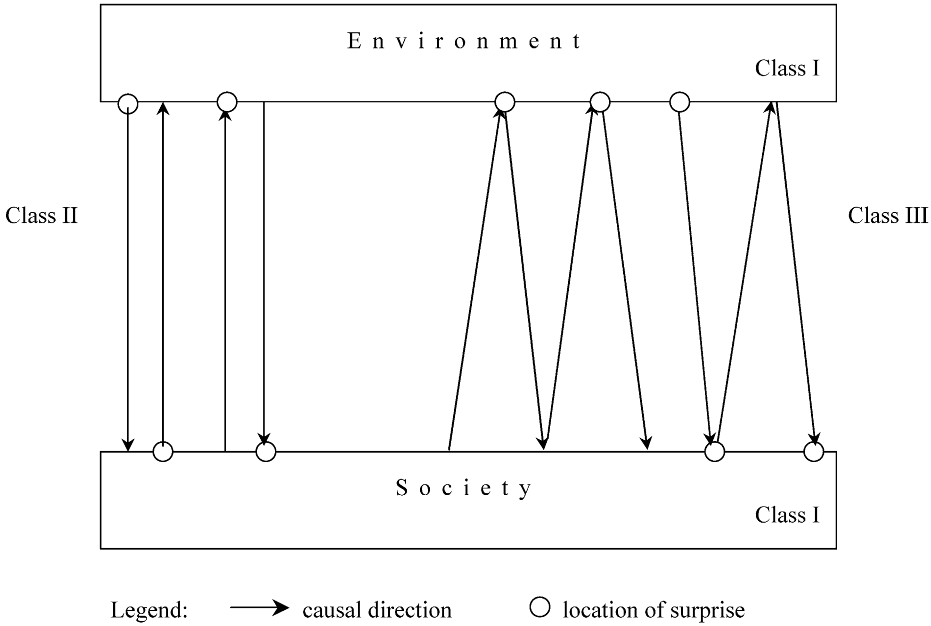

Figure 8.2 Surprises in the society-environment interactions.

Type A surprises are defined as environmental surprises with social implications. The origins of these environmental surprises are rooted completely in the biophysical environment and have nothing to do with any anthropogenic trigger. An outbreak of a volcano that has been dormant for hundreds of years or a major earthquake in what was considered to be a geologically stable region are examples of such environmental surprises. A recent tragic example is the Tsunami of December 26, 2004 in the Indian Ocean where it was totally unexpected (in contrast to the Pacific Ocean where such events are considered much more likely to occur). The social implications of these events are typically addressed by natural disaster preparedness programs and disaster management.

Type B surprises are defined as social surprises with environmental implications. The fast market penetration of sport utility vehicles (SUVs) in the United States was a surprising socio-technological development (at least to those who supported the introduction of the Corporate Average Fuel Economy regulation) with environmental consequences in the form of higher CO_2 emissions from personal mobility. A fast proliferation of vegetarian diet in Western societies is another example of a possible social surprise with environmental implications.

Type C surprises occur when social forcing triggers an unexpected environmental response. This type of surprise has been investigated most intensely so far. The most typical examples include saturation processes in which socioeconomic drivers gradually deplete or undermine the absorbing capacity of the environment and trigger a discontinuous response when a threshold point (depletion, saturation) in the environmental system is reached. More generally, environmental systems and processes may possess several equilibrium states and anthropogenic forcing can push them beyond certain thresholds at which the system flips into a different equilibrium state and displays a qualitatively different behavior. The possible collapse of the thermohaline circulation and the potential transformation of the vegetation cover and regional climate in particular regions of the world as a result of anthropogenic climate change (discussed by Schneider, 2004) are examples of Type C surprises.

Type D surprises may occur when an environmental forcing triggers a surprising social change. The degradation or depletion of an environmental resource due to natural causes may trigger a technological innovation resulting in an artificial replacement (backstop technology) or a value or behavioral change eliminating the demand for the particular environmental good or service.

As archetypes, of course, these four surprise types constitute a rather oversimplified characterization of possible surprises in the interactions between humanity and nature. The long history of anthropogenic use of environmental resources and of the human management of nature in general has produced a rich diversity of variations of these four archetypes.

The final category, Class III surprises are defined as *propagating surprises*. They involve a cascading sequence of unexpected trends and events in the human-nature interactions. A typical example is when a type C surprise (social forcing triggering an environmental surprise) is followed by a type A surprise (the environmental surprise generating social implications). This in turn could lead to another type C surprise (modified social forcing producing a new environmental surprise). Alternatively, a type A event could be followed by a type B surprise (social surprise with environmental implications). This could either establish a new stable regime of environmental management or could lead to a type D surprise: an environmental forcing triggering a social surprise (technology or behavioral change) that will then build the basis of the stable management regime. An example of propagating surprise is the history of refrigeration, chlorofluorocarbons (CFCs), and stratospheric ozone. In response to the inconvenient characteristics of ammonia, non-toxic and non-volatile but very stable substances were introduced (social forcing, Type C surprise). These substances have accumulated over decades in the stratosphere and depleted the ozone layer harming humans and environmental assets (Type A surprise). The technological response was the introduction CFC-substitutes (another Type C event) that turned out to be rather potent greenhouse gases (another Type A surprise).

The four surprise types in Class II are the core of this classification. Surprises in Class I are irrelevant for environmental management while those in Class III involve different combinations of the core surprise types. Considering the wide diversity of uses of environmental scenarios, which types of surprises are most useful for which purpose? The next section provides a concise overview.

Table 8.1 The main types and selected functions of environmental scenarios and the relevance of different types of surprises

Purpose/function of scenario	Type of scenario/surprise			
	Scenarios serving as input to models or studies	Type of surprise required	Complete self-contained scenarios	Type of surprise required
Scientific assessment	XXXX	B, D	X	A, C
Exploration	X	A, C	XXXX	A, B, C, D
Forecasting	XXX	B	XX	C
Policy making	XX	C	XXX	B, C, D
Planning	XXX	A	XX	A, C
Opinion elicitation	X	A	XXXX	A, C, D
Collective inquiry	XXX	A, B, C	XX	B, C, D
Cross-check	XX	A, C	XXX	A, B, C, D
Education	X	A, B, C, D	XXXX	A, B, C, D
Moralizing	X		XXXX	C, D
Curiosity/speculation			XXXXX	A, B, C, D

Note: The number of X marks indicates an estimate of the relative uses of the two main scenario types for different purposes of scenario applications. For example, when scenarios are used in scientific assessments, the bulk of the applications are "for-input" scenarios, whereas for the purposes of education, the use of self-contained scenarios is predominant.

5. Surprises for Environmental Scenarios

Environmental scenarios can be used to support activities in different phases of environmental management. Table 8.1 lists eleven different uses of scenarios. Most of these uses can take either of two distinctive forms of scenario applications. In the first case, scenarios serve as an input to models and studies. They summarize the boundary conditions for addressing the problem at hand. Such *for-input scenarios* embrace all assumptions about the external factors and circumstances that are necessary for understanding and managing the problem explicitly addressed by the study. Scenarios of the second type present a complete self-contained picture of the problem and its evolution together with the boundary conditions. While the for-input type scenarios provide the context or set the scene for the detailed study, *self-contained scenarios* incorporate the whole movie of the implications: processes, evolutions, causes, and effects. Determined by these two dimensions (the purposes/functions of the scenario and the type of scenario), the need for and the potential usefulness of the four surprise archetypes in Category II above diverge significantly. This section presents the most typical uses of the different surprise types in scenarios developed for specific purposes in environmental assessment and management.

5.1 Scientific assessments

Scientific assessments have become increasingly important in recent decades as information sources and input for decision making. Parallel to this development, scenarios have become increasingly prominent input to the scientific assessments. Scenarios summarize the possible evolution of external driving forces and other relevant external conditions for use in the assessment of the problem itself. The most typical scenarios serving scientific assessments are those that describe socioeconomic development and the associated pollutant emissions implications of which will then be evaluated as part of the assessment. The most extensively used for-input scenarios in global environmental change are the emission scenarios developed by the IPCC (2000). Surprises of type B and D seem to be the most relevant for such scenarios. A notable exception to the general rule of scenarios serving as input to scientific assessments is the Millennium Ecosystem Assessment project in which complete self-contained scenarios are used to trace the evolution of driving forces, ecosystem responses, the implications for human well-being, and the social responses to ecosystem changes in different future histories. For such scenarios, surprise types A and C appear to be most relevant although interesting scenarios of this kind should certainly involve cascading surprises described under Type III in the previous section.

5.2 Exploration

One specific subset of scientific assessment is *exploration*. It is a concerted effort to investigate problems that are either poorly understood or feared to be misunderstood. Scenarios can be useful input to such explorative studies but their real exploratory power can be exercised by developing complete self-contained scenarios of the problem area. Such exercises can lead to the discovery and identification of earlier unimagined problems and opportunities. For exploration activities, all four types of surprises should be considered to stimulate imagination and trigger innovative thinking.

5.3 Forecasting

Forecasting is a special area of scenario development and use. Some definitions draw a very sharp line of division between scenarios (defined as descriptions of plausible futures) and forecasting (labeled as the effort to predict expected or most likely futures). In practice, however, scenarios can be productively used as input to a forecasting project. Scenarios summarize the main drivers and external conditions and the forecast itself develops "what if" storylines of the possible directions of expected future evolution. Making predictions in a relatively well-understood area is a valuable service to managers who need to understand what to expect in a given area if they observe certain directions of the evolving external conditions in order to get prepared for coping with the emerging events and situations. As a result, forecasting is a serious profession in which clients and providers must have a shared and clear understanding of what is to be forecasted, what is the marginal value of the additional investment in terms of increasing forecasting accuracy. The quality of the scenarios to be used for a forecasting project is the main factor in determining the quality of the forecast itself. For the most difficult areas of forecasting in environmental studies, scenarios involving type B surprises appear to be most useful. In some cases, a forecast is complemented with some simple assessment of the implications and thus it is being turned into a self-contained scenario. In such cases, type C surprises need to be considered as well.

5.4 Policymaking

Whether or not it has been preceded by a scientific assessment, the process of policy making tends to make use of scenarios for various purposes. The most common use of scenarios in policy making involves the following functions:

- expectations about the evolution of the problem in the absence of a new or modified policy;
- the possible evolution of external factors interacting directly with the considered intervention;
- the expected responses of the actors whose behavior is supposed to be changed by the policy.

Depending on the magnitude and the complexity of the problem and on the diversity of the actors affected by the policy, scenarios could be used either as an input to the policy-making process or as a complete self-contained story of the problem the policy intends to address together with an account of its possible implications. In the former (for-input) case, type C surprises are most useful to consider for inclusion in the scenario. In the latter (self-contained) case, surprise types B, C, and D are likely to generate useful insights for policy making through the development and use of the scenario.

5.5 Planning

Environmental planning is the specific design process in which all canonic, legal and technical details of an environmental policy or regulation are developed. It requires the rigorous clarification and specification of all organizational, information, logistic, and other details with the objective to prepare and operate the new regulatory system. Scenarios are, once again, a crucial and useful input to the planning process. If a scenario is used as an input only, then type A surprises are most relevant. If the environmental planning problem is more complex, a self-contained scenario may be required for which type A and C surprises can be illuminating.

5.6 Opinion elicitation

Most environmental policy problems involve complex multi-faceted issues. Accordingly, expert opinion and assessment should play an important role in the decision making process. One useful way to obtain expert input is through opinion elicitation. In such cases, a range of experts with experience and expertise in the related areas would systematically evaluate complete scenarios of the given environmental problem or the proposed policy intervention to tackle it. Type A, C, and D surprises are particularly useful to consider for such self-contained scenarios. In some simpler cases, scenarios could be used just as an input to opinion elicitation and type A surprises are the prime possibility to consider in this case.

5.7 Collective inquiry

Whereas opinion elicitation is typically undertaken individually, many environmental problems and policies could be better understood and explored through a collective inquiry. Typically such techniques would take scenarios as input to the process. Surprises of the type A, B, and C could create an especially stimulating and fertile environment for the collective thinking. In a smaller number of cases, the collective inquiry process could consider complete scenarios in which surprises of the type B, C, and D may have been incorporated.

5.8 Crosscheck

In the contemporary world of sector-oriented public policy making and sector-specific environmental policies, crosschecking the proposed or planned interventions for their repercussions in other sectors or other policy concerns is largely neglected. This should be nevertheless an important part of the policymaking process because it could help detect flaws or inconsistencies in the planned policy or it could lead to confirmation of, additional confidence in and support to the proposed policy. Crosschecking processes can be well served by for-input scenarios, and type A and C surprises may well work in these cases. Alternatively, self-contained scenarios can be prepared in the crosschecking process and in such cases, depending on the nature of the problem, any of the four types of surprises might turn out to be useful.

5.9 Education

Scenarios have become increasingly used in the teaching of a diversity of subjects. They are also becoming fashionable in environmental education. Complete storylines (self-contained scenarios) involving any type of surprise could help students in learning about the diverse range of environmental problems and the difficulties to manage them. For more advanced audiences, a simple for-input scenario could be the starting point for the students' own practical exercise. Here again, any type of scenario might work and the actual choice depends on the educational objective and the level of progress of the student.

5.10 Moralizing

While the main purpose of environmental education is to explain the basis and management of environmental problems and provide a reasonably value-free treatment of the issues, more and more environmental education takes the form of environmental advocacy and aims to stimulate more "environmentally-friendly" behavior. This type of environmental education makes widespread use of scenarios. The most instructive messages emerge from complete storylines (self-contained scenarios), most typically doomsday scenarios. Such scenarios mainly operate with type C and D surprises.

5.11 Curiosity/speculation

This final category is the summary term for all fiction and science-fiction literature involving environmental problems, natural resource shortages, and the associated social and economic calamities. The underlying purpose can be moralizing or education as well. This application field of scenarios involves, without exception, complete self-contained stories and makes use of all categories and types of surprise listed in the previous section.

The above list clearly shows that surprises of various sorts can be incorporated into scenarios of either type (for-input and self-contained) and for all purposes and uses. The role of the surprise in the scenario, its magnitude, and its importance vary considerably depending on the domain of application, the clientele, and ultimately on the problem itself. It is also clear that surprises should be seriously considered for most scenario types and uses. The crucial question is how one can conceive surprises that, in the spirit of the discussions in Sections 2 and 3, are not surprises to the conceiver any more but would be surprises to the scenario user.

6. Generating Surprises for Environmental Scenarios

By definition, a surprise should astonish the scenario user. There is a very fine dividing line between surprises that are convincing and accepted by the scenario user as perfectly plausible and surprises that are perceived as totally impossible or inconceivable by the scenario user who will then reject the scenario as a result. Plausibility is the key concept in identifying and presenting surprises. Unfortunately, it also involves a fair amount of subjectivity: what appears to be perfectly plausible to one person might be discarded as "out of question" by someone else. Factual or logical evidence of plausibility is often difficult or outright impossible to find. One type of implausibility is relatively easy to identify: if a surprise contradicts verified scientific relationships (basic laws of physics, chemistry, etc.) then it is in the realm of impossible and totally useless. Beyond this small niche, however, there is a vast area in which some surprises look totally plausible to some people while they strike others as entirely inconceivable.

The important precondition of generating plausible surprises for scenarios is a clear explanation of what triggers them. This is usually all that is needed in the case of for-input scenarios. The next important criterion is related to the effects. What are the primary consequences of the surprise? What are the secondary repercussions (the indirect and induced effects)? A convincing explanation of the consequences is optional in the case of for-input scenarios while it is a must for self-contained scenarios. The third item is the response. How will the people affected by a surprise cope with it? Imaginative explanations about the responses are optional in for-input scenarios while they are absolutely essential in self-contained scenarios. In the latter case, a list of response options could be developed, each of them reacting to the same surprise, but possibly triggering embarkations on different subsequent paths. In this way, surprises can be branching points in a scenario, depending on the responses and reactions to the surprise depicted in it.

Surprisingly little attention has been devoted so far to identify and experiment with methods for unearthing and investigating surprises. The surprise component of the Biosphere Project at the International Institute for Applied Systems Analysis (directed by William C. Clark between 1984–1987) adopted a structured participatory technique to generate surprising end-points for long-term socioeconomic development and to produce alternative storylines elucidating plausible ways of getting to those end-points (see Svedin and Aniensson, 1987; Toth et al., 1989). The exercise at the surprise session of the 1994 Aspen Global Change Institute was based on simply asking participating scientists to think about and document events, trends, and outcomes that would surprise them in the domain of global climate change (Schneider et al., 1998). There are other interesting and valuable efforts to come to grips with environmental surprises, but it might be useful to consider more sound methodological foundations in order to generate fascinating and pertinent surprises for environmental scenarios.

The main avenue to generating surprises is to enhance creativity and foster thinking "outside the box." Several disciplines have developed techniques that might be borrowed by environmental scenarists to identify, explore, and inject surprises into their scenarios. The following list is just a small sample of such techniques, largely based on the methods developed and applied in futures research. The list includes a carefully selected set of methods that are thought to be suitable for detecting surprises. We take them in turn and briefly elaborate how to use them for generating surprises for environmental scenarios.

6.1 Model-based scanning

For environmental issues that lend themselves to modeling or where models are already available, models can be run in an "extended sensitivity analysis" mode by expanding the ranges of variations of key model parameters far beyond their traditional intervals. The parameter space should be checked before each run to exclude impossible combinations. A systematic analysis of the model runs produced under a very large number of parameter combinations might reveal plausible constellations producing strange model behavior, including earlier unknown discontinuities. Model-based scanning also includes extended trend analysis in which powerful trends of key variables of concern are combined in a simple modeling framework to identify possible saturation points of single trends or regimes in which multiple trends may clash to produce trend-breaks or structural changes in the underlying system.

6.2 Cross-impact method

The Cross-Impact Method (Gordon, 1994a) is a systematic exploration of conditional probabilities of a large set of plausible events. An application of this method starts with defining the events to be included in the set and assigning initial probabilities to them. This is followed by the estimation of conditional probabilities: if event K occurs, what is the probability of event J? One or more rounds of revisions follow as changing the conditional probability between any two events has repercussions for the relationships between other pairs. Finally, a simple procedure is applied to produce a consolidated version of the cross-impact matrix. An application of this technique in searching for possible surprises would pursue the relationships and chains of event that are often dismissed in traditional analyses because of their very low conditional probabilities.

6.3 Environmental scanning

The main objective of Environmental Scanning is to systematically look at and beyond the horizon of the current and planned operating environment. The intention is to generate new perspectives regarding future opportunities and risks. Of the four approaches to Environmental Scanning listed by Gordon and Glenn (1994) (expert panels, computer on-line literature review, hard copy literature review, essays on issues by experts), expert panels appear to be the most interesting technique for generating and exploring surprises. In the standard version, members of an expert panel are asked to provide observations and judgments about their perceptions of emerging trends and potential new evolutions. When the task is to generate surprises for environmental scenarios, the quality of the submission by panel members will be heavily influenced by the quality of the solicitation. Posing the right question to a panel is a delicate task. Loosely formulated or overly general questions could result in interesting but largely irrelevant propositions of surprises. At the other extreme, narrowly focused or tightly specified problem formulation might impose a constraint for the creative thinking of panel members.

6.4 Participatory methods

Futures research has been relying on different sorts of participatory methods for decades. Glenn (1994a) describes six methods that have been successfully applied in a wide range of futures studies. These include *Focus Groups, Charrett, Syncon, Public Delphi, Future Search Conference, and Groupware*. Since a whole chapter is devoted to participatory techniques of developing and processing environmental scenarios in this volume, only a few short remarks are made here regarding participatory techniques with the emphasis on their use for generating surprises. Interestingly, the participatory methods listed by Glenn (1994a) are all presented as techniques predominantly used to reach consensus across smaller or larger groups. This objective is perhaps least explicit in the case of *focus groups* where the main objective is opinion solicitation. *Charrett* is a process involving a series of parallel small group discussions and plenary meetings repeated until a consensus is reached. The *Syncon* (synergetic convergence) process involves working towards consensus through a gradually expanding exploration process. A large number of small groups start discussing specific topics, they then merge into larger groups in which participants clarify the relationships among the themes developed by the smaller groups previously. In the final phase, members of all groups would meet and discuss the complete picture. The *Delphi* method was originally developed to facilitate the convergence of expert opinion towards consensus. It could be used in principle with lay people to explore questions of broad public interest. *Future Search Conference* itself involves several approaches but all emphasize the objective of finding an agreement. Among the processes used in the Future Search Conference, the *visioning* process is the most promising for inventing surprises. Finally, *Groupware* is a process making use of a special computer hardware and software connecting groups of people who collaborate on the same project.

The above list is a mix of methods that have a long history of application in numerous areas of operations research, systems analysis, and policy analysis. Some of them (like the Future Search Conference) denote a collective name for several related techniques, while others (like Syncon) are very specific and detailed procedures to be followed in any field of application. With more or less difficulties and with some imaginative design work, all of these techniques could be turned around in the sense that participants are challenged to move away from conventional thinking and consensus and to try to astonish each other with strange ideas that may turn out to be plausible surprises. These surprising events and outcomes could then be integrated into the scenarios.

6.5 Delphi

Given its historical roots in forecasting, the conventional objective of the Delphi method (see, for example, Linstone and Turoff, 1975; Gordon, 1994b) is to accomplish the most likely prediction of a future state or trend by going through several rounds of expert solicitation. For the purposes of surprise generation, one could think of an "inverse Delphi" in which the objective would be to move towards events and developments that have been beyond imagination so far, but cannot be dismissed as impossible. The solicitation questionnaire should be formulated accordingly. In processing responses, relationships, or outcomes put forth by more than a limited number of participants (the limit could be as low as two), the particular event should be checked and might be dismissed as no surprise. The process then continues with a revised solicitation questionnaire providing more impulse for imagination to come up with a new set of surprises.

6.6 The futures wheel

The Futures Wheel (Glenn, 1994b) is a special technique to organize speculation about and exploration of the future by a group. It can be interpreted as a structured brainstorming. It starts with a real or hypothetical event that could result in several possible outcomes. These outcomes are listed around the starting event as spikes of a tire. In the next round, possible outcomes of the secondary events are defined and the process is repeated until the implications at the outmost circle are still meaningfully related to the original event. The Futures Wheel technique could be a particularly useful tool to explore propagating surprises (Class III) by individual experts or in some form of group brainstorming, but its use in the surprise context would also involve diversions from the original design. Most importantly, participants in the Futures Wheel exercises would be explicitly instructed to abandon spikes that correspond to more or less expected (conventional wisdom) events or outcomes. They should explicitly search for plausible but stunning outcomes already in the first round and trace their repercussions as they proceed outward from the initial event.

6.7 Intuition and visioning

As the preceding list of approaches and techniques demonstrates, one can think of many ways to evoke new phenomena. A more difficult, but also more promising way of inventing surprises is through intuition and visioning (Glenn, 1994c). These activities of the human mind are at the boundary of rationality and irrationality. *Intuition* is both the event and the product of reaching beyond the realm of presently known into the realm of the unknown. *Visioning* is an activity perhaps a step closer to irrationality. In the context of surprises, visions of the previously inexperienced or unknown are particularly relevant. It is fiercely debated whether intuition and visioning can be learned and improved by practice. Glenn (1994c) lists a series of techniques that might be helpful. The list ranges from the rather trivial methods of "reading and scanning diverse sources" to more systematic and creative techniques. *Guessing* involves keeping track of and evaluating one's guesses and systematically evaluating what mental model triggered guesses that turned out to be correct and guesses that failed. *Meditation* has been used in several cultures for millennia to create visions and to inspire one's own intuition. A modern version is guided meditation. It is an exercise that starts from a given or hypothetical situation or externally given values and the task is to explain and develop a consistent explanation or story around that initial condition.

Additional visioning techniques take us closer to deep psychology. *Dreams* can be important sources of intuition. The term *feelysis* refers to a feeling about another feeling that combines things into intuition. The most generic form of feelysis is meditation in which one would focus his/her attention on one's feelings and would follow them through as one feeling evolves into the next.

It is obvious even from this short but diverse list of techniques that the task of inspiring creative thinking about the future in general and thinking about plausible future surprises in particular is considerable. Fortunately a diverse set of techniques and procedures is available to choose from. Table 8.2 presents an overview and a rather subjective assessment of which technique might be useful to experiment with for which types of surprises.

Since the list includes both specific techniques (e.g., Futures wheel) and larger families of methods (e.g., Participatory methods), some of them are marked as promising candidates for inspiring the thinking about more surprise categories. Another important aspect in the choice of the technique is personal predilection and attitude. Those advocating rationality, disciplined thinking, and systematic

Table 8.2 Selected methods suitable for generating surprises for environmental scenarios

Method	Class I	Class II				Class III
		Type A	Type B	Type C	Type D	
Model-based scanning	X	X	x	X		
Cross-impact method		x	X	X	X	X
Environmental scanning	x	x	x	X		
Participatory methods	X	x	X	X	x	X
Delphi	X	X	X	X	X	
Futures wheel		x	x	X	x	X
Intuition and visioning	X	X	X	X	x	x

X – very promising; x – worth considering.

approaches to inspire creativity might find some techniques more in the realm of witchcraft than science. Others may be willing to accept the validity of such techniques to some extent but maintain that the identification and exploration of unprecedented phenomena requires mindsets stretching far beyond traditional thinking and perhaps rationality. The ultimate choice of the method in any particular scenario study will depend not only the nature of the problem, the purpose and audience of the scenario, but also on the type of participants who are expected to contribute to the "surprise" exercise.

7. Summary and Conclusions

This chapter identifies a large array of applications of different types of environmental scenarios. It provides a concise overview of different types of surprises one might consider for inclusion in environmental scenarios. The selection of a particular scenario and surprise depends on many factors: the bounding and complexity of the issue, the objectives of the scenario development and use, the client or intended user of the scenario and many others. Given the large number of possible combinations, it is not practical or simply impossible to give detailed guidance for choosing the scenario type and the surprises to be included. Therefore, our strategy has been to provide some general guidance about the compatibility of different kinds of surprises into environmental scenarios according to their purpose (ranging from scientific assessment to curiosity/speculation) and their function (for-input or self-contained).

This chapter also provides some guidance about what could be effective ways to think creatively about the various surprise types in the scenario creation/analysis process. Drawing on selected techniques developed and applied in futures research, possible ways of envisioning surprises are elaborated. The actual approach to incorporating surprises in the scenarios can follow one of two principle ways. One can develop a surprise-free scenario and inject surprises as the last step to check directly or to help check indirectly the robustness of the main scenario components with respect to drivers far away from the range of expectations. Alternatively, one can start with identifying a range of relevant surprises, build the scenarios around them and conduct a thorough plausibility check in the end. For most scenario exercises, the fruitful and practical way to go is in between: to identify and incorporate surprises as a regular part of the scenario elaboration procedure.

The process of including surprises in scenarios always begins with a discussion of why to include surprises and how they will be useful to the scenarios' end users. The most important questions to be answered are: What type of scenario should be used? ("For-input" or "self-contained"?) And, what is the strategy for including surprises? (As a foundation for building the rest of the scenario; as an organic part of the scenario construction process; or, added as an afterthought once the scenarios are almost completed?) The answers to these questions depend on the characteristics of the problem, the perceived or stated user needs, and the purposes of the scenario. Once these questions are resolved, the type of surprise can be chosen (see Table 8.1) based on available time, budget, and expertise. After the types of surprises are selected, they can be elaborated using one of the methods listed in Table 8.2 (perhaps with some adjustment to the method). Finally, a good and flexible process for constructing the surprises and scenarios is essential, although this doesn't guarantee success. All we can say with confidence is that work on surprises will itself be full of surprises.

ACKNOWLEDGEMENTS

I thank Joseph Alcamo for the invitation to "Scenarios of the Future: the Future of Scenarios – An International Workshop on Scenarios of the Environment," the University of Kassel in Germany, 17–19 July 2002, and participants in the surprise session of the workshop for stimulating discussions. I am grateful to two anonymous referees for their thorough comments on the manuscript and the excellent recommendations to improve it.

REFERENCES

Barney, G.O., 1980. The Global 2000 Report to the President: Entering the Twenty-First Century. Council on Environmental Quality, U.S. Government Printing Office, Washington, DC.

Bazykin, A., Bunnell, P., Clark, W.C., Gallopin, G.C., Gross, J., Hilborn, R., 1979. Expect the unexpected: An adaptive approach to environmental management. ER-79-01, International Institute for Applied Systems Analysis, Laxenburg, Austria.

Brooks, H., 1986. The typology of surprises in technology, institutions and development. In: Clark, W.C., Munn, R.E. (Eds.), Sustainable Development of the Biosphere. Cambridge University Press, Cambridge, UK, pp. 325–348.

Choi, I., Nisbett, R.E., 2000. Cultural psychology of surprise: Holistic theories and recognition of contradiction. Journal of Personal and Social Psychology 79, 890–905.

Clark, W.C., 1986. Sustainable development of the biosphere: Themes for a research program. In: Clark, W.C., Munn, R.E. (Eds.), Sustainable Development of the Biosphere. Cambridge University Press, Cambridge, UK, pp. 325–348.

Clark, W.C., Munn, R.E. (Eds.), 1986. Sustainable Development of the Biosphere. Cambridge University Press, Cambridge, UK.

EEA (European Environmental Agency), 2001. Late lessons from early warnings: The precautionary principle 1896–2000. EEA, Copenhagen, Denmark.

Faber, M., Manstetten, R., Proops, J.L.R., 1992. Humankind and the environment: An anatomy of surprise and ignorance. Environmental Values 1, 217–241.

Gendolla, G.H.E., Koller, M., 2001. Surprise and need for causal explanation: How are they affected by outcome valence and importance? Motivation and Emotion 25, 327–349.

Glenn, J.C., 1994a. Participatory methodology. In: Glenn, J.C. (Ed.), Futures Research Methodology. American Council for the United Nations University, Washington, DC, ISBN 0-9657362-2-9. CD-ROM, 1999.

Glenn, J.C., 1994b. The futures wheel. In: Glenn, J.C. (Ed.), Futures Research Methodology. American Council for the United Nations University, Washington, DC, ISBN 0-9657362-2-9. CD-ROM, 1999.

Glenn, J.C., 1994c. Genius forecasting, intuition, and vision. In: Glenn, J.C. (Ed.), Futures Research Methodology. American Council for the United Nations University, Washington, DC, ISBN 0-9657362-2-9. CD-ROM, 1999.

Gordon, T.J., 1994a. Cross-impact method. In: Glenn, J.C. (Ed.), Futures Research Methodology. American Council for the United Nations University, Washington, DC, ISBN 0-9657362-2-9. CD-ROM, 1999.

Gordon, T.J., 1994b. The Delphi method. In: Glenn, J.C. (Ed.), Futures Research Methodology. American Council for the United Nations University, Washington, DC, ISBN 0-9657362-2-9. CD-ROM, 1999.

Gordon, T.J., Glenn, J.C., 1994. Environmental scanning. In: Glenn, J.C. (Ed.), Futures Research Methodology. American Council for the United Nations University, Washington, DC, ISBN 0-9657362-2-9. CD-ROM, 1999.

Holling, C.S., 1986. The resilience of terrestrial ecosystems: Local surprise and global change. In: Clark, W.C., Munn, R.E. (Eds.), Sustainable Development of the Biosphere. Cambridge University Press, Cambridge, UK, pp. 292–317.

IPCC (Intergovernmental Panel on Climate Change), 1992. Houghton, J.T., Callander, B.A., Varney, S.K. (Eds.), Climate Change 1992 – The Supplementary Report to The IPCC Scientific Assessment. Cambridge University Press, Cambridge, UK.

IPCC (Intergovernmental Panel on Climate Change), 2000. Special Report on Emissions Scenarios. Cambridge University Press, Cambridge, UK.

Kant, I., 1790 [2004]. Kritik der Urteilskraft. Suhrkamp, Frankfurt am Main, Germany.

Kates, R.W., Clark, W.C., 1996. Environmental surprise: Expecting the unexpected?. Environment 38, 28–34.

Linstone, H.A., Turoff, M. (Eds.), 1975. The Delphi Method. Techniques and Applications. Addison–Wesley, Reading, MA.

Luce, R.D., Raiffa, H., 1957. Games and Decisions Introduction and Critical Survey. Wiley & Sons, New York, NY.

Meadows, D.H., Meadows, D.L., Randers, J., Behrens, W.W., 1972. The Limits to Growth. Universe Books, New York, NY.

Morgan, M.G., Henrion, M., 1990. Uncertainty. A Guide to Dealing with Uncertainty in Quantitative Risk and Policy Analysis. Cambridge University Press, Cambridge, UK.

Myers, N., 1995. Environmental unknowns. Science 269, 358–360.

van Notten, Ph.W.F., Sleegers, A.M., van Asselt, M.B.A., 2005. The future shocks: On discontinuity and scenario development. Technological Forecasting and Social Change 72, 175–194.

Olson, J.M., Janes, L.J., 2002. Vigilance for differences: Heightened impact of differences on surprise. Personality and Social Psychology Bulletin 28, 1084–1093.

Qi, Y., Mu, M., Wu, J., 2002. Temperature sensitivity of soil respiration and its effects on ecosystem carbon budget: Nonlinearity begets surprise. Ecological Modelling 153, 131–142.

Raskin, P., Gallopin, G., Gutman, P., Hammond, A., Swart, R., 1998. Bending the Curve: Toward Global Sustainability. Stockholm Environment Institute, Stockholm, Sweden.

Reisenzein, R., 2000. The subjective experience of surprise. In: Bless, H., Forgas, J.P. (Eds.), The Message Within: The Role of Subjective Experience in Social Cognition and Behavior. Psychology Press, Philadelphia, PA, pp. 262–279.

Schneider, S.H., 2004. Abrupt non-linear climate change, irreversibility and surprise. Global Environmental Change 14, 245–258.

Schneider, S.H., Turner, B.L., 1994. Surprise and global environmental change. Report of the 1994 Aspen Global Change Institute Summer Session on Surprise and Global Environmental Change. Accessed 01.09.05 at http://sedac.ciesin.columbia.edu/mva/iamcc.tg/articles/surprise.html.

Schneider, S.H., Turner, B.L., 1995. Anticipating global change surprise. In: Hassol, S.J., Katzenberger, J. (Eds.), Elements of Change 1994. Aspen Global Change Institute, Aspen, CO, pp. 130–145.

Schneider, S.H., Turner, B.L., Morehouse Garriga, H., 1998. Imaginable surprise in global change science. Journal of Risk Research 1, 165–185.

Schwartz, P., 2004. Inevitable Surprises. Thinking ahead in a Time of Turbulence. Gotham Books, New York, NY.

Smith, D.C., 2003. Power cuts. Risks and alternatives to the current transmission system. Refocus 2003, 22–25.

Svedin, U., Aniensson, B. (Eds.), 1987. Surprising Futures: Notes from an International Workshop on Long-Term Development, Friiberg Manor, Sweden, January 1986. Swedish Council for Planning and Coordination of Research, Stockholm, Sweden.

Timmerman, P., 1986. Mythology and surprise in the sustainable development of the biosphere. In: Clark, W.C., Munn, R.E. (Eds.), Sustainable Development of the Biosphere. Cambridge University Press, Cambridge, UK, pp. 453–455.

Toth, F.L., Hizsnyik, E., Clark, W.C. (Eds.), 1989. Scenarios of Socioeconomic Development for Studies of Global Environmental Change: A Critical Review. RR 89-4. International Institute for Applied Systems Analysis, Laxenburg, Austria.

UNEP (United Nations Environment Programme), 2002. Global Environment Outlook 3 (GEO 3). Earthscan, London, UK.