Chapter 11

How to Make IAs More Adaptable

11.1 HIGHLIGHTS

In this chapter, we address how IA processes can adaptively anticipate and respond to the uncertainties associated with difficult problems in chaotic and complex environments. It is commonplace in IA literature and practice to emphasize that the IA process should be adaptive, flexible, and iterative. Specific means for accomplishing this aim are less evident. The major approaches advanced for managing uncertainties are controversial and only partially or indirectly connected to IA process management. This chapter provides a systematic, integrated approach to managing uncertainties in the IA process.

- The analysis begins with three applied anecdotes (Section 11.2). The stories describe applied experiences associated with efforts to make IA practice more adaptive.
- The analysis in Section 11.3 then defines the problem. The problem is a failure to adequately characterize and manage uncertainties in the IA process. In this section, we explain why it is necessary to formulate IA processes that adaptively manage uncertainties.
- In Section 11.4 we explore the potential roles in IA of difficult problems and complex and chaotic environments, uncertainty and adaptation, the analysis and management of risks, the precautionary principle, and human health.
- In Section 11.5 we detail how an adaptive IA process could be implemented at the regulatory and applied levels. In Section 11.5.1 we explain how regulatory requirements and guidelines can facilitate uncertainty management and adaptation. In Section 11.5.2 we describe how the uncertainty concepts, strategies, tactics, and approaches can be linked and combined in practice. In Section 11.5.3 we describe the characteristics of an adaptive IA process for different IA types.
- In Section 11.6 we address the contemporary challenge of climate change. We define key terms, draw major distinctions, describe a climate change impact assessment process, and summarize good institutional arrangements/capacity building and regulatory and applied level practices.
- In Section 11.7 we highlight the major insights and lessons derived from the analysis.

11.2 INSIGHTS FROM PRACTICE

11.2.1 Adapting Strategic CEA to the Needs of Institutional Partners

Initiated in 2001, the Transboundary Crown of the Continent Manager's Partnership (CMP) was formed to address cross-boundary cumulative environmental effects within the Crown of the Continent ecosystem, a shared region of the Rocky Mountains between Alberta and British Columbia, Canada, and Montana, United States of America. More than 20 government agencies responsible for land management in the region joined forces in a strategic partnership facilitated by the Mistakiis Institute at the University of Calgary. By pooling knowledge and resources, land use managers on both sides of the Canada–U.S. border planned to formulate strategic actions and partnerships to proactively influence developmental trends in their respective jurisdictions. The partnership was also motivated by a common need for strategic, landscape-level information to provide context for the assessment of individual project proposals.

The methodological approach to the strategic cumulative effects assessment initiative was straightforward: following the establishment of a collective regional vision for the future of the ecosystem, the partners contributed baseline and trend data to an ALCES (A Landscape Cumulative Effects Simulator) modeling initiative. ALCES is a "stock" and "flow" simulator of ecosystem dynamics that can assist in understanding how overlapping land uses and natural disturbance regimes can combine to alter terrestrial and aquatic landscapes over time. Using ALCES, the likely environmental effects of various regional development scenarios in the Crown of the Continent ecosystem were analyzed. Attempts to continuously improve the modeling exercise were made through ongoing regional collaboration.

This modeling-intensive approach to cumulative effects assessment was ultimately fraught with unanticipated

Impact Assessment: Practical Solutions to Recurrent Problems and Contemporary Challenges, Second Edition. David P. Lawrence.

roadblocks. When ecosystem-scale results were eventually produced, it proved difficult to translate them into field-level operational actions in the various jurisdictions. Further, the CMP found progress toward strategic goals hard to track due to the number of "puzzle pieces" involved. Unexpectedly, rapidly shifting regional baseline conditions, both environmentally and politically, rendered modeling results obsolete almost as fast as they were produced; perhaps most surprisingly, a curious form of political pushback occurred when the modeling exercise delivered results that were perceived as "pointing fingers" at certain interests and were ultimately unpalatable. This forced the CMP to abandon the original "effects prediction" approach in favor of a strategic initiative to establish regional environmental targets and thresholds for change. The switch ensured that partners retained a sense of autonomy in determining how to meet ecosystem management goals.

More than 10 years on, the CMP has shown remarkable adaptive propensity and persistence in the face of early challenges. The recently released 2011 Strategic Plan identifies five additional strategic initiatives including documenting ecological health trends and developing institutional capacity. This story demonstrates that significant thought must go into making impact assessments at the strategic level, not just practical, but adaptive. Strategic assessment is not simply assessment outside or "upstream" of a project context, as the CMP initiative was, but an assessment that adopts a strategic mindset with regard to institutional and political realities, which it eventually did. In this case, significant adaptations to the strategic assessment exercise were necessary so that, in effect, it was sensitized to the ability and willingness of partners to respond, not overreaching what was possible to do, given the current state of ecosystem management and institutional development.

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11.2.2 A Technically Driven Impact Assessment in an Evolving Social Environment

Environmental assessment of a new greenfield mining and industrial project in the small locality of Anitápolis, Southern Brazil is a story that spans over two decades, starting in 1989, when a first EIS was prepared. This initial EIA process was very conventional, as the EIS itself, and led to the project approval by the State environmental authorities. However, due to a U-turn in economic policy that made imported produce (fertilizer) much cheaper, the proponent didn't go ahead with construction. The project remained on the shelf for 15 years, when it was revived by a new proponent. In fact, the ownership of the parent company changed completely and the new management had no memory of the previous EIA process. More than that, they acknowledged that the most consistent information about the project was documented in the EIS, not in the company's files. The new proponent was a joint venture between two multinational corporations, each partner running their own operations in Brazil and abroad.

A project team was established and commissioned new engineering and environmental studies. A decision was made to hire the same environmental consultancy that had prepared the first EIS, largely due to the fact that individuals working for the firm held part of the project's memory.

The second EIS was prepared between 2005 and 2006, in parallel with engineering design. Environmental fieldwork updated and constructed a new baseline, capturing a few important changes. While the local economic basis remained virtually unchanged, a small municipality of ~5000 inhabitants featuring declining population (due to migration to the capital city) and small-scale agriculture, in the project's area the natural vegetation kept regenerating and parts of the property featured outstanding ecological value. Another change, whose implications were not adequately captured by the EIA team, was a slow shift toward a conversion of small rural properties into secondary or hobby farms and development of land into secondary housing estates.

Although the proponent's project team was prepared to make changes in project design to accommodate environmental mitigation, they were not attentive to initiating public involvement early enough. On the other hand, they were very keen on preparing a solid environmental assessment document and hired an experienced third party to review successive drafts of the EIS, aiming at filing an excellent document.

Similar care was not exerted toward communications with stakeholders. Many individuals in the host municipality featured positive expectations about the revival of the project, as they did in the late 1980s. By then, a new hotel had been built by a local investor to cater to the influx of people during construction, but this initiative was frustrated. Similarly, there was a hope that many new jobs could possibly be assumed by local people who had left for bigger cities. Hence, the rebirth of the project was positively received by part of the local community.

A different perspective was assumed by a group of residents in the neighboring municipality of Rancho Queimado. Situated in the mountain range near the capital city of Florianópolis, they were benefiting from a new rurality represented by the secondary residences and hobby farms and projecting a future of increased rural and ecotourism activities boosting the local economy. They saw a mine and an industrial plant, albeit situated 30 km downstream, as incompatible with such a bright future, especially because the project would induce increased truck traffic on the roads and possible correspondent truck drivers' services.

In between was the small rural locality of Rio dos Pinheiros, where most significant impacts would be felt. Locals voiced mixed feelings about the project. Acknowledging benefits in terms of jobs and increased access to services, they also felt that a few thousand construction workers would mean potential trouble for a very small community, as well as dozens of lorries circulating during the production phase.

On the other hand, a new law protecting the remnants or particular type of rainforest natural to the area came into force. In the 15+ years since the first EIS, the forest stand that would need to be felled, regenerated to higher conservation status, which made any approval for clearance more difficult.

The staff at the State EIA agency was well aware of the challenges and performed a careful review of the EIS. In the review process, they twice asked for supplementary information to be provided, but their standpoint was similar to the consultants: to perform technically sound tasks and to comply with relevant laws and regulations.

A public hearing was called for, heavily attended by citizens from every affected community. Only in preparation for this public hearing did the proponent seriously considered engaging with the public. But the proponent didn't look at the "public" as segmented into different groups of stakeholders, each with different perspectives, being differently affected by the project, and having different influence or leverage to influence the environmental licensing decision. This proved to be a fatal flaw.

Brazilian law entrusts public prosecutors to litigate in order to protect environmental and cultural values. Many systematically follow-up every EIA in their jurisdiction and it is not uncommon that lawsuits challenge the outcomes of the environmental approvals process, not only in terms of observance of legal procedures, but also in terms of contents of EISs. The best EIS will always be imperfect, baseline can always be more extensive and detailed, modeling more sophisticated, and mitigation more detailed (and expensive).

As opponents campaigned against the project, the prosecutor pressured for a second public hearing to be held and subsequently filed a lawsuit. After considering the case, the judge ruled that the license issued by the State should be dismissed. At the time of writing (mid-2012), one of the shareholders had been sold to a bigger mining company and no new developments are known.

The main message from this story is that it describes an EIA process that was very classical and technically led, but did not pay enough attention to stakeholder involvement and did not consider the failure risks (under the proponent's point of view) derived from judicial challenges. An early and thorough stakeholder mapping process would have provided the proponent with a more accurate picture of the potential beneficiaries, as well as of groups that could perceive themselves to be adversely affect by the project. In preparing the EIS, the consultant could have addressed the differentiated distribution of impacts over different social groups, looking for more focused mitigation.

