# Chapter 9

# FUTURES OF URBAN ECOSYSTEMS

## 9.1 The Challenges: Complexity, Heterogeneity, and Surprise

Planning agencies in urbanizing regions face unprecedented challenges: Rapid environmental change places enormous pressure on their ability to support urban populations while maintaining a healthy ecosystem. Agencies must devise policies to guide urban development and to make decisions about where and how to invest in infrastructure that is economically viable while simultaneously minimizing environmental impact. In regions that are becoming urbanized, the form and pace of urbanization mediate the complex interactions between humans and ecological processes. In turn, urbanization places increasing pressures and constraints on natural resources. Planning decisions, especially those about urban growth and infrastructure, can influence the directions of urban development and determine the sustainability of our urban planet. To make sound decisions, it is crucial to assess the effectiveness of infrastructure choices and the robustness of urban planning strategies under alternative future scenarios.

Strategic decisions about urban infrastructure and growth management are based on our assessment of the past and our expectations for the future. How we think about the future has important consequences for how we define the problems to be addressed and how we search for solutions. Traditional approaches to planning and management typically rely on predictions of probable futures extrapolated from past trends. Alternatively, planners and managers have developed participatory processes to imagine desirable futures based on a set of shared community values and goals. However, with respect to long-term trends, complexity and uncertainty in coupled human-natural systems make their future increasingly unpredictable. Planners and managers need to rely on a much broader and diverse knowledge of the past to build a view of what Stewart Brand (1999) calls the “long now.” Expanding on this concept, Steve Carpenter (2002, 2069), in his MacArthur lecture entitled “Building an Ecology of the Long Now,” noted that in many cases of environmental decision-making, what ecologists cannot predict is at least as important as what can be predicted. Thinking about the future, however, is challenging. Scientists and managers are constrained by their assumptions about how the world works and what drives change. In combination, all these conditions tend to limit planners' imagination to a default set of scenarios, and thus limit their ability to deal with surprise.

For example, climate variability and change are expected to signifycantly impact essential human services (i.e., supplies of water and energy) and ecological functions (i.e., primary production) within urban areas. Increasingly, policy makers and planners must balance the need to provide critical services to the urban population while maintaining important ecological functions. While climate change may be inevitable, strategies can be implemented to make urban systems more resilient to potential changes in climate, and simultaneously maintain human and ecological functions. To identify and prioritize urban planning and management strategies, we must explore future scenarios of climate change and the ways they interact with other drivers of change. Further, we must also identify vulnerable systems, and assess the effectiveness of alternative strategies in reducing risk under each scenario.

For environmental decision-makers, it has become crucial to assess alternative strategies and take action in the face of irreducible uncertainties. Predictive models that are designed to provide accurate assessments of future conditions can only partly account for the interactions between highly uncertain drivers of change and the surprising, but plausible, futures over the long term. While important progress has been made in complex modeling, and improved simulation and computer power have allowed us to process quite astonishing amounts of data, our models are constrained by our limited knowledge, assumptions, and mindsets. How can we articulate and explore possible futures when coupled human-natural systems are so complex, and their futures so uncertain? How can we challenge the assumptions and mindsets that both scientists and managers hold about the future? And how can we build institutions that take a "long now" perspective?

In this chapter, I discuss the challenges of predicting future dynamics of coupled human-ecological systems and of building models of urban ecosystems to assess the ecological future of urbanizing regions. Aiming at predicting the future by estimating probabilities on the basis of past trends is not sufficient. Coupled human-natural systems exhibit complex dynamics that can cause surprising behaviors (Holling 1996, Scheffer et al. 2001 Carpenter 2001, 2002). I propose to link predictive modeling with scenario building in order to explore systematically and creatively plausible futures. Strategists at Royal Dutch/Shell originally proposed this approach in the 1970s, and it was recently applied in the Millennium Ecosystem Assessment (MEA 2005). By focusing on key drivers, complex interactions, and irreducible uncertainties, scenario building generates the narratives within which we can use predictive models to test hypotheses and develop adaptive management strategies. This approach, of linking models and scenarios, is relevant to both science and policy. It provides a basis for developing an integrated understanding of the processes and mechanisms that govern urban ecosystem dynamics; at the same time, it provides tools to predict and assess the impact of future urban growth and to evaluate alternative urban planning and growth-management strategies.

## 9.2 Complexity and Predictability

In modeling the interactions between human and ecological systems, we need to consider that multiple factors operate simultaneously at various scales. Coupled human-ecological systems are very complex. Complexity emerges as interacting agents engage in simple behaviors in systems that are nonlinear (i.e., strongly coupled) or open (driven from equilibrium by external factors). Change and evolution are inherent in these systems. The feedback mechanisms that operate between ecological and human processes can amplify or dampen changes and thus regulate the system's response to external pressures. In the Millennium Ecosystem Assessment summary report, the authors conclude that "there is established but incomplete evidence that changes being made in ecosystems are increasing the likelihood of nonlinear and potentially high-impact, abrupt changes in physical and biological systems that have important consequences for human well-being" (MEA 2005).

In urban ecosystems, urban development controls the ecosystem structure in complex ways. Land use decisions affect species composition directly by introducing species and altering land cover, and indirectly by modifying the agents that naturally cause disturbances. Human choices about what and how much to produce and consume determine the amounts of resources that are extracted and the amounts of emissions and wastes. Decisions about investing in infrastructures or adopting control policies may either mitigate or exacerbate these effects. But there are also important feedbacks. Ecological productivity affects the regional economy. Thus interactions between decisions and ecological processes at the local scale can result in large-scale environmental change.

Emerging properties in complex systems are aggregate behaviors that we cannot infer from studying the system components that have generated them (Parrott 2002). Emergent properties make complex systems inherently unpredictable. But while highly unpredictable, complex systems can be studied with the objective of gaining knowledge on their behavior and dynamics. Holling (2001, 391) explains that "Complexity does not emerge from a random association of a large number of interacting factors." Rather, it emerges from a smaller number of controlling processes. These systems are self-organized; a small set of critical processes creates and maintains this self-organization and drives the systems' evolution (Levin 1999). Holling (2001) argues that there is an essential simplicity behind complex systems that can lead us to understand their dynamics. The approach for studying such systems should be "as simple as possible but no simpler" than is required for understanding and communication. It should be dynamic and prescriptive, not static and descriptive, so we can connect policies and actions to the evaluation of different futures. And it should embrace uncertainty and unpredictability because change and surprise are inevitable in coupled human-natural systems.

In science, all predictions involve some level of uncertainty. Although in some cases uncertainty may be great, scientists most often assume that it is quantifiable. Complex systems are inherently unpredictable, thus the uncertainty cannot be completely quantified. In coupled human-natural systems, future dynamics are dependent on multiple drivers, such as population growth and climate change, that have very different degrees of uncertainty. The probability distribution of predictions for coupled human-natural system depends on the distributions of such drivers. But since future driver distributions may be unknown, the uncertainty in such predictions cannot be calculated (Carpenter 2002).

In coupled human-natural systems, uncertainty and unpredictability can be generated by surprising interactions among the driving forces and the reflexive interactions between human behavior and their anticipated knowledge for the environmental change their action can have. As Steven Carpenter (2002, 2080) points out: "Even the uncertainties are uncertain, because we do not know the set of plausible models for the dynamics of the probability distributions."

## Dynamic urban ecosystems

Human systems and natural systems both change over space and time. One major problem in modeling their relationships is that they operate at very different spatial and temporal scales. The lag time between a human decision and its impact on the environment complicates any attempt to model their interactions. Human impacts on ecosystems may become apparent only after irreversible changes have already taken place and caused undesirable consequences. The delayed response to human-induced changes in ecological systems has been known for a long time. The depletion of fish stocks is an example of a lagged environmental response to over-fishing (Jackson et al. 2001). Another example is climate change (Burkett et al. 2005). It took a long time for the climate to respond to the concentrations of greenhouse gases in the atmosphere, and it can take a long time before ecosystems respond to climate change.

Time-lags between human and ecosystem function are exacerbated by scale mismatches. People and ecosystems work at very different time scales (Cumming et al. 2006). In coupled human-natural systems, drivers of change differ considerably in their response times (MEA 2005), and the speed at which a driver reacts has an important impact on the system's ability to adjust. The extinction of species due to habitat loss or climate change can be considered irreversible on a human time scale. Failure of people or society to detect or recognize such impacts adds to the lag in response. In an urban region, the extraction of groundwater may exceed the system's capacity for recharge long before the costs of extraction begin to reflect that depletion. The economic costs associated with long-term ecological effects are often not reflected in market prices for goods and services.

Complex spatial dynamics are also affected by boundaries and scale mismatches, and human impacts may be widely distributed and distanced over space. Changes in upstream catchments affect water availability and ecological conditions in downstream regions. Emissions of atmospheric pollutants affect those living downwind. Changes in landscape structure in one part of a watershed has consequences on disturbance regimes on a larger scale. Global climate change affects regions unequally. The spatial units of human influence and institutional response (through land-use regulations and policies) do not match those that govern biophysical processes and ecosystem functioning.

Both spatial and temporal lags have important consequences on the ability to manage coupled human-natural systems. In fact, the temporal and spatial separation between cause and effect make it extremely difficult to assess costs and benefits and to fully appreciate the distributional consequences of human action. For people to take responsibility for the environmental consequences of their behaviors in space and time requires a much more expanded perspective in time and space.

We must treat time and space explicitly if we are to accurately represent the dynamics of urban and environmental change. Spatially-explicit models are increasingly being implemented in modeling coupled human-natural system dynamics, taking advantage of the advancement in geographic information science technology, available spatial data, and computer power (Goodchild 2003). When building models of urban ecosystems, time can be represented as either a discrete or as a continuous variable. While treating time as continuous is certainly daunting, we can use multiple time steps for the different processes; this approach represents an important improvement over stationary models. Today, most operational urban models are based on a cross-sectional, aggregate, equilibrium approach; we could improve on them by representing time explicitly as a discrete variable, and by explicitly identifying slow- and fast-changing variables.

## Multiple adaptive agents

We also need to challenge the implicit assumption of most urban models that decisions are made by one single decision-maker at one point in time. Urban development is the outcome of dynamic interactions among the choices of many actors, including households, businesses, developers, and governments (Waddell 1995). These actors make decisions that determine and alter the patterns of human activities and ultimately affect ecosystem change. Their decisions are interdependent; for example, employment activity affects housing location, which affects retail activity and infrastructure, which in turn affect housing development. Urban decision-makers are a broad and diversified group of people who make a series of relevant decisions over time.

In order to model urban ecological interactions, we must explicitly represent the location, production, and consumption behaviors of these multiple actors. This approach requires a highly disaggregated representation of human agents (i.e., households and businesses) and ecological agents (i.e., species and populations). We can disaggregate economic sectors by using a revised version of the input-output model methodology. Microsimulation may also help us address the difficult tradeoffs that households and businesses make between location, production, and consumption preferences. Agent-based models allow us to implement multi-attribute utility functions that correspond to the different agents and allow them to place different values to the different attributes (Monticino et al. 2007).

## Feedback mechanisms

In modeling urban ecological systems, we also need to consider the feedback mechanisms that connect the natural and human systems. These are control elements that can amplify or dampen a given output. For example, ecologists describe negative feedback in the biosphere: A homeostatic integration of biotic and physical processes keeps the amount of carbon dioxide in the air relatively constant. But we do not completely understand the feedback loops—both positive and negative—between human and environmental systems. We know that human decisions leading to the burning of fossil fuels and land use change affect the carbon cycle and in turn, the associated climate changes will affect human choices, but the nature of these interactions remains controversial. In particular, the feedback of environmental change on human decisions is difficult to represent: Environmental change affects all people independently of who has caused the environmental impact in the first place, while the impact of each individual decision-maker on the environment depends on the choices of others (Ostrom 1991).

Interactions between ecological and human functions involve several feedback mechanisms. Within urban development, for example, real estate markets involve the feedback mechanisms of buyers and sellers adjusting their prices in reaction to the relative abundance or scarcity of real estate. Feedback mechanisms can be negative, or dampening forms that tend to stabilize systems—such as real estate markets. Feedback can also be positive, accelerating adjustments and leading to unstable conditions that change catastrophically as in the case of ecological succession or the extinction of species. The shift between these multiple states is often abrupt, and systems respond to perturbation in ways that are complex and highly nonlinear. The process becomes nonlinear as multiple agents, such as natural vegetation and urban development, interact and compete for space. The characteristic response shows strong hysteresis; that is, when an ecosystem shifts from the vegetation state to the sprawl state, it becomes highly resistant to switching back.

## 9.3 Spatial and Temporal Heterogeneity

Variability in time and space is a defining characteristic of ecosystems—on all scales. Individual organisms, populations, and communities vary among them, and over space and time (Hewitt et al. 2007). Sources of heterogeneity in urban ecosystems are both natural and human. Natural sources of heterogeneity include biological and physical agents, disturbance regimes such as storms and earthquakes, and stresses such as droughts and flooding (Pickett and Rogers 1997). Humans also increase heterogeneity: They introduce exotic species, modify landforms and develop drainage networks, control or modify natural disturbance agents, and build extensive infrastructure (Pickett et al. 1997). They also break existing landscapes into smaller patches; landscape ecologists have started to explore the impact that the various, dynamic arrangements of patch structures have on ecosystems (Godron and Forman 1982, Turner 1989, Forman 1995, Collinge 1996).

Ecological scholars have long-recognized the importance of spatial and temporal heterogeneity and the consequences on scaling across heterogeneous systems (O'Neill et al. 1986, Wiens 1989, Levin 1992). But empirical studies often still assume stationarity. This assumption creates important limitations on what ecologists can infer and how much they can generalize (Wagner and Fortin 2005, Hewitt et al. 2007).

Hewitt et al. (2007) point out several ways that heterogeneity challenges extrapolation. First, the variance in ecological systems tends to increase with spatial and temporal extent (Schneider 1994). Second, large-scale variations can dominate the dynamics of small-scale processes (i.e., demographic or biotic) and potentially confound small-scale experiments (Schneider et al. 1997). A third major problem is generalizing the results from studies conducted at one or a few locations or times, or at one spatial and temporal scale. The results may change dramatically at another scale, even shifting the direction of ecological responses (Hewitt et al. 2007).

Spatial heterogeneity created by human-natural interactions (i.e., patchiness of the urban landscape) has important consequences for the ability to model coupled systems. Spatial heterogeneity violates assumptions of parametric tests by creating autocorrelation in the error structure and reducing the degree of freedom (Wagner and Fortin 2005). Spatial autocorrelations imply that characteristics and dynamics of nearby land cover patches tend to be more spatially clustered and similar than expected due to random chance. In urban ecosystems, positive spatial autocorrelation and spatial dependence are driven by urban development.

To model complex coupled human-ecological systems, we must explicitly address the effect of spatially and temporally heterogeneous processes across multiple scales. The challenge is to identify these heterogeneities, and to take them into account in model building. A number of approaches and techniques can be used to identify and address spatial and temporal non-stationarity. The most straightforward approach is model segmentation. Wagner and Fortin (2005) suggest wavelet analysis as a promising alternative to characterizing and partitioning landscapes in the presence of multiple, overlapping processes. Integrating discrete and continuous data models in representing landscapes may be an effective approach for identifying and modeling heterogeneity (Cova and Goodchild 2002). In general, the integration of multiple approaches and methods that combine statistical analysis with natural history and experiments is critical to allow for generalizations (Hewitt et al. 2007).

## 9.4 Threshold, Discontinuity, and Surprises

Thresholds are transition points between alternate states or regimes (Liu et al. 2007). A regime shift between alternate stable states occurs when a controlling variable in a system reaches a threshold, modifying its dynamics and feedbacks (Walker and Meyers 2004). Subtle environmental change can set the stage for large, sudden, surprising, and sometimes irreversible, changes in ecosystems. Regime shifts depend not only on the perturbation, but also on the size of the basin of attraction (Holling 1973, Sheffer et al. 2001, Figure 9.1). In systems with multiple stable states, gradually changing conditions may reduce the size of the basin of attraction around a state. This is what Holling (1973) defines a loss of ecological resilience. This is typically described using the heuristic of the fate of a ball in a landscape of hills and valleys. As represented in Figure 9.1, a small perturbation or external event may be enough to cause a shift to an alternative stable state. However, this loss of resilience makes the system more fragile, in the sense that the system can easily be tipped into a contrasting state by stochastic events.

Recent studies have provided empirical evidence that alternative stability domains exist in a variety of ecosystems such as lakes, coral reefs, oceans, forests, and arid lands (Scheffer et al. 2001). Walker and Meyers (2004) describe a database documenting thresholds in ecological and socio-ecological systems that drive system-shifts. In coupled human-natural systems the effects of environmental change on human function and well-being may not be apparent until ecological changes reach a threshold. Complex feedbacks between natural and ecosystem thresholds can generate regime shifts (Walker and Meyers 2004). Regime shifts in ecosystems are

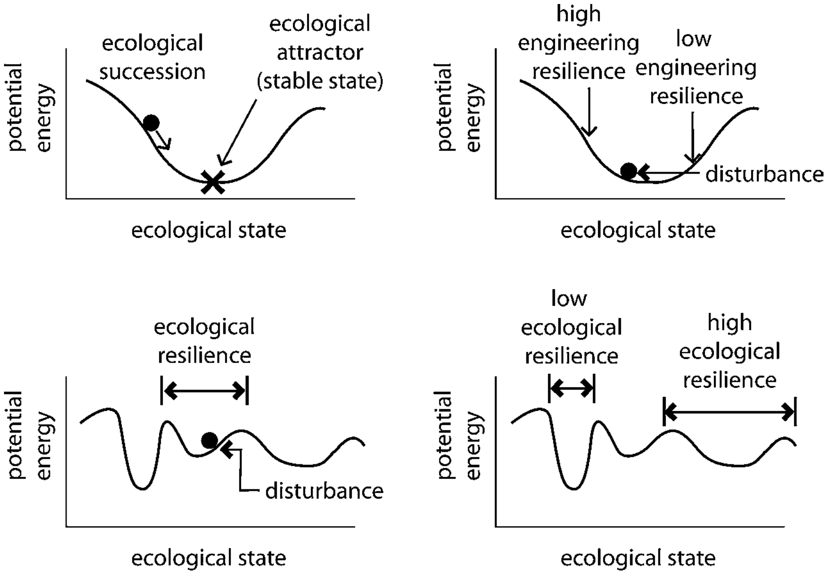

Figure 9.1. Ecological resilience. The four diagrams describe the difference between ecological and engineering resilience according to Holling (1973). Engineering resilience is the rate at which a system returns to a single steady state following a perturbation. In the diagrams, the steepness of the sides of a stability pit. The deeper a pit the more stable it is. Ecological resilience is a measure of the amount of change that is required to transform a system from being maintained by one set of mutually reinforcing processes and structures to a different set of processes and structures. Ecological resilience is a measure of the regional topography of a stability landscape. In the diagram, ecological resilience of a system corresponds to the width of its stability pit. (Peterson 2004).

difficult to predict (Scheffer and Carpenter 2003). There is, however, increasing evidence that ecosystem dynamics become more variable prior to some regime shifts (Berglund and Gentz 2002, Brock and Carpenter 2006, Carpenter and Brock 2006). For example, by studying variability around predictions of a simple time-series model of lake eutrophication, Carpenter and Brock find that rising standard deviation (SD) could signal impending shifts about a decade in advance. Brock et al. (2006) explain how this can occur for one-dimensional systems. Carpenter and Brock (2006) showed that the variance component related to an impending regime shift could be separated from environmental noise using methods that required no knowledge of the mechanisms underlying the regime shift.

The presence of alternative stable states has profound implications for our response to environmental change. In urbanizing regions, multiple steady and unstable states exist simultaneously (Alberti and Marzluff 2004). Eventually urban sprawl leads the ecosystem to shift from a natural steady state of abundant and well-connected natural land cover to a second steady state of greatly reduced and highly fragmented natural land cover (Figure 9.2). The exact form of the natural "steady" state depends on natural disturbance regimes. The sprawl state is a forced equilibrium that relies on incomplete information regarding the full ecological costs of providing human services to low-density development. Sprawl is an unstable stable because it is based on importing ecosystem services from other areas.

As I showed in Chapter 1, the state of an urban ecosystem is driven between the natural and sprawl states by the amount of urbanization. As we replace ecological functions with human functions in urbanizing regions, the processes supporting the ecosystem may reach a threshold and drive the system to collapse (Figure 9.2). An incomplete view of the relationship between urbanization, ecological functions, and human functions assumes that ecological and human functions are independent (Figure 9.3, p. 236). In contrast, a view of urban ecosystems as coupled human-natural systems indicates that there may be a threshold in the relationship between urbanization and ecological conditions. Ecosystem function directly supports the human population in non-urbanized areas and indirectly supports human function in urbanized areas. Urbanization degrades ecological conditions to a level in which ecological functions collapse. Eventually human function in urbanized areas declines as the ecosystem functions are reduced by urbanization.

To assess the resilience of urban ecosystems, we must first understand how interactions between humans and ecological processes affect the

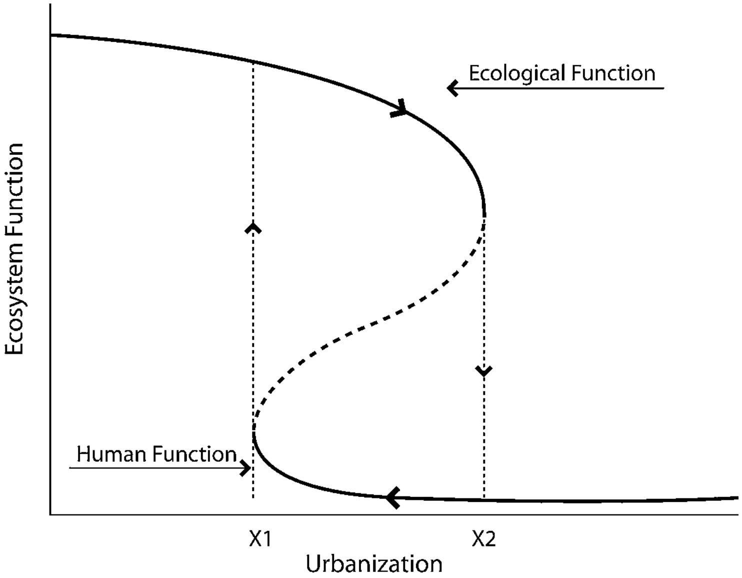

Figure 9.2. Multiple states in urban ecosystems. The graph illustrates alternate stable states in urban systems. Structural changes in the urban landscape (e.g., Chapter 1, Figure 1.8) result in a shift in system's dynamics.

resilience of the inherently unstable equilibrium points between the natural ecosystem attractor and the sprawl attractor. In other words, we must understand how best to balance human and ecosystem functions in urban ecosystems. Ecosystem functions are the ecological processes and conditions that sustain humans and other species (Daily 1997). Human functions in urban areas, such as housing, water supply, transportation, waste disposal, and recreation depend on ecosystem functioning and productivity over the long term. Urban areas also depend on the ecosystem's ability to act as a sink to absorb emissions and waste. Ecosystems provide other important functions to the urban population: They regulate climate, control flooding, and absorb carbon, to mention a few (Ehrlich and Mooney 1983, Daily 1997, Costanza et al. 1997).

Using as a framework the resilience hypothesis proposed in Chapter 1, consider how the built infrastructure in an urban ecosystem modifies hydrological functions. As an area becomes urbanized, humans tend to

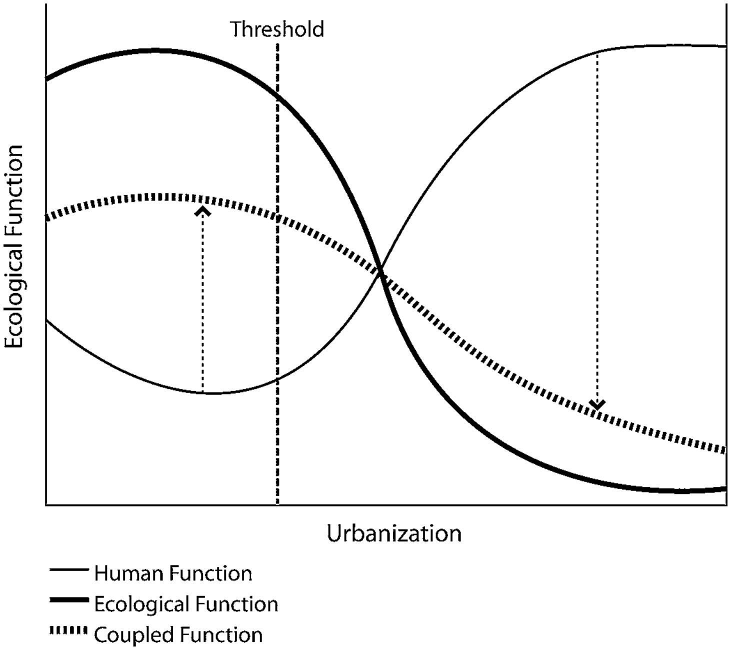

Figure 9.3. Interaction between human and ecological functions in urban ecosystems. The two solid lines represent a partial view of the relationship between urbanization, ecological functions, and human functions. Urbanization is measured as the amount of developed land per unit area. The heavy black line indicates the decline in ecological function that results from urbanization. The lighter black line indicates human services replacing ecological services. This view however is flawed since it assumes that ecological and human functions are independent. In contrast, a view of urban ecosystems as coupled human-natural systems indicate that there may be a threshold in the relationship between urbanization and ecological conditions.

replace the natural hydrological functions with built infrastructure; doing so lets them control the water flow, extract and distribute water for human uses, and purify water before it returns to the natural water bodies. In this process, urbanization decreases the amount and quality of natural hydrological functions, and replaces them with the built infrastructure that supports human functions.

At first glance, the human and natural functions in an urban ecosystem may seem to be operating independently, but in reality they are highly coupled. For example, the infrastructure's ability to serve multiple uses depends on the size, availability, and recharge capacity of the clean water supply. But the decline of the natural hydrological function may constrain that supply. As a result of human pressure, the coupled hydrological function (both human and natural) may decline as ecosystem functions, both local and global, are reduced. The functional form of the relationships between ecosystem function, human function, and urbanization depends on the specific ecosystem functions being considered; it may also depend on alternative future conditions caused by complex interactions between drivers of change (i.e., climate or technology), as I discuss later in this chapter.

Making it even more difficult to model interactions between drivers and predict potential shifts in system behaviors is the fact that their impacts are both cumulative and synergistic. In general, environmental disturbances have an important impact when the factors causing them are grouped so closely in space or time that they overwhelm the natural system's ability to remove or dissipate those impacts (Clark 1986). Human stresses in cities may cross thresholds beyond which the stresses may irrevocably damage important ecological functions. In most ecological systems, processes occur step-wise rather than progressing smoothly (Holling 1986), and sharp shifts in behavior are natural. These related properties of ecosystems require us to consider resilience: the amount of disturbance a system can absorb without changing its structure or behavior.

Modeling urban ecological systems will require us to pay special attention to uncertainty, which can be caused by many factors: We may not sufficiently understand a given phenomenon; we may make systematic and random errors or subjective judgments; natural systems can change abruptly and in discontinuous ways; and characterizing the responses of the system function will involve thresholds and multiple domains of stability. Because the knowledge of environmental systems is always incomplete and uncertain, surprise is inevitable (Holling 1996). For all these reasons, urban planners must explicitly characterize and analyze uncertainty.

## 9.5 Scenario Planning and Adaptive Management

Coupled human-natural systems challenge our traditional assumptions and strategies for planning and managing natural resources and the environment (Liu et al. 2007). The success or failure of many policies and management practices is based on their ability to take into account the complexities and uncertainty of these systems. For instance, many decisions that do not consider cumulative impacts, cross-boundary effects, threshold, and uncertainty may result in unexpected and undesirable environmental consequences. When assumptions regarding climate variability and extreme events do not take uncertainty into account, it is harder to prepare and respond effectively (consider Hurricane Katrina). Furthermore, when policies aim at stabilizing the ecological system or eliminating its variability, the outcome is inevitably its collapse (Carpenter and Gunderson 2001).

Authors of recent studies of coupled human-natural systems indicate that to face the challenges described above, planners and managers must take several factors into account: emergent properties, reciprocal effects, nonlinearity, and surprises (Liu et al. 2007). Because humans' predictive ability is inherently limited, we must incorporate uncertainty into decision-making. Scenario building is a strategy to explicitly consider what futures are plausible in the face of irreducible uncertainties (Shwartz 1991). We need strategies that enhance the adaptive capacity of systems while preserving key aspects of their structure and functioning, because coupled human-natural systems will inevitably change in response to various exogenous stressors, and we cannot predict their internal dynamics (Carpenter 2002).

Scenario building is both a systemic method and a framework to expand our ability to think creatively about the future by focusing on complexity and uncertainty (Peterson et al. 2003). Rather than focusing on accurately predicting a single outcome, scenarios let us examine the interactions of various key uncertain factors creating alternative futures. If we focus only on what is likely or predictable within some reasonable confidence interval, we will not be able to identify as broad a range of possible risks and surprises. Scenario building requires an open mind, and a willingness to explore uncharted territory.

Several authors have examined alternative approaches to future studies and have discussed the benefits of building scenarios in light of increasing uncertainty (Amara 1981, Marien 2002, Börjeson et al. 2005). Peterson et al. (2003) identify three major benefits of using scenarios in ecological conservation: (1) Planners can better understand key uncertainties; (2) they can incorporate alternative perspectives into conservation planning; and (3) they can formulate decisions that become more resilient to surprises. In the rest of this chapter, I discuss scenario building as an approach for planning and managing in urban ecosystems.

## What are scenarios?

Scenarios are narratives about alternative environments in which the participants can play out their decisions about planning and management strategies (Ogilvy and Schwartz 1998). They are not predictions or visions. Instead, they are hypotheses about different futures designed to highlight the risks and opportunities involved in specific strategic issues. To clarify this distinction, we can represent predictions, visions, and scenarios in terms of probability distributions (Figure 9.4). Peterson et al. (2003) define a scenario

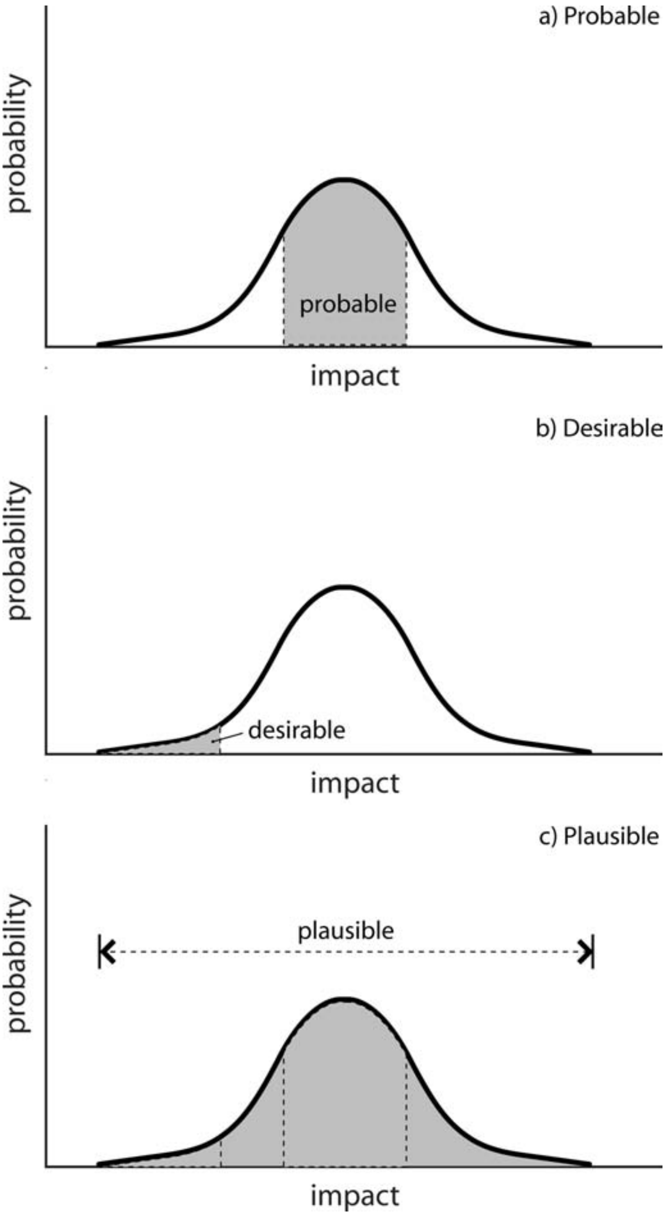

Figure 9.4. Probability distributions. This graph compares predictive models (a) probable, visions (b) desirable, and scenarios (c) plausible using probability distributions.

as a “structured account of a possible future.” Scenario planning is a method for learning about the future by exploring how the potential impact of the most unpredictable and important driving forces can shape the future.

Scenarios are written as plausible stories—not probable ones. Traditional approaches to planning and management rely on predictions based on probabilities and quantified uncertainties. A prediction is understood to be the best possible estimate of future conditions (Peterson et al. 2003). By comparing scenarios to predictions, Peterson et al. (2003) emphasize that ecological predictions assume that we know the probability distribution of specified ecological variables at a specified time in the future; the accuracy of this prediction will depend on current conditions, specified assumptions about drivers, the measured probability distributions used in model parameters, and the measured probability of the model itself being correct (Clark et al. 2001).

Predictive models are effective over short time frames and under stable conditions (Lindgren and Bandhold 2003). To build such models, we generally need to know significant amounts about the mechanisms that drive the behavior of a phenomenon, and to have a substantial amount of historical data. Predictive models generate probabilities (Peterson et al. 2003). However, such models do not work as well with complex, nonlinear processes or thresholds. As I point out at the beginning of this chapter, all predictions are approximations of what may happen, and they involve some level of uncertainty. But what makes future dynamics of coupled human-natural systems inherently unpredictable is the interactions of multiple drivers with very different degrees of uncertainty. The probability distribution of coupled human-natural system predictions is unknown (Carpenter 2002).

Scenarios are also distinct from what planners have traditionally called visions. Visions are generated through a participatory process: Planners use a variety of techniques to engage stakeholders in imagining a desirable future. The objective of a visioning process is to identify a set of goals and strategies to guide a planning effort. Through a visioning process, stakeholders collectively imagine possible futures rather than exploring what might occur. Although visioning has its important role in the planning process, the lack of systematic considerations of what we know does not provide an effective tool to assess alternative futures.

Scenarios are intended to go beyond predictions, using uncertainty and complexity to provoke the participants' imaginations and provide a more comprehensive view of risk, so that the results can be embedded in critical strategic decisions. Scenarios first emerged following World War II as a method for military planning. In the 1960s, Herman Kahn, refined scenarios as a tool for what he called business prognostication: predicting according to present indications or signs. In the 1970s, Pierre Wack, working for Royal Dutch/Shell, used scenario building to analyzed two plausible energy futures: a realistic one in which oil prices would increase dramatically, and a less-realistic one in which they did not.

Approaches to scenario planning vary, but they follow a similar structure. Scenario planning focuses on key drivers, uncertainties, and interactions that might shape plausible alternative futures. Scenario planning generally involves eight key steps: (1) Identify the focal issue; (2) identify the driving forces; (3) rank the drivers by their importance and uncertainty; (4) select the scenario logics; (5) flesh out the scenarios; (6) select indicators for monitoring; (7) assess the impacts for different scenarios; and (8) evaluate alternative strategies (Schwartz 1991, Peterson et al. 2003, Lindgren and Bandhold et al. 2003).

Scenario planning has many purposes. The list below can be used to evaluate the effectiveness of a scenario planning process:

- Expand perspectives.
- Help decision-makers think about the future.
- Challenge assumptions (in both science and planning).
- Develop and test strategies and plans.
- Synthesize and communicate complex information to decision-makers.
- Provide insight into drivers of change.
- Reveal the implications of potential future trajectories.
- Illuminate options for action.
- Improve education and public awareness.
- Understand differences in perspectives among stakeholders and jointly explore the consequences.

Scenario planning should not be seen as an alternative to traditional planning approaches such as predictions and visions; rather, scenarios complement other planning tools. Essential in long-term planning, scenarios work best when the trajectories of driving forces are highly uncertain, when multiple interactions among these drivers may occur, and when looking far into the future. To succeed, however, scenario planning requires the integration of science and imagination. Participants need to keep an open mind and be willing to challenge their assumptions and mindsets. By making use of scientific facts, models, and imagination, scenarios can be effectively integrated with predictive models to test hypotheses on the possible impacts of alternative urban strategies. They also can serve to make communication among scientists, policymakers, and the public more effective.

## 9.6 Hypothetical Scenarios of Urban Ecosystem Functions

To explore how scenarios can be used to assess alternative planning strategies, I use a hypothetical example of how changes in urban hydrological function can interact with technology and human choice. Such interaction can potentially reach a threshold in the human and ecosystem functions and generate a system shift between multiple stable states under climate change. How resilient are alternative patterns of urban development to environmental change? This is a fundamental question in urban planning. As I discussed in Chapter 1, in urbanizing regions, urban sprawl leads the ecosystem to move from a natural steady state to a second steady state of greatly reduced ecosystem function (McDonnell et al. 1997, Vitousek et al. 1997b, Dobson et al. 2001, Costanza et al. 2002, Hansen et al. 2002). Human functions may also be compromised in sprawling developments because of higher infrastructure costs and the effect of reduced ecosystem function on human function in the long term (Frank 1989). Time lags in system feedbacks can result in a rapid collapse of system dynamics. Feedback can take decades to appear, and it often appears in unexpected forms that decision-makers do not see as connected to the original cause. For example, most people living in the suburban periphery do not appreciate how much it costs for the municipality to provide them with public services (e.g., utilities) (Ottensmann 1977). Often, such provision subsidizes sprawling development, because the price of services does not reflect their real cost and distance from central facilities (Ewing 1994, 1997).

I use this hypothetical example to illustrate how scenarios can effectively help in exploring plausible futures. In the example, the interaction between natural and human hydrological function may vary under different scenarios, but we do not know the probability distribution of the scenario emerging from such interaction. The probability distribution of such outcome depends on the distributions of multiple driving forces. In the example, climate change and technology drive human and ecosystem function. Since the distributions for these factors can take different forms, their interaction is unpredictable. As I show in Figures 9.5, 9.6, and 9.7, not only may the mean impact shift under alternative scenarios, but also the shift in variance may offset our ability to calculate the distribution of the outcome, given alternative hypotheses about thresholds in human and ecological functions under alternative climate and technological scenarios.

For example, the ability of an urbanizing watershed to perform hydrological functions essential to humans and other species depends on various scenarios of climate change, as well as various alternative technological scenarios. In the hypothesized example, climate change and its impact range from high to low (based on IPCC scenarios). I also hypothesize alternative technological trajectories based on the type of innovation that emphasizes reactive versus proactive and self-regulating end points. Once we consider the various possibilities, we can then hypothesize alternative thresholds under different scenarios that may result from the interactions between two driving forces: climate change and technological innovation (Table 9.1, Figure 9.8).

In response to the human, ecological, and economic costs of sprawling development, the field of urban planning has attempted to stabilize inherently unstable states—by balancing the conversion of natural land cover with the development needed to support human services. The assumption behind such planned development is that the development pattern affects ecological conditions, as well as the maintenance of ecosystem and human functions. In the phase of reorganization and renewal of adaptive cycles, urban ecosystems have a chance to change their trajectory and begin to develop self-organizing processes of interacting ecological and socioeconomic functions. This forced equilibrium is inherently unstable, as it has to balance the tension between providing for human functions and ecosystem functions as shown in Figure 9.2. Alternative patterns of development may have an impact on the ecosystem functions under alternative scenarios. Human and ecosystem functions are interdependent. Alternative urbanization patterns have different levels of resilience, measured as their capacity to simultaneously support ecological and human functions (Figure 9.9).

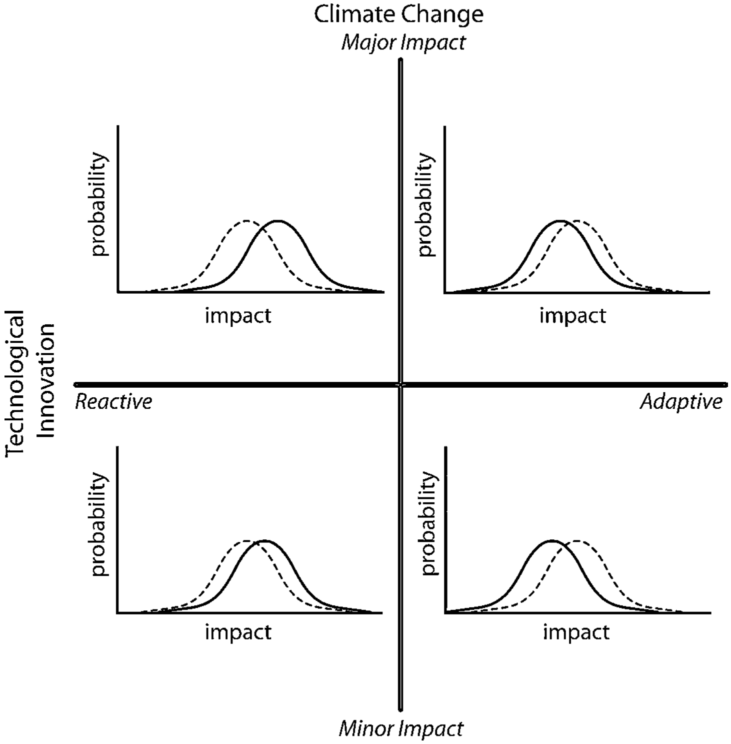

Figure 9.5. Probability distributions under alternative scenarios. The probability distributions of impact may shift in mean under different scenarios.

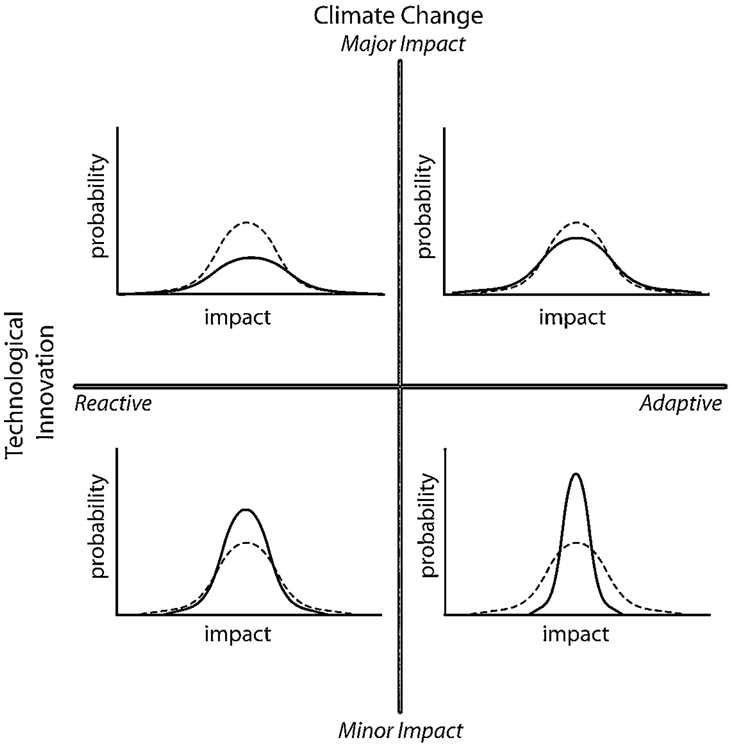

Figure 9.6. Probability distributions under alternative scenarios. The probability distribution of impact may shift in variance under different scenarios.

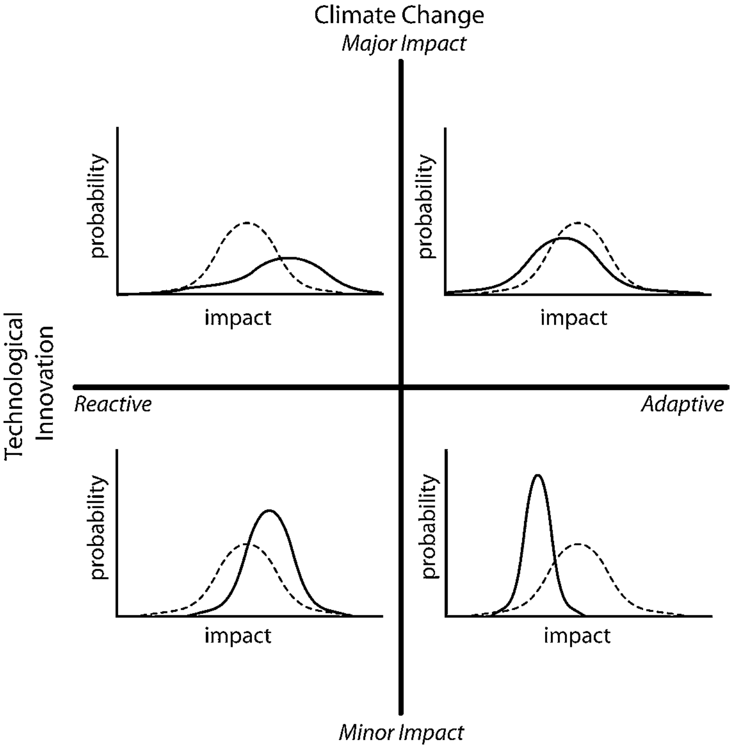

Figure 9.7. Probability distributions under alternative scenarios. The probability distribution of impact may shift in both mean and variance under different scenarios.

Table 9.1. Scenario descriptions.

***Climate Change***

*Major Impact*: Large magnitude of climate impacts, as described in Scenario A1 of the IPCC scenarios (IPCC 2000). High sea level rise, glacial melting, temperature increase, summer droughts, winter flooding.

*Minor Impact*: Limited climate impacts, as illustrated in the IPCC scenario B1 (IPCC 2000). Few regional effects from changes in temperature and hydrology.

***Technological Innovation***

*Adaptive*: Technological innovation solutions are proactive, mimic natural cycles, reflect context and variability, aim at resource efficiency, flexibility, and self-reliance.

*Reactive*: Technological innovation solutions are reactive, aim at controlling natural cycles, are rigid, and depend highly on resources inputs.

| **Scenario** | **Hydrological function** | **Infrastructure** |
|---|---|---|
| ■□<br>□□ | System collapse, reaching an early threshold due to droughts & flooding and reactive & rigid infrastructure. | Stepwise change provides minor improvements and are unable to substitute for lost hydrological function. |
| □■<br>□□ | Overall function decline is dampened. Thresholds delayed due to adaptive technologies and proactive approach. | Self-regulating infrastructure adapts to climate impacts and results in a sustainable level of service. |
| □□<br>■□ | Decline is significantly delayed by reduced impacts of climate change. Threshold is reached in third quarter. | Minor climate impacts leave more resources to expand on infrastructure. More improvements, but less effective. |
| □□<br>□■ | Optimum hydrological scenario adaptive technologies increase hydrological resliency and delay impacts. | Greater gains in efficiency coupled with minor disturbances produce high service levels. |

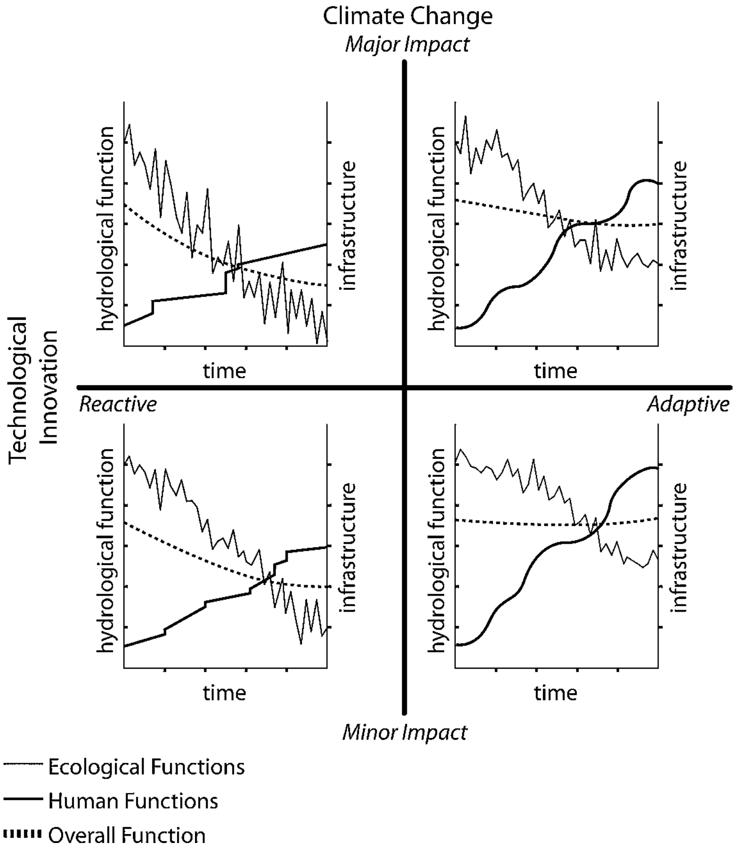

Figure 9.8. Alternative trajectories of hydrological functions under four scenarios.

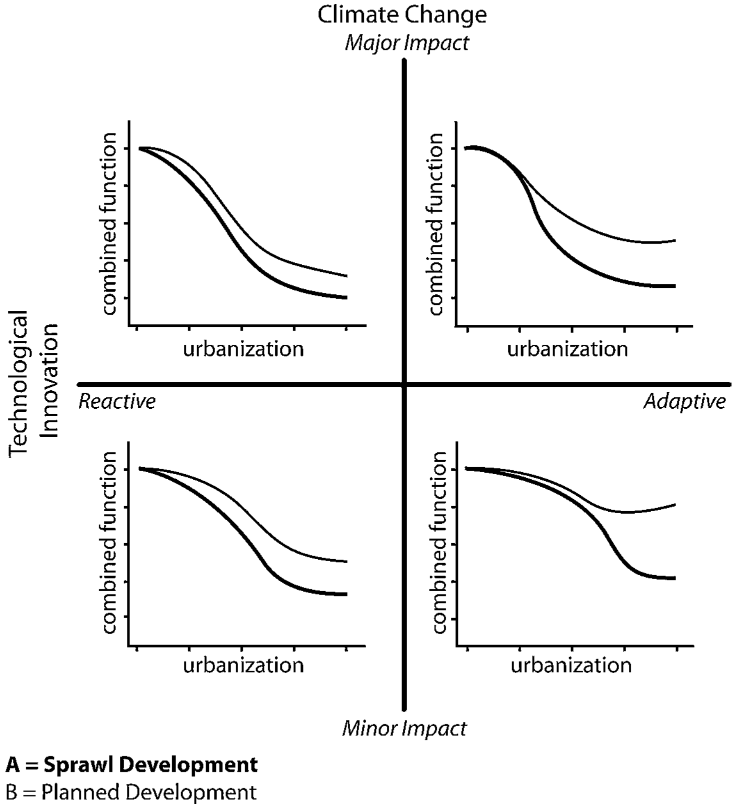

Figure 9.9. Relationships between urban development patterns and combined ecosystem and human functions under alternative scenarios. The graphs represent the hypothesized relationship between urban development patterns and combined human and natural ecosystem function under alternative scenarios to emphasize the potential role that urban form can play in minimizing environmental impact and increasing urban ecosystem resilience. Under all scenarios, sprawling development (A) will lead to reduced ecosystem function and, ultimately, will affect human function. Planned development (B) enables urban ecosystems to support increasing levels of urbanization. The effectiveness of planned development is dependent on the alternative scenarios.

How can we plan in the face of complexity, uncertainty, and heterogeneity? What can we learn from this hypothetical example? Six principles for planning and management emerge:

- *Resilience*. Focus on increasing system resilience instead of aiming to control system dynamic and/or to eliminate change.
- *Diversity*. Maintain diverse development patterns to enhance system resilience and to support a diversity of species and ecosystem functions.
- *Integration.* Minimize resource use and diversify resource supplies (e.g., water and energy), and invest in infrastructure that supports integration.
- *Learning.* Create buffers for error and opportunities for experimenting, updating, and learning about system function and thresholds.
- *Flexibility.* Create flexible policies that mimic the variability of environmental processes and the heterogeneity of human communities, and their evolution over time.
- *Adaptation.* Plan as designing a set of experiments, monitor progress, evaluate outcomes, and systematically adapt strategies.