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11.2.3 Understanding Policy Chaos Through the National Environmental Policy Act

The Bonneville Power Administration (BPA), a federal Power Marketing Agency for the Pacific Northwest region under the U.S. Department of Energy, needed to make a decision on how to achieve a comprehensive and consistent policy to guide the implementation and funding of its fish and wildlife mitigation and recovery efforts. After decades of spending billions of dollars on previous attempts to address the decline of some populations of fish and wildlife in the Columbia River Basin, some due to hydro generation, BPA needed a new policy strategy. The agency was spending over $100 million annually and species were still being proposed for protection listing. The major difficulties were coordinating attempts in the region where nine federal and four state agencies, over 50 Indian tribes, and numerous other pertinent interests struggled with their different and conflicting values and priorities; lack of clear and agreed-upon scientific answers; and conflicting directives and jurisdictions of regional authorities. Some form of a unifying strategy to assess a comprehensive and consistent policy fit well into the National Environmental Policy Act (NEPA) process. The Fish and Wildlife Implementation Plan Environmental Impact Statement (FWIP EIS, DOE/EIS-0312, April 2003) became the instrument to assess impacts and alternatives at the policy level, rather than the previously typical practice of proposing an uncoordinated series of program and project actions.

One of the many unique tools within the FWIP EIS was the *Policy Finder*. It represented the process for reviewing relevant regional actions by all major decision makers and creating a structured assessment of the perfunctory functioning regional policy. This process permitted BPA to break down the proposed actions in the individual regional plans and strategies and place them into a set of five BPA basic and distinctly different policy direction alternatives developed during the public scoping efforts; Natural Focus, Weak Stock Focus, Sustainable Use Focus, Strong Stock Focus, and Commerce Focus. Each basic policy alternative had a subset of the same 40 key issues that denoted the must have buy-in issues drawn from public participation of vested regional parties to be satisfied with a policy plan. By placing the proposed regional actions using this process, BPA was able to discern where the different regional plans and strategies fell within the five basic policy direction alternatives. This also highlighted how the regional entities' plans overlapped multiple policy directions and lacked fulfillment of all the key issues.

The final step of the Policy Finder process for BPA was to merge all of the assessed regional plans into a workable consolidated regional policy direction. It honed in on the heart of what policy direction or blend of policy directions were at work. BPA was then able to reasonably infer from this operational regional policy direction what missing key issues were needed to fully complete a comprehensive and consistent strategic policy. The culmination of this process was the development of BPA's own Preferred Policy Direction alternative. Not only could the Policy Finder be used to discover the working regional policy and a Preferred Policy Direction but it had the ability to, at any time in the future, to be used to recast what regional policy is at work and assist in modifying an agency's policy direction to correct for the changes. It also could be reversed and used as a desired policy direction to determine what types of proposed actions would be necessary to implement it.

The BPA Fish and Wildlife Implementation Plan Environmental Impact Statement policy finding process accentuates the ease and importance of understanding public policy and the human environment. Many federal agencies continue to face the lack of an undefined or unrecognizable policy at work in their area of influence and responsibility. The policy doesn't only have to be made up of government agencies but can also include what the private sector is promoting. It is less important that all parties agree to how their proposed actions are sorted than to have an understanding that they have been systematically distributed into key issues and the different basic policy directions drawn from a public process. Without a way of gaining this level of understanding for agency decision makers and the public concerning the current public policy atmosphere, proposed regional program and project actions go unchecked with regard to a comprehensive, consistent implementation plan. Additionally, this process leaves the agency with a more adaptable decision-making tool fueled by the ability to quickly and efficiently assess public policy and potential implementing programs and projects while understanding the human environment consequences within the context of the spirit and letter of the law for NEPA. This is truly a practical strategic environmental assessment process for informing both the agency decision makers and the public.

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11.3 DEFINING THE PROBLEM AND DECIDING ON A DIRECTION

The three stories address uncertainty in different ways. The first story describes a strategic cumulative environmental assessment that adaptively evolved in response to unanticipated methodological challenges and the changing needs and expectations of the major partners in the process. The process involved careful planning, institutional capacity building, a practical approach to problem solving, sensitivity to political resistance and database uncertainties, and an adaptive propensity and persistence in the face of rapidly changing conditions and major challenges. The second story illustrates the risks associated with a technically driven IA process that does not appreciate or mitigate potential sources of proposal failure, does not recognize changing institutional arrangements, is insensitive to varying stakeholder perspective and interests, and is unwilling or unable to adapt to an evolving regional context. The third story describes how a proponent learned from past mistakes and built on past successes. The process adopted made it possible to rapidly keep abreast of, integrate, and adjust to changing policies and requirements; to operate effectively in a complex, multistakeholder institutional environment; to fully integrate evolving public and private sector perspectives, concerns, and preferences; and to focus on key issues, obstacles, and opportunities. The three stories underscore the need for IA processes to be open and adaptive if they are to operate effectively in complex, rapidly changing decision-making environments fraught with uncertainty.

Uncertainty is about not knowing and about not being sure (Yoe, 1996). IA practice has been faulted both for being overly deterministic (i.e., unsupportable precision) and for being overly vague (i.e., a lack of precision). In the former case, uncertainty is not acknowledged or adequately addressed (Byer et al., 2009). In the latter case, vagueness stems more from a lack of effort to be precise than from an acknowledgement of uncertainty and its implications. IA practice tends to give limited consideration to uncertainties and errors (Byer and Yeomans, 2007; Tickner, 2003b). Instead, it tends to assume that a single number can represent the range of values potentially associated with a measured or predicted parameter (Carpenter, 1995). Such thinking fails to acknowledge or account for natural variation, knowledge gaps, or indeterminacy (Power et al., 1995). IA tends to operate under the illusion that present and future conditions can always be readily and precisely measured, predicted, and controlled (i.e., optimistic bias) (Gardner, 2010; Hodgson and White, 2001). The predictive models so prevalent in IA practice, moreover, tend to diminish the disclosure of uncertainty (Duncan, 2008). Often, decision makers and other stakeholders are not made aware of uncertainties or the nature of uncertainties and their implications are poorly communicated (Byer et al., 2009; Tennøy et al., 2006).

IA rarely understands the irreducibility of risks and uncertainties and generally fails to adopt unpredictability and incomplete control assumptions, even when addressing issues such as climate change, when effective uncertainty management is crucial (Byer et al., 2011; Govender et al., 2006). IA analyses and decision making, based upon such thinking, neither acknowledge nor explicitly consider uncertainty (Lobos and Partidário, 2010; Reckhow, 1994). Equally unacceptable are vague, unsupported, qualitative statements about current or future conditions (Culhane et al., 1987; Malik and Bartlett, 1993). Such statements provide the reader with minimal insight regarding what is known (or knowable) or unknown (or not known with precision). IA predictions tend to appear more certain than they are and the processes for deriving the predictions are often not transparent (Tennøy et al., 2006). False assurances of certainty are misleading. Vague and unsupported "musings" are similarly uninformative. IA approaches that employ unconnected indicators and that fail to address interconnections across disciplines inhibit and undermine the search for innovation, and adaptive and transdisciplinary solutions (Wiek and Binder, 2005). IA effectiveness reviews demonstrate that accurate forecasts, the use of confidence limits (as a means of acknowledging uncertainties), and monitoring (as a means of testing the accuracy of forecasts and the effectiveness of mitigation measures) are still more the exception than the rule (Culhane et al., 1987; Lobos and Partidário, 2010; Sadler, 1996). As IA practice is broadened to address new and critical issues such as climate change, the need to more effectively understand and manage uncertainties becomes much more critical (see Section 11.6).

Accepting the need to address uncertainties and for adaptive IA processes is only the beginning. Good practice uncertainty management principles need to be identified (Sadler, 1996). Dubious assumptions (e.g., equating vagueness with flexibility, assuming that reducing uncertainty will increase certainty) need to be avoided (Hodgson and White, 2001). Identifying uncertainty types and sources, characterizing uncertainty concepts, and formulating, adjusting, and applying adaptation approaches, methods, and concepts all require further attention. IA literature and practice often acknowledge the uncertainties associated with difficult issues and problems and with complex and chaotic environments. Reference is frequently made to matching the IA approach to the problem and the environment. Less attention is devoted to characterizing those problems and environmental conditions most prone to uncertainty and to exploring IA management implications.

Uncertainty is commonly coupled with risk as alternatives to certainty. Arguably, risk is a subset of uncertainty (i.e., a form of uncertainty to which probabilities can be attached). Risk, however, goes further in considering potential negative implications. Risk combines probabilities with harmful outcomes—to people, to property, and to ecological systems. The treatment of risk in IA guidelines and practice is often either superficial or highly variable (Eccleston, 1999b; Malik and Bartlett, 1993; Sadler, 1996). Increased attention has been given to if and how risk and more particularly, risk assessment and management could be linked and integrated with IA, although in practice IA and risk assessment are rarely used in a complementary manner (Barrow, 1997; Canter, 1993b; Carpenter, 1995; Demidova and Cherp, 2005; Erickson, 1994; Harrop and Nixon, 1999; Ugoretz, 1993; Westman, 1985). Although the need for IA to consider risk is broadly acknowledged, the merits of elements of risk assessment and management and whether and how the two fields might best be linked, integrated, or modified have been intensely debated. The debates extend to comparisons with alternatives to risk assessment and management (e.g., performance standards, semiquantitative hazards assessment). In recent years it has broadened to encompass alternative risk, uncertainty, and health effects management approaches (e.g., human health impact assessment, the precautionary principle, adaptive environmental assessment and management, emergency planning and management)—approaches that could provide a framework for, be subsumed within, or represent an alternative to risk assessment and management.

The precautionary principle has been identified as a sustainability principle (Sadler, 1996). It is integrated into IA requirements in some jurisdictions (Australia and Europe, for example), although implications have yet to be fully determined. There are, however, numerous definitions, a host of positions concerning potential IA and decision-making roles, and a lengthy list of ascribed advantages and disadvantages. Adaptive environmental assessment and management (AEAM) blends scientific, ecological model building with adaptive, heuristic group planning and decision making. It has been widely applied in environmental and resource management, although frequently only partially and sometimes with mixed results. AEAM has been identified as an effective approach to uncertainty management in IA (US CEQ, 1997a). As with the precautionary principle, there is an intense debate surrounding AEAM. Its potential IA practice roles and attributed strengths and deficiencies are often overstated.

Harm, in the sense of human health effects, is a component of risk. Although human health risk is invariably a major public concern, human health effects are often not or are only superficially, partially, inconsistently, and inadequately addressed at both the SEA and project EIA levels (Arquiaga et al., 1994; BMA, 1998; Bond et al., 2011; Canter, 1990; Davies and Sadler, 1997; Dora, 2004; Harris and Spickett, 2011; Noble and Bronson, 2006; Ortolano and Shepherd, 1995; Steinemann, 2000). IA guidelines tend to devote limited attention to health concerns or define health issues very narrowly (Sadler, 1996). The propensity to equate health-related concerns with environmental standards ignores the health implications of substances and processes not covered by standards (Arquiaga et al., 1994). HIA is rarely applied at the policy level (McCaig, 2005). The treatment of the nature, significance, and distribution of health effects, at both the EIA and SEA levels, generally falls well short of good practice standards (Kørnøv, 2009). When it is applied, the tendency is to focus on positive impacts and to ignore or superficially address negative impacts (Kauppinen and Nelimarkka, 2004). A major response to these types of deficiencies has been health impact assessment (HIA). Several jurisdictions have issued HIA guidelines in recent years (Enhealth Council, 2001b; IPHI, 2001; Health Canada, 2004; WHO, 1987, WHOROE, 2001a,b). The effectiveness of these guidelines is yet to be determined. HIA institutional relationships, the relationship between HIA and other forms of impact assessment, and the relationships between HIA and other risk and uncertainty management approaches require additional attention. HIA practice needs to more proactively influence the choice of preferred options rather than just mitigate the adverse effects of predetermined proposals (Fischer et al., 2010).

The problem then is a combination of confusion regarding the nature of uncertainty and the related concepts of risk and health effects and ambivalence concerning the most appropriate approach (or combination of approaches) for managing uncertainties in the IA process. The direction, as illustrated in Figure 11.1, is: (1) to classify the types of problems commonly associated with high levels of uncertainty; (2) to identify the relevant properties of chaotic and complex environments and systems; (3) to describe uncertainty sources, types, and concepts; (4) to provide an overview of general adaptation strategies and tactics; (5) to explore the role of uncertainty in adaptive IA processes; (6) to describe adaptive environmental assessment and management and potential IA process links; (7) to

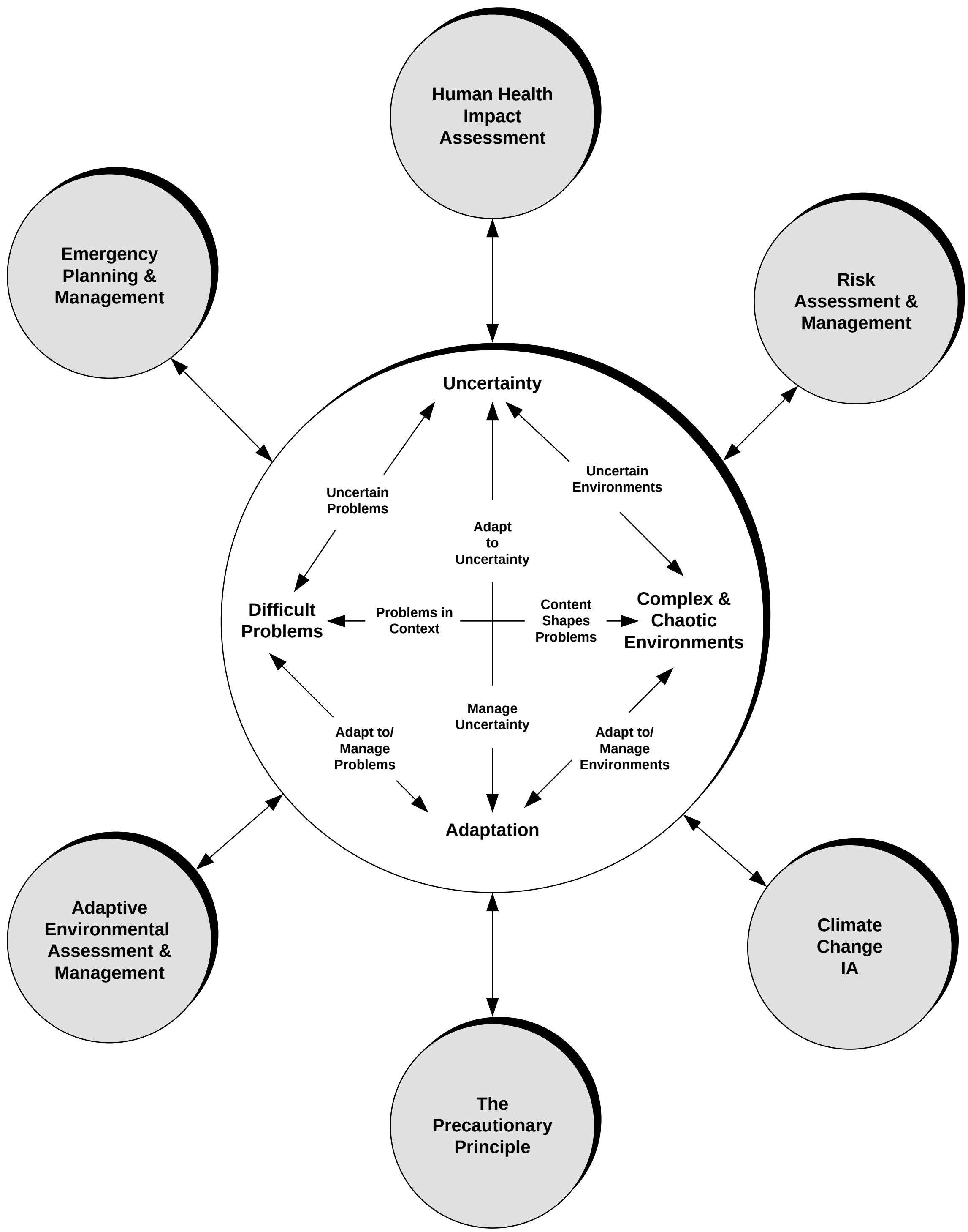

Figure 11.1 Examples of uncertainty management elements.

describe risk assessment and management and potential IA process relationships; (8) to address the treatment of emergencies in IA practice; (9) to describe the precautionary principle and potential IA process roles; (10) to describe human health impact assessment and potential IA process connections; and (11) to address the treatment of climate change in IA practice. These analyses collectively provide the basis for adaptive IA process management at the regulatory and applied levels.

11.4 SELECTING THE MOST APPROPRIATE ROUTE

11.4.1 Difficult Problems and Complex and Chaotic Environments

Difficult Problems The impetus for an IA process is often a desire to solve a problem or take advantage of an opportunity (the opposite of a problem). Problems and opportunities also arise during the IA process. A problem has the following general properties: (1) a question, an issue, or a situation triggers the problem; (2) it has negative connotations (e.g., it is perplexing, vexing, or distressing), and (3) it needs to be dealt with, solved, or addressed. Perceptions of the incidence and nature of problems vary among stakeholders (i.e., problems are subjective) (Cartwright, 1973). Problem-solving processes often begin by identifying, describing, defining, bounding, and stating the problem (Bardwell, 1991; VanGundy, 1988). The initial problem statement is progressively refined through the process. IA practice frequently assumes that the problem is "obvious," that the proposed action will "solve" the problem and that additional problems will not arise. More attention to problem delineation in IA could reduce such recurrent mistakes as solving the wrong problem, stating the problem so it cannot be solved, solving a solution, stating the problem too generally, and trying to obtain agreement on the solution before there is agreement on the problem (International Associates, 1986).

IA, planning, and environmental management problems tend to fall within four broad, overlapping categories: (1) simple or tame problems; (2) compound or semistructured problems; (3) complex or ill-structured problems; and (4) crises or metaproblems (Cartwright, 1973; Miller, 1993; VanGundy, 1988). Uncertainty progressively increases from Level 1 up to Level 4. The adverse consequences of uncertainty are particularly acute at Level 4. IA practice has tended to focus on or to assume Level 1 and 2 problems. Conventional IA approaches are poorly suited to addressing Level 3 and 4 problems, defined here as difficult problems. Table 11.1 outlines several concepts relevant to difficult problems. An adaptive IA process should be designed to cope with difficult problems.

Simple or tame problems are well defined. Ends can be readily established. Much is known about environmental conditions, technologies, methods, and available alternatives. Simple problems can generally be resolved with standardized, often quantitative, procedures and methods. Some but not all the parts are known with compound or semistructured problems. There may be varying perspectives regarding ends. There are likely to be a mix of calculable variables, uncertainties, knowledge gaps, and surprises. Routine procedures will not suffice. Additional analyses are required to fill data gaps. Experimentation, innovative approaches, and practical procedures are needed to deal with new, emerging, and unanticipated issues. Frequent and ongoing stakeholder consultation, mediation, and bargaining are required to cope with varying and conflicting perspectives, values, and interests. Well-defined and managed "good practice" IA procedures are generally adequate for compound or semistructured problems.

High levels of uncertainty and variability and low levels of understanding and control characterize complex or ill-structured problems. Complex problems are dynamic, interdependent, "messy," ambiguous, unique, and real. They involve multiple variables, interactions, and interdependencies. They often defy simplification. Models of complex systems and problems frequently fail to capture critical components and interrelationships. Analytic science and rational/synoptic planning tend to be poorly suited to complex problems. Complex problems are often less amenable to quantification. The past is of limited value either in understanding the present or as a basis for prediction. Ends are not agreed to and means are not known. There are usually multiple perspectives concerning which methods best suit complex problems. Many uncertainties cannot be understood with additional analysis nor effectively managed with "good practices." Complex problems transcend disciplinary boundaries. They often extend over broad geographic boundaries, involve multiple jurisdictions, and are long term. Traditional hierarchical institutional structures and analytical methods rarely cope well with complex problems. Complex problems can be ameliorated but not solved. They require creative approaches tailored to their unique and changing characteristics. Flexibility and adaptability are essential to anticipate and accommodate change and surprise. Scientific approaches that transcend individual disciplines (e.g., trans-scientific, postnormal science, complexity science) are more appropriate when addressing complex problems. Conventional IA approaches are not well suited to managing complex problems.

Metaproblems or crises are more than difficult or even intractable—they are deadly or "wicked." Crises take many forms and are often interdependent. Efforts to address metaproblems frequently encounter paradoxes, dilemmas, and contradictions. Metaproblems are impossible to fully understand or manage. Untended, they can rapidly become disasters or catastrophes. No experimental intervention is consequence free. Incremental adjustments and other adaptive behaviors can exacerbate the problem or even trigger an irreversible chain of deadly consequences. Crises often emerge or occur because of a widening gap between the

Table 11.1 Examples of Difficult Problems

Real Problems

- Problems that exist in the real world
- Principal characteristics—large size, high spatial and temporal variability, not conducive to experimental control, ambiguous and poorly defined

Complex Problems

- Occur in systems where there are multiple interactions among numerous variables, there are many unknown variables and relationships are hard to identify and understand
- Absence of deterministic and complete information about the options, impacts, and interest groups; also multiple interests and multiple and often conflicting objectives and perceptions of problem
- Implications—only superficial control over problems, character of problem often misunderstand, not possible to address problems through training, past nor a good guidepost for future and many social and economic hierarchies unworkable

Transboundary Problems

- Effects cross-jurisdictional boundaries (within or among countries) or affecting global commons
- Multiple jurisdictions, each with different priorities
- Need to create new institutional mechanisms to address; tension because of fears regarding loss of sovereignty

Trans-scientific, Postnormal Science, and Complexity Science Problems

- Crosses and transcends disciplinary boundaries
- Not amenable to analytical scientific methods
- Requires intelligent scanning; succession of judicious nudges
- Addresses situations where facts are uncertain

Paradoxes, Dilemmas, and Contradictions

- Paradox—variety of meanings—(1) something that appears contradictory but that is true; (2) something that appears true but that is contradictory; (3) a series of deductions from a self-evident starting point that leads to a contraction
- Both visual and linguistic paradoxes
- Example—arrow impossibility theory—demonstrates that no method of combining individual preferences to produce a social choice that meets all democratic choice conditions

Impossibilities/Insoluble/Intractable Problems

- Cannot discover all truths
- Types—incompleteness, undecidability, logical and practical impossibilities and technological, cosmological, human and deep limits

Wicked/Messy Problems

- No definitive formulation; no stopping rule; solution are not true or false or good or bad; no immediate and no ultimate test of a solution; every solution is a "one shot" opportunity, because there is no opportunity to learn by trial and error, every attempt counts significantly; do not have an enumerable or an exhaustible describable set of potential solutions, nor is there a well described set of permissible operations; every wicked problem is essentially unique; can be considered a symptom of another problem; the existence of a discrepancy representing a wicked problem can be explained in numerous ways—the choice of explanation determines the nature of the problem's resolution; the practitioner has no right to be wrong
- Involves complex and dynamic situations of changing and interdependent problems
- Analysis and solutions cannot be standardized into general laws or theories; cannot be managed through traditional analytical science

Latent Time Bombs/Catastrophes/Crises

- Latent time bombs—potentially major, sudden disasters such as earthquakes, droughts, floods, or financial collapse; can be interpreted spatially and temporally and can take many forms (e.g., physical, ecological, social, and economic)
- Concerns major events, predictions about them are credible, early intervention is understood to be possible and potentially beneficial, costs associated with advance preparation are significant and highly visible
- Catastrophes—as move through a family of functions a stable fixed point of the family loses its stability; this change of stability forces the system to move abruptly to the region of a new stable fixed point
- Tendency of governments to take action after, rather than before, threatening events occur because of the need to engage in cost distribution

Ingenuity Gaps

- A shortfall between the rapidly rising need for ingenuity and adequate supply
- Problems intrinsically harder to understand and knowledge slow to develop; result critical time lag between problem recognition and delivery of sufficient ingenuity; converging complexities and connections result in need for high-speed decision-making and associated management difficulties
- Human knowledge and ingenuity progress at different rates in different domains; impeded by human cognitive limits, intrinsic complexity of subject matter, nature of scientific institutions and slow and unwieldy economic, social, and political systems
- Roles for markets, science, and democracy but failures and constraints associated with each (e.g., market failures, cognitive limits, varied rates of scientific progress in different domains, rising costs, political gridlock and corruption, social turmoil)

Sources: Allen and Gould (1986), Barrow (1998), Casti (1994), Dery (1997), Gasparatos et al. (2007), Homer-Dixon (2000), Patterson and Williams (1998), Rittel and Webber (1973).

need for and supply of ingenuity. Early intervention is possible, potentially beneficial, but costly. Markets, science, and democratic institutions can all contribute to avoiding, ameliorating, and staving off crises but all have limitations, some profound. Crises require a unique mix of sustained ingenuity, commitment, institutional reform, capacity and network building, leadership, high-speed decision making, and precaution. The likelihood and severity of crises can be reduced, sometimes delayed, and occasionally reversed. Major uncertainties will remain, notwithstanding best efforts. Conventional and even "good practice" IA approaches tend to fare poorly when coping with metaproblems and crises.

Complex and Chaotic Environments It is often stated that IA processes should match the environment or the context. Environment or context generally encompasses ecological, political, social, economic, institutional, and technological components and systems. Some context types are more uncertain than others. Classification systems for environments, contexts, situations, systems, or futures generally involve a continuum from the simple to the highly complex (Barrow, 1998; Hodgson and White, 2001; Trist, 1980). Simple systems have a limited number of variables and interactions and a slow and usually, predictable pace of change. Such systems are not commonly constrained by human or natural limits. Command and control management approaches tend to work well in such situations. Intermediate levels have greater complexity, more interactions and interdependencies, and a higher level of uncertainty. Decision making is more constrained by environmental conditions. Operating in such environments requires effective planning, consultation, and coordination. Turbulent, complex, and interdependent systems are very difficult to understand, predict, or influence. Decision making in such environments is more effective when oriented toward social learning, judicious experimentation, and the proactive anticipation, review, and selective management of risk, error, and uncertainty.

Context classification systems closely parallel those for problem types. Not surprisingly, the most difficult situations encountered in IA practice often involve a combination of difficult problems in complex and chaotic environments. In such cases the problems and the context are poorly defined and overlapping. Practitioners and decision makers face the double dilemma of not knowing when to begin (i.e., separating the problem from the context) and not knowing when to end (i.e., no "stopping rule" for determining that the problem response has been adequate). The related concepts of chaos and complexity are highly relevant to IA practitioners seeking to operate in highly uncertain environments. Table 11.2 outlines some key properties of chaotic and complex environments. Simply put chaos involves lower level order (i.e., system apparently governed by a small number or rules) that evolves into higher level disorder or randomness (i.e., rules are transcended at the higher level). Chaotic systems are highly sensitive to initial conditions. Complexity begins with disorder or randomness but order emerges. Such self-organizing behavior results from feedback mechanisms. Complex systems can be organized or disorganized. They involve multiple variables, interactions, and interdependencies. Chaotic systems are not always complex. Complex systems are often chaotic. Both chaotic and complex systems evolve, often abruptly, in unpredictable ways. Both tend to be irreducible, incomputable, irreversible, incoherent, unstable, dynamic, and nonlinear. Errors and surprise are inevitable with complex and chaotic systems.

Table 11.2 Examples of Characteristics of Chaotic and Complex Environments and Systems

Chaos—General

- Order without predictability; deterministic randomness
- Characteristics—outputs transcend rules, local rather than system order, self-referential, sensitive to initial conditions (the Butterfly Effect), loss of information about initial conditions; basic cause–effect processes still operate among system components but interactions over time and large-scale behavior unpredictable; some systems flip back and forth between chaos and order
- Chaotic systems not always complex (chaos can be observed in simple systems)
- Analysis and interpretation implications—impossible to know a system's exact initial state (incomputable), prediction logically impossible, errors of measurement and calculation inevitable, amplifies uncertainties, impossible to infer from its present state how it got there, can never be fully understood, surprise inevitable, strategy of breaking down whole into components does not apply, value of introspection, humility and pluralism, recognizes that the world infinitely complex and the human mind fallible
- Planning and management implications—ensemble of forecasts and simple models, sensitivity analyses applied to initial state, look for patterns of system behavior, local and incremental predictions, planning as a succession of judicious nudges rather than a step-by-step recipe, unlike natural systems humans can learn and can change behavior to avoid chaos, underlying systems cannot be reduced to equations, future will be determined by an almost infinite array of interlocking contingencies

Complexity—General

- Intricate tangles of shifting and often opposing forces that unfold in unpredictable and frequently surprising ways
- Complex systems not always chaotic but common in complex systems
- As complexity rises, precise statements lose meaning and meaningful statements lose precision
- Slightest error in knowledge of initial state eventually grows
- Complex systems tend to be highly decentralized; end result—large number of local choices and bottom-up information flow

Table 11.2 (*Continued*)

- Characteristics—multiple variables, interactions and feedback, and feed-forward loops; absence of deterministic information, acausal, diffuse authority, new laws come into play when the level of complexity increases, sensitive to the smallest changes and perturbations, behavior can flip from one mode to another suddenly and dramatically, openness to outside environments, global behavior outlasts behavior of component parts and exhibits different characteristics at different scales
- Types—disorganized complexity (millions or billions of variables only approached by statistical mechanics or probability theory), organized complexity (moderate number of variables but all variables interrelated)
- Critical processes—coevolutionary diversity (competition and interdependence of system entities), structural deepening (individual entities become steadily more sophisticated to improve performance) and capturing software (systems take over or task simpler systems)
- Analysis and interpretation implications—counterintuitive behavior of system, as complexity increases not only limited but self-limiting (theory predicts cannot predict), current events heavily influence the probabilities of many kinds of later events, increasing model complexity does not necessarily lead to error reduction, objectivity and subjectivity must be in balance and inform one another, usual statistical approaches may be misleading, variance in outcomes may be enormous
- Planning and management implications—unable to predict or manage the behavior of complex systems, results in confusion and sometimes fear, importance of ability to switch between different modes of behavior as environmental conditions are varied, resulting flexibility and adaptability introduces notions of choice and of collective or social learning, still possible to make general warnings, can explore possible scenarios and expose fragilities but no mathematical model may exist to tell how system will behave, expected harm may be higher than medium, potential for nasty surprises, characteristics support a precautionary approach to risk management, as understand system dynamics can move to adaptive management

Self-Organizing

- A self-organizing system produces complex organization from randomness without external intervention; self-organizing systems use feedback to bootstrap themselves into a more orderly structure
- In self-organizing systems, orderly patterns emerge from lower level randomness; opposite of chaotic systems where unpredictable behavior emerges out of lower level deterministic rules
- If equilibrium of self-organizing systems destroyed pushes system to edge of criticality and perhaps chaos
- Complex systems have a tendency to organize themselves into critical states that are optimally sensitive
- Self-organizing/self-learning; intelligence builds from bottom-up; macrointelligence (system learning) and adaptability derive from local knowledge
- Elements renew and reorganize after change; adaptive capacity resides in memory, creativity, innovation, flexibility, and diversity
- Properties (e.g., the whole is greater than the sum of the parts, self-controlled within larger scale constraints, they evolve)
- Aim of management should be to enhance the capacity of the system for self-management, with active management being used to steer it away from large discontinuities

Emergent

- Properties of a system that the separate parts do not have; the idea that simple elements that are governed by a few simple rules and operate through trial and error with interaction and feedback can produce persistent and systematic patterns that are quite unlike the original elements
- Complex structures seem to display thresholds that, when crossed, give rise to sudden jumps in complexity
- Rarely a smooth, steady increase in the consequences of similar changes in complexity
- Emergent properties cannot be computed
- Self-organizing; dependent on feedback loops
- Emergent system-design principles—more is different (critical mass), ignorance is useful (better to build from simple elements), encourage random encounters, look for patterns and pay attention to neighbors (local information can lead to global wisdom)
- A top-down analytical approach (dissecting whole into parts) will miss emergent or synergistic properties
- Making an emergent system more adaptive generally entails tinkering with different kinds of feedback (positive and negative)
- Emergent organizational systems (e.g., a more cellular, distributed network of small units) tend to be more innovative and adaptable to change than hierarchical models
- Recognizes emergent issues and environmental threats, considers emergent strategies and prioritizes early warning

Turbulent/Unstable/Dynamic

- Turbulence—the apparently random eddying and twisting of the flow; a special case of chaotic behavior
- A dynamic system is in constant flux; the higher its variety, the greater the flux
- Instability and commotion are common

Nonlinear/Feedback

- A change in a system can produce an effect that is not proportional to its size
- Does not obey the laws of addition; generally produces complex and frequently unexpected results
- Small changes can produce large effects; large changes can produce small effects
- Feedback involves some element of the system looping back on itself and either driving the effect up or dampening it down
- Often a consequence of positive feedback, which tends to amplify small perturbations

(*continued*)

Table 11.2 (*Continued*)

- Characterized by multiplicative or synergistic relationships among components or variables
- Entails nonlinear knowledge generation and social learning

Irreducible/Synergistic/Irreversible/Antagonistic

- Nonreductionist; behavior cannot be decomposed into parts
- Synergy—whole more than sum of parts
- Antagonism—whole less than the sum of parts (offsetting)
- Irreversible—the one way time evolution of a real system
- Irreducible risks and uncertainties

Variable/Random/Heterogeneous

- The number of possible states of a system is called its variety; a measure of complexity in a system
- Inherent randomness or variability (stochasticity); difficult to reduce because an inherent characteristic of system being assessed
- A population's natural heterogeneity or diversity, particularly that which contributes to differences in exposure levels or in susceptibility to the effects of chemical exposures
- In risk assessment arises from differences in the nature and magnitude of a population's exposure to hazards and from variations in people's susceptibility to hazardous exposures; quantities vary from time-to-time and place to place
- The only thing that control variety is more variety; variety absorbs variety (Ashby's Law—The Law of Requisite Variety)
- Randomness—uncertainty that is impossible to reduce

Incoherent

- Aspirations and activities do not integrate with one another
- Do not cohere conceptually, operationally, linguistically, or socially
- Function of forecasts and planning—to enhance focus, direction—coherence—for whatever ends

Unpredictable/Surprise/Incomplete Control/Uncomputable

- Chaotic systems are unpredictable (lack of predictability inherent rather than situational); starting situation is never the same between two circumstances; outcome can never be predicted and solution to achieve the desired outcome will need to be created in each new situation
- Complex systems are deterministic but not predictable or manageable
- Uncomputable—systems that cannot be accurately modeled using equations
- Need to accept the fact that what we would like to predict will forever be unpredictable
- Interventions should accept unpredictability and design for surprise

Interdependent

- An increasingly interdependent world
- A dense web of causal connections among components
- Interdependencies of social and natural systems
- The density, intensity, and pace of interactions sharply increases with complex systems
- Positive (reinforces or amplifies initial change) and negative (counteracts the initial change) feedback among system components

Resilience and Stability

- Resilience determines the persistence of relationships within a system in the face of sharp and unexpected external pressures
- Stability is the ability of a system to renew, reorganize and return to an equilibrium state after a temporary disturbance; it is quantified in terms of return time
- Part of resilience is the potential to create innovation opportunities
- Other definitions emphasize conditions with more than one stable equilibrium, where instabilities can flip a system into another regime of behavior
- A concept that relates to a system's ability to absorb, cope with and benefit from change, without losing its basic integrity
- Originally developed in an ecological context but since applied to economic, social, and political systems
- Policy design criteria—maintain different distinct modes of behavior because of rather than despite variability; the more that variability in partially known systems is retained the more likely it is that both the natural and management parts of the system will be responsive to the unexpected (i.e., adaptive capacity)

Sources: Axelrod and Cohen (1999), Barrow (1998), Calow and Forbes (1997), Carpenter (1995), Cardinall and Day (1998), Cartwright (1991), Casti (1994), Cherp et al. (2007), Coveney and Highfield (1995), Croal et al. (2010), Dearden and Mitchell (1998), Dimento and Ingram (2005), Donnelly et al. (2007), Duncan (2008), Farber (2003–2004), Gardner (2010), Gibson (2011), Gleick (1988), Govender et al. (2006), Greene (1999), Grinde and Khare (2008), Hermans and Knippenberg (2006), Hodgson and White (2001), Hollick (1993), Homer-Dixon (2000), Jasonoff (undated), João et al. (2011), Johnson (2001), Innes and Booher (1999), Michael (1989), Nicolis and Prigogine (1989), Nooteboom (2007), Orwell (2007), PCCRARM (1997b), Radford (1988), Rothman and Sudarshan (1998), Rotmans (2006), Rowe (1994), Slootweg et al. (2010), Suter (1993), Stern and Fineberg (1996), Tickner (2003b), Treweek (1999), Trist (1980), Yoe (1996), US ACE (1992), US EPA (1998c).

There are no standardized approaches to operating in chaotic and complex environments. It is prudent to be sensitive to initial conditions, to behavioral patterns at the local level, and to interdependencies. Confusion, fear, and surprise should be expected. An ensemble of simple models, in combination with local, incremental predictions are likely to provide more insights than a single, grand model and long-term system-level forecasts. Variety should be matched to variety. Multiple sensitivity analyses (i.e., tinkering with positive and negative feedback mechanisms) can reveal critical interdependencies and potential thresholds. Adaptability and creativity are essential. A cellular network of small organizational units is usually more innovative and flexible than hierarchical models. Organizational and social learning, synthesis, and the capacity to respond quickly as conditions change are attributes to be fostered. Limits, errors, risks, and uncertainties should be priorities. Approaches that selectively intervene to enhance the self-management capabilities of systems, that maintain and reinforce resilience, and that steer systems away from large discontinuities are often more appropriate. Approaches that evolve and change in parallel with complex and chaotic systems are more likely to be effective in coping with uncertainty.

11.4.2 Uncertainty and Adaptation

Uncertainty Uncertainty, broadly defined, is any situation where we are not absolutely sure (i.e., the opposite of certainty) (Yoe, 1996). There is doubt, incertitude, or lack of clarity. There may be an absence of knowledge (something is not known or knowable), knowledge may be partial, or knowledge may be imprecise. Uncertainty, narrowly defined, focuses on situations where the direction or system characteristics are known but the nature of the outcome or its probability is unknown (Carpenter, 1995; Dearden and Mitchell, 1998; Hyman et al., 1988). Risk is included where probabilities can be ascertained. This analysis (i.e., risk as a subset of uncertainty) applies the broader definition. With both risk and uncertainty, it is largely a question of degree (of certainty or uncertainty), with overlapping or highly permeable boundaries between the two concepts. Interpretations of when there is uncertainty and how much uncertainty exists are subjective, social, and political (Gullett, 1999).

Uncertainty is ubiquitous and unavoidable in environmental decision making and in IA practice because humans operate in complex, unpredictable, and uncertain systems, and because IA is inherently concerned with a difficult to predict and manage future (Gibson, 1992; Tennøy et al., 2006; Tickner, 2003b; Tonn, 2000). Uncertainty is not well understood. As Tonn points out, there can be (1) too much uncertainty (inadequate effort to reduce), (2) too much certainty (a failure to consider the consequences of inaccurate predictions), (3) conflicting perspectives on certainty and uncertainty, (4) misrepresented certainty, (5) misunderstood uncertainty, (6) the confounding of uncertainty and values, and (7) a lack of foresight (Tonn, 2000). Uncertainties occur throughout the IA process (Gibson, 1992). Not acknowledging uncertainties or addressing uncertainties with simplistic and unsupported "safety factors" can impair decision making and contribute to inequities (e.g., increased uncertainties in the lives of the weak) (Cardinall and Day, 1998; Marris, 1996). Explicitly addressing uncertainties and, by extension, follow-up is essential to good IA practice (Government of Canada, 2001; Sadler, 1996; Yoe, 1996). Paralysis is not inevitable (Gibson, 1992). Uncertainty analyses help hedge away from large losses and aid in avoiding and reducing the potential for nasty and tragic surprises (Gibson, 1992; Reckhow, 1994). An uncertainty-oriented IA process is necessarily flexible, adaptive, and iterative. Flexibility (anticipating and rapidly adjusting to changing conditions) and iterative (linking IA activities and stages with feed forward and feedback loops) are commonly identified as good practice principles (IAIA, undated b, Sadler, 1996).

There are many uncertainty forms. Uncertainty can be quantitative or qualitative, objective or subjective, shallow or deep/extreme (CEC, 2000; Dearden and Mitchell, 1998; US ACE, 1992). There can be scientific or methodological uncertainties concerning the choice of parameters, the measurements made, the conditions of observation, the samples drawn, the models used, and the causal relationships employed (Carpenter, 1995; CEC, 2000; CRAM, 1993; Rowe, 1994; US EPA, 1998c, 1999). Perceptions of uncertainties often vary between scientific and technical specialists and lay observers (Grima et al., 1986). There can be substantive knowledge or epistemological uncertainties regarding organizational or environmental systems (Cardinall and Day, 1998; Friend and Hickling, 1997; Mostert, 1996; US EPA, 1998b,c). Knowledge uncertainties can sometimes be reduced through additional analysis but also can be inherent (i.e., fundamental limits to our knowledge of the world) (Tonn, 2000). Uncertainties can pertain to the past, to the present, or to the future (Rowe, 1994). There can be uncertainties concerning guiding values and desires, especially when values, perspectives, and interests conflict, interact, and change (Cardinall and Day, 1998; Friend and Hickling, 1997; Tonn, 2000). There can be contextual uncertainties (e.g., technology, infrastructure, politics, the perceptions and interests of actors) and operational uncertainties (e.g., related to IA process) (Lyhne, 2009).

Many sources can contribute to uncertainty. There can be a lack of data, knowledge, experience, or understanding (Carpenter, 1995; US ACE, 1992; US EPA, 1998c; Yoe, 1996). Theories, explanatory paradigms, methods, and models can be inadequate (Carpenter, 1995; US ACE, 1992; US EPA, 1998c; Yoe, 1996). Time, expertise, and other resources can be insufficient (Carpenter, 1995). Analyses can lack focus because of an absence of direction or poor management (US ACE, 1992). Institutional capacity constraints, or deficiencies in IA requirements and guidelines can contribute to uncertainty (Mostert, 1996). Uncertainties can be exacerbated by poor communications, errors, bias, conflict, and dubious judgments (Carpenter, 1995; Rowe, 1994; Treweek, 1999; US EPA, 1998c; Yoe, 1996).

Uncertainties can result from inherent variations, changing proposal characteristics, randomness, and the multiplicity of intervening variables associated with complex systems (Carpenter, 1995; US EPA, 1998c; Yoe, 1996).

Novel situations and new technologies, materials, and methods tend to be especially uncertain and prone to surprise (Carpenter, 1995). Uncertainty is generally heightened as analysis scales are increased, as time horizons are extended, and as study schedules are abbreviated. Uncertainties in IA can pertain to systems functioning and to cause–effect chains (Seidler and Bawa, 2003). Examples of uncertainty sources, often evident at the SEA level, include natural environmental variability, predicting future conditions, determining carrying capacity, understanding environmental behavior, data inadequacies, future technological changes, socioeconomic conditions, changes in political and economic priorities, how strategic actions will be integrated into projects, unanticipated changes during implementation, effects from other strategic actions and projects, model simplifications, errors in modeling application, analysis and interpretation uncertainties, how results are presented, and value judgments (João, 2007). Uncertainty is often introduced into IA by means of decision rules. Examples of uncertainty-related decision rules include minimizing the maximum regret, maximizing the minimum outcome, and providing for a mix of optimism and pessimism (e.g., Hurwicz alpha criterion) (Byer et al., 2011).

Table 11.3 briefly describes several key uncertainty-related concepts. Recognizing ignorance or lack of knowledge can be humbling. It acknowledges inevitable knowledge gaps. It can stimulate efforts to reduce knowledge deficiencies. Errors and bias will always occur in IA practice. It can be helpful to understand the different types of errors that can occur, to be sensitive to the conditions that contribute to errors and bias, to focus on those types of mistakes likely to have the most serious implications, and to proactively anticipate, minimize, and correct mistakes and bias. Indeterminism and inconclusiveness underscore the limits to uncertainty reduction and the need to ensure that conclusions are not more definite than supporting analyses.

Table 11.3 Examples of Uncertainty Concepts

Ignorance/Incomplete Knowledge

- Lack of knowledge; not all outcomes are known; also ignorance of own ignorance (don't know what don't know)
- Scientists surprised by the outcome; they do not know, but, with hindsight, can usually explain it
- Two faces—positively—a humble admission that we don't know what we don't know; negatively—the practice of making decisions without considering uncertainties
- Cure—obtain knowledge (e.g., education, training, talking to experts, acquiring experts through hiring, contract or coordination)
- Culpably ignorant—need for certain supplementary specific information or measures to avoid harm recognized but failure to obtain

Errors/Mistakes/Bias

- Type I errors (false positives—concluding that there is an effect when, in fact, there is none); Type II errors (false negatives—concluding that there is no effect when, in fact, there is); Type III errors (wrong problem)
- Errors of measurement, calculation and judgment
- Bias in data acceptance (can treat research too leniently or too harshly) and bias in data interpretation (e.g., overemphasis on avoiding Type 1 errors)
- Measures to address errors should provide new information, should not destroy the experimented and should not cause irreversible environmental change; when errors occur it should be possible to learn from error (a source of new information) and to start over

Uncertainty Principle (Heisenberg)

- Places an absolute, theoretical limit on the combined accuracy of certain pairs of simultaneous, related measurements
- Specifically gives a theoretical limit to which a particle's position and momentum can be measured simultaneously
- Recognizes that knowledge of social and natural world is incomplete and can never be complete given constant change and variations over space and time
- Has been elevated by some to the status of a philosophical principle, called the principle of indeterminacy, which has been taken to limit causality in general

Indeterminism/Inconclusiveness

- Means that the uncertainties are of such magnitude and variety that they may never be significantly reduced
- Scientific knowledge is inadequate; causal chains and networks are open and not understood
- Reflects the lack of direct causal linkages in open ended systems
- Potentially relevant concepts from new physics (e.g., new ideas of time, space and causation evident in theories of relativity and quantum indeterminism)
- Inconclusive means information that cannot lead to conclusive or definitive results

Fuzziness/Vagueness

- Fuzziness—vagueness; haze at the edges; degrees of truth; arguable that probability is a special case of fuzziness
- Fuzzy thinking is not precise; it reflects truths, not facts or statistics; a convenient way to approximate nonlinear systems

Table 11.3 (*Continued*)

- Asks if a particular conclusion, which is always tentative, is more true than untrue, or more untrue than true; by progressive steps, it backs and fills its way, merely reflecting the observed phenomena; a sliding scale
- Addresses intensity, extent, and persistence
- Admits the possibility of partial membership in a class, generalizing what might be otherwise crisp sets into ones where class boundaries are, or cannot, be defined clearly
- Reflects judgments that permeate all scientific inquiry and decision making; fuzzy set theory addresses nonspecificity and fuzziness
- A potential bridge between probabilistic risk assessments and qualitative assessments; quantifies the qualitative, while preserving imprecision; also can be integrated into IA simulation models (e.g., fuzzy cross-impact simulation)

Deep/Extreme Uncertainties

- Causal mechanisms not available
- No probability distribution
- Parties value outcomes of alternative decisions differently
- Extreme uncertainties resulting from both limitations of current scientific tools and nature of complex systems

Ambiguity/Nonspecificity

- Having more than one possible meaning; intentionally or unintentionally, obvious (patent) or hidden (latent)
- Also pertains to vague, uncertain or doubtful meaning or interpretation
- When faced with ambiguity about rules, obligations, promises, mandates and duties, practitioners tend to look for precedent, tradition, a source of legitimacy, a consensually based interpretation and an appropriate and fitting response

Approximations

- Simplifications of complex real systems
- Four types—(1) can be solved exactly but do not know correct equation; (2) to solve problem is impossible so resort to approximation; (3) simplify equations (a further abstraction from reality); (4) solution too complicated to understand (approximate to make result understandable)

Doubt

- Occurs in more complex decision-making contexts; issues and problems typically have no exact precedent or involve several parties with divergent or conflicting interests; also insufficient or unreliable data, disagreement over the importance of variables and the fact that some variables may not be quantifiable
- Generally handled through the rules and structures of the procedure within which the parties interact

Confusion/Linguistic Imprecision/Dissonance

- Dissonance—pure conflict (one statement is true and its rivals are false); addressed by probability theory
- Confusion—pure and potential conflict; addressed by possibility theory
- Procedural confusion—the complexity and uncertainty of the situation exceeds the problem-solving capacity of existing decision-making techniques, procedures and institutions
- Linguistic imprecision—imprecise communications

Surprise

- A manifestation of uncertainty that cannot be predicted; a qualitative disagreement between observations and expectations
- Typology—local (created by broader scale processes for which there is little or no previous local knowledge); cross-scale (similar to local surprise but larger scale fluctuation intersects with slowly changing internal variables to create an alternative stable, local system state) and novelty (something truly unique, in which new variables and processes transform the system into a new state)
- Revenge effects—ironic, unintended consequences of mechanical, chemical, biological, or medical ingenuity
- Surprise generating mechanisms and effects—logical tangles (paradoxical conclusions), catastrophes (discontinuities from smoothness), chaos (deterministic randomness), uncomputability (output transcends rules), irreducibility (behavior cannot be decomposed into parts), and emergence (self-organizing patterns)

Uncertainty Analysis

- Analysis of information about risks that are only party known or unknowable; describes the degree of confidence in the assessment
- Quantitative uncertainty analyses explicitly describes the magnitude and direction of uncertainties
- Qualitative descriptions of uncertainties avoid false sense that know precisely extent of risk, helps identify uncertainties with the largest impacts, explains differences in risk estimates generated by different stakeholders and suggests research opportunities

Sources: Benveniste (1989), Burdge et al. (1994, 2004), Calow and Forbes (1997), Carpenter (1995, 1997), Casti (1994), Cardinall and Day (1998), Cartwright (1991), CEC (2000), Coveney and Highfield (1995), Crossley (1996), Dearden and Mitchell (1998), Gunderson (1999), Hodgson and White (2001), Holling (1978), Homer-Dixon (2000), Jones and Greig (1988), Kaiser (2003), Lein (1992), McNeil and Freiberger (1994), Parashar et al. (1997), Peche and Rodríguez (2011), PCCRARM (1997b), Rothman and Sudarshan (1998), Rowe (1994), Stern and Fineberg (1996), Suter (1993), Thissen and Agusdinata (2008), Tickner (2003b), Tickner and Raffensperger (1998), Treweek (1999), Westman (1985), Yoe (1996), US ACE (1992), US EPA (1998c), WHOROE (2001c).

Science offers potential insights into the nature of indeterminism and into its implications for understanding and action. The uncertainty principle (also from science) illustrates the limits of measurement and causality. Fuzziness or vagueness demonstrates that boundaries often are permeable, blurred, and overlapping (i.e., degrees of truth). Methods (e.g., fuzzy set theory, fuzzy cross-impact simulation) can apply this conceptual insight to bridging the qualitative and the quantitative. Ambiguity and nonspecificity point to vague or multiple meanings and to the need to scrutinize the meanings associated with statements and observations. Deep or extreme uncertainty illustrates that there are degrees of uncertainty, up and including a complete inability to know or understand. Approximations illustrate how complex real systems are simplified. Doubt can be both a healthy attitude (consistent with good scientific practice) and an acknowledgment that stakeholders (often with good reason) tend to be skeptical of "experts," specialist analyses, and IA processes. Confusion can arise because of miscommunications, conflict, and poorly adapted problem-solving approaches. Perceptions of confusion frequently vary among IA process participants. Surprises cannot be predicted. The generating mechanisms for surprises can be characterized. Uncertainty analysis, a common stage in risk assessment, illustrates that uncertainties can be systematically assessed. There is a danger in confining the analysis of uncertainties to a single stage in the IA process.

Managing Uncertainty in the IA Process Addressing uncertainty in IA should begin with an attitude or perspective change. Uncertainty is a fundamental process attribute, rather than as "a distasteful transition to attainable certainty" (Holling, 1978). A dynamic perspective, oriented toward constant improvement, is essential (Faber et al., 2010). The irreducibility of risks and uncertainties is understood and unpredictability and incomplete control is accepted (Govender et al., 2006). Priorities shift from prediction and control to adaptability and responsiveness. It is necessary to learn from error, live with, and obtain benefits from uncertainty, avoid the unwarranted appearance of certainty, and address uncertainties throughout the IA process (Canter, 1993b; Dickman, 1991; Hollick, 1993; Mostert, 1996; US ACE, 1992). The IA process becomes an ongoing investigation rather than a one-time prediction of impacts (Holling, 1978). The process is iterative (anticipatory scanning and feedback loops), open, and adaptive (Gibson, 1992; Mulvihill and Keith, 1989). It evolves with and selectively and proactively influences both the problem and the context. It incorporates insights from postnormal and complexity science (Gasparatos et al., 2007). This perspective shift is necessary at both the regulatory (e.g., performance-oriented requirements and guidelines) and applied (e.g., IA process management) levels. It also should be present in each IA activity.

An adaptive IA process begins with a thoughtful, open (to divergent perspectives and interests), and systematic search of the problem space or situation. Uncertainties in the problem definition and in governing norms, values, and interests are explicitly identified (João, 2007; Mostert, 1996). Care is taken to use uncertainty language consistently (Tonn, 2000). The IA process is carefully bounded (US EPA, 1998c). It is highly conscious of and sensitive to the relevance of context (Hindling-Rydevik and Bjarnadóttar, 2007). Climate change concerns are fully integrated into the process (Larsen et al., 2012; Wilson, 2010). Constraints, ambiguities, and cognitive and resource limits are openly acknowledged (Cardinall and Day, 1998; Feldman and Khademian, 2008; Kørnøv and Thissen, 2000). Measurement limits are recognized. Vulnerabilities and blind spots associated with predictive models are identified, ramifications are explored, and appropriate adjustments are made (Duncan, 2008). The process brings together the best of the qualitative and the quantitative (Hodge, 2004). Risk and uncertainty issues are identified, objectives are formulated, and methods are determined (US ACE, 1992). A resilient mix of reliable solutions is identified—each treated as a case study. The proposed action(s) encompasses components intended both to prevent failure (i.e., fail-safe) and aimed at responding and surviving if failure occurs (i.e., safe-fail) (Holling, 1978). The proposed action (or more likely, suite of actions) is adapted and refined as circumstances change, both during and subsequent to approvals (Hollick, 1993). Ideally, the action is suited to staged approval (i.e., self-contained components) and implementation. In this way, the monitoring results can lead to modifications to and, where warranted, termination of the action (Hyman et al., 1988).

The process is open and involves multiple parties and perspectives in a creative and heuristic search for reversible, low magnitude, flexible, simple, error-friendly, proven reliable, safe-fail, and harm reducing options that hedge away from large losses or catastrophic effects; provide benefits even if problems are less serious than feared (i.e., no regrets); involve simple, known, and predictable environmental conditions; have minimum potential for synergistic effects; protect and enhance environmental integrity and sustainability; and can be harmonized with surrounding natural and social systems (Gibson, 1992, 2006a; Hollick, 1993). Baseline conditions are explored with scenario analyses (Hacking and Guthrie, 2008; João, 2007). Risks and uncertainties are recognized and managed (Govender et al., 2006). Complexity is carefully considered (Grinde and Khare, 2008). A proactive effort is made to identify and reduce interdisciplinary obstacles (Gee and Stirling, 2003). Assumptions and the basis for scale and data choices are clearly stated and fully substantiated (João, 2007). Multiple sources of information are utilized (Gardner, 2010). Radically different futures and options are considered (Wilson, 2010). Both possible and preferable futures are considered (João et al., 2011). Option evaluation criteria reflect these types of properties. Alternative criteria and criteria rankings and multiple sensitivity analyses test varying assumptions and perspectives. The evaluation narrows the list of options, but several, potentially acceptable, options and option combinations are carried forward into the process as far as practical. Retaining multiple options enhances action and process flexibility (Hollick, 1993, Gibson, 2006a). The preferred options are those best able to adapt to changing conditions, are lasting and resilient, will do well in most possible future circumstances, pose the least threat to the vulnerable environmental components and systems (assuming flawed predictions and ineffective mitigation), can be adapted as the future unfolds, and make the most positive contribution to sustainability (Gibson, 1992, 2006a, 2011; Homer-Dixon, 2000; Thissen and Agusdinata, 2008).

Uncertainty is a central consideration in baseline and impact analysis, interpretation, and management. Vulnerable (to impact, change, and surprise) environmental components, interactions, and systems are identified. The analysis focuses on change processes and identifies key variables and processes likely to amplify fluctuations (Gibson, 1993; Hollick, 1993). Uncertainties are systematically identified and assessed (Thissen and Agusdinata, 2008). Major uncertainties are identified once data are obtained (João, 2007; Yoe and Skaggs, 1997). Supplementary analysis and research reduce the uncertainties. Knowledge from multiple disciplines is integrated and connected (Dovers, 2005). Multiple models are developed, refined, and applied to characterize the system. Future conditions are predicted in ranges (João, 2007). Uncertainties are analyzed using a combination of scenario and probabilistic analyses (Byer and Yeomans, 2007). Sensitivity analyses, wide error margins, and confidence ranges test assumptions, assess the consistency of relationships, and bound uncertainties (Hacking and Guthrie, 2008; Hyman et al., 1988). Mitigation and adaptation measures are linked (Larsen et al., 2012). Considerable uncertainties remain despite such measures. Predictions are difficult, sometimes impossible. More emphasis is placed on understanding the system, on ensuring that real world conditions are accounted for, and on obtaining a rough sense of the possibilities and probabilities rather than on accurate prediction (Gardner, 2010; Gee and Stirling, 2003; Holling, 1978). The future is addressed by exploring planned and unplanned alternative futures, using such techniques as scenario analysis and sensitivity analysis (Hollick, 1993; João, 2007). Allowance is made for a wide range of errors and outcomes. More stress is placed on avoiding Type II errors (predicting no impacts when impacts occur) than on avoiding Type I errors (predicting impacts when no impacts occur) (Interorganizational Committee, 1994).

Impacts are assessed over the life cycle of the proposed action under normal and abnormal conditions (Tonn, 2000). Extreme and worst-case scenarios are formulated. Broad safety margins and conservative assumptions are employed. Predictions are expected to be inaccurate. Mitigation measures are assumed to be ineffective (Gibson, 1992). Experiments and pilot projects (both at the site and for comparable undertakings and settings) help refine and test the analysis (Treweek, 1999). Uncertainty, vulnerability to change, reversibility, resilience and adaptability, and consequences of error and failure are major impact significance factors. The known and the unknown are rationally connected to decision-making choices (Atkinson et al., 2006). A collective judgment is sought (Gardner, 2010). A good decision is one that delivers positive results in a wide range of futures (Gardner, 2010). Robust, diverse, and adaptable solutions, caution, and design for learning are favored (Gee and Stirling, 2003; Gibson, 2006a). Effective use is made of local knowledge as well as relevant expertise (Gee and Stirling, 2003). Learning is fostered and reinforced through organized evaluation, innovation, integration, and interaction (Tuinstra et al., 2008). Conclusions are questioned, challenged, and tested (i.e., metacognition) (Gardner, 2010). Adaptive management encompasses both ignorance and uncertainty (Gee and Stirling, 2003).

The mitigation analysis stresses emergency and contingency planning, early warning systems, reversibility, adaptability, and the availability of fallback positions and damage control systems (De Bono, 1992). Natural mitigation approaches, which require minimal intervention and which recognize and cultivate the self-organization capacity of systems, are favored over methods reliant on a high degree of intervention, control or "engineering" (Hollick, 1993). A risk and uncertainty analysis identifies, analyzes, interprets, and determines appropriate management measures for risk and uncertainty types and sources (Reckhow, 1994; Tonn, 2000; US ACE, 1992; Yoe and Skaggs, 1997). Uncertainty management includes targeted research and error reduction procedures. Uncertainties are presented in a form suitable for decision making and monitoring (Glasson et al., 1999; Holling, 1978). Monitoring begins early in the IA process by assessing comparable environments, comparable undertakings, and pilot projects. It continues during and following a staged review and approval process. Monitoring focuses on maintaining and enhancing the health of vulnerable environmental components, on detecting emerging discontinuities, and on contributing to environmental integrity and sustainability (Axelrod and Cohen, 1999). Monitoring uncertainties are explicitly acknowledged. Actions taken in response to monitoring err on the side of environmental protection.

Public attitudes toward uncertainty, including value differences regarding uncertainties, are identified (US ACE, 1992). All potentially affected parties are involved in addressing uncertainties (Mostert, 1996). The IA process is open and collaborative. The need for multiple perspectives is recognized (Govender et al., 2006). Reciprocity facilitates trust. Trust among social groups is acknowledged as essential for ameliorating complex, collective, action problems (Ostrom, 1998). Consultation is a social learning opportunity, where the knowledge limits of all parties are recognized. What is and is not certain, the magnitude and consequences of uncertainties, what is and is not being done about uncertainties, and the rationale for all actions taken or not taken in response to uncertainty are transparently communicated to all parties (Hance et al., 1990; Tennøy et al., 2006). Interpretations are open to challenge and comment and subject to independent peer review (Yoe, 1996).

Study teams are selected and managed with uncertainty in mind. Study team leaders identify productive areas of uncertainty and confusion and lead the team toward opportunities (Hodgson and White, 2001). The study team is willing and able to explore ambiguities, handle uncertainties, tackle difficult and unknown problems, readily adapt to changing situations, span boundaries, focus on essentials, scan ahead, communicate effectively, and accommodate conflict (Hodgson and White, 2001). IA documentation explicitly identifies risks, uncertainties, limitations, and constraints. Simplifying assumptions and subjective interpretations and choices are fully justified (Mostert, 1996). The limits of data, technologies, methods, and procedures are acknowledged (US EPA, 1998c). Key uncertainty issues and how they were addressed are described (US ACE, 1992). Aspects of uncertainty most likely to affect decision making are identified (Reckhow, 1994).

Decisions are supported by uncertainty analysis and management techniques (e.g., fuzzy set analysis, bounding analysis, subjective probability analysis, expert panels, scenario analysis, sensitivity analyses, life cycle analysis, simulations, comparative analysis, decision and event trees, exploratory modeling and analysis) (Bro-Rasmussen, 2003; Duinker and Grieg, 2007; Gibson, 1992; Thissen and Agusdinata, 2008; Tonn, 2000; Treweek, 1999; US ACE, 1992; Yoe, 1996). Proposed actions with high uncertainties and potentially grave and likely irreversible consequences are generally rejected (Gilpin, 1995; Hyman et al., 1988). Actions are deferred if short-term studies and pilot projects can reduce high uncertainties and can manage the remaining uncertainties (Gilpin, 1995; Wende et al., 2012). Actions are more likely to be approved if experience elsewhere suggests low magnitude impacts and uncertainties that can be adequately addressed by conditions and monitoring (Gilpin, 1995). Staged approval is applied, where practical, to maximize the opportunity to monitor, adjust, defer, or even terminate proposed actions. Decision making is risk aversive. It hedges decisions away from large losses (e.g., no or least regrets, minimize the maximum regret, maximize the minimum value) (Byer et al., 2011; Gibson, 1992). It recognizes that the need for follow-up is greatest when there is inherent uncertainty (Marshall, 2005). Adaptive management and governance approaches are utilized (Govender et al., 2006). Monitoring is connected to adaptive design and management (Hunsberger et al., 2005). Outcomes of similar actions are monitored (João, 2007). The effectiveness of adaptive methods and procedures is continually assessed. Early warning is prioritized (Donnelly et al., 2007). Feedback loops are closely monitored (Grinde and Khare, 2008). Institutional constraints and implications are identified. Adaptive organizations provide for rapid and continuous knowledge acquisition; have effective information flow and communications networks; have regenerative–restructuring capability; have a bias toward action, preventative planning, and monitoring; and are vertically and horizontal integrated. They tend to be collaborative, experimental, flexible, creative, reliable, and evolving. They have error detecting and error correcting mechanisms, encompass varying critical and systems perspectives, are open to scrutiny, and are responsive to interested parties and diverse interests (Homer-Dixon, 2000; Michael, 1989; Mulvihill and Keith, 1989). Adaptive organizations are much like self-organizing, emergent, complex systems.

Adaptation Concepts and Distinctions Table 11.4 identifies several potentially relevant adaptation concepts. Design confronts complexity with positive visions, pragmatic, tested concepts, and the creative use of analogies, analogs, and models. It progressively explores, evaluates, refines, and embellishes. It structures incremental adjustments that build toward a coherent whole, effectively fitted within larger systems. Ingenuity is concerned with innovative (both new ideas and novel applications of known ideas) and practical, technical, and social solutions to difficult problems in complex environments. Social ingenuity (both in an institutional reform and in a policy sense) is generally a prerequisite to technical ingenuity. Creativity is often mentioned but rarely understood or systematically applied as a means of coping with uncertainty. Sufficient advances have been made to provide a good general sense of the creative process and to offer numerous practical individual and group techniques for fostering creativity. Strategic choice offers a well-tested mix of frameworks, methods, and procedures for exploring and managing multiple uncertainties in high pressure planning situations. It employs an array of useful concepts pertaining to problems, comparisons, decisions, and interactions, all within a highly flexible and iterative group decision-making process. Consilience demonstrates how science has and can interlock facts and fact-based theory across disciplines and branches of learning. It offers a science-based explanatory model of the convergence and unity of knowledge—a model potentially capable of coping with complex system uncertainties. Resilience thinking focuses on interdependencies and on enhancing the ability of critical and irreplaceable system elements and vulnerable parties to adapt and recover from change. Holistic science provides an alternative perspective and framework for spanning boundaries, for escaping the constraints of analytical thought, and for understanding the interdependencies and interconnectedness of complex living and nonliving systems. Sustainability science is concerned with how the equilibrium of complex, interdependent, self-organizing natural, social, and economic systems can be maintained and made more adaptive and resilient. Integrated sustainability assessment applies an integrated systems approach to complex societal problems. It transcends individual disciplines is nonlinear and adaptive, draws upon complex systems theory, is reflective and learning oriented, and seeks to foster the potential for innovation and the realization of transformative outcomes.

Table 11.4 Examples of General Adaptation Concepts and Methods

Design

- Idea of a growing whole; operates at many levels in many different ways; object is to incrementally produce wholeness or coherence
- Establishes a context for future actions; visionary—experienced and then expressed as a vision; a vision that can be communicated to and felt by others; positive—aim to create a positive character based on urban, ecological, and sustainability visions and principles
- Begins from a few well tested concepts that pragmatically respond to prevailing conditions (initial ideas often from analogies, analogs, and models); consequences explored and re-evaluated; ongoing refinement, adjustment, and embellishment

Ingenuity

- Sound sets of instructions; minimum ingenuity requirement—shortest set of instructions to solve problem
- Ideas that can be applied to solve practical technical, social, and environmental problems
- Amount of ingenuity dependent on intrinsic difficulty of achieving goal and kinds and amounts of available resources
- Innovation (truly new ideas) and application of known ideas in different ways and in different contexts
- Technical (helps solve problems in physical world) and social (well functioning markets, institutions, social arrangements) ingenuity; social a prerequisite to technical ingenuity
- Within social ingenuity can distinguish between structural ingenuity (used to create or reform institutions) and policy ingenuity (for actions pursued within an existing institutional framework)
- Measure of ingenuity—quantity (number of instructions) and quality (how well works in practice)
- Can distinguish between ingenuity applied to short-term and to long-term problems; entangled with social and political processes (context)

Creativity

- Key characteristic of brain; the ability to improvise in novel situations; intelligence implies flexibility and creativity; capacity for analogy and metaphor especially important; value of affect or emotion in higher level integrative brain functions
- Concerned with the changing of concepts and perceptions and with the generation of new concepts and perceptions
- Creativity operates on more than one plane and is liberating (defeats habit by originality), visionary, nonlinear; involves both differentiation and integration; also transcends logic (thinking aside or laterally), rationality (i.e., the extrarational), language and science
- Creative thinking; can be fostered deliberately with approaches (e.g., lateral thinking, synectics) and by specific techniques (e.g., brainstorming); facilitated by training
- Individual and group creativity; better in combination; creativity involves preparation, incubation, illumination, and verification
- Potential role in improvement, in problem solving, in realizing value, and in taking advantage of opportunities; particular need for creativity in order to generate future possibilities and to devise ways of coping with multiple possibilities
- More than a way to make things better; approaches and techniques seek to break out of old structures, patterns, concepts, and perceptions
- Stresses value of employing analogs, metaphors, imagery, illusion, simulation, story-telling and games, of exploring apparent contradictions, of searching for patterns and interconnections, of transcending dualisms, of identifying hidden assumptions, of formulating theme variations, and of connecting concepts

Strategic Choice

- Choosing in a strategic way; stresses interconnections among decisions; focus on planning under pressure; seeks opportunities for managing uncertainties through time
- Links technology, organization, process and product in a process that involves shaping, designing, comparing, and choosing
- Creatively manages multiple uncertainties (about the working environment, guiding values, and related decisions)
- Employs various concepts concerning problems (e.g., current and modified decision problems, broader planning problems, problem focus or foci), options (e.g., option bars, option graphs, exploratory options, composite options), comparisons (e.g., comparison area, relative assessment, advantage comparison, working shortlist, evaluation framework), decisions (e.g., decision areas, decision links, decision schemes, immediate decisions, future decision space, action scheme, commitment packages), and interactions (e.g., lateral connections, switching, looping, coalescing decision areas)
- Systematically explores uncertainties (e.g., eliciting limits of surprise, identifying uncertainty areas, linking uncertainties to decision areas, reformulating composite uncertainty areas, comparing alternative responses to uncertainty, weighing uncertainty against urgent decision making, accommodating uncertainty in future decision spaces)
- Applies in a flexible and iterative group decision-making process; provides skill development and practical advice

Consilience

- Consilience—proof that everything in our world is organized in terms of a small number of fundamental natural laws that comprise the principles underlying every branch of learning
- Argues for fundamental unity of knowledge; entails the interlocking of facts and fact-based theory across disciplines and branches of learning (e.g., biology, social science, ethics, environmental policy) to create a common groundwork of explanation (i.e., a “jumping together of knowledge”)
- Argues for extending the habits of thought (e.g., reductionism, integration, competing hypotheses, no claim accepted as final) that have worked so well in material world into social sciences and humanities; natural sciences already has constructed a webwork of causal explanations ranging from quantum physics to brain sciences and evolutionary biology—already converging
- Consilience (i.e., units and processes of a discipline that conform with solidly verified knowledge in other disciplines) a criterion for theoretical quality; others include parsimony, generality, and predictiveness

(*continued*)

Table 11.4 (*Continued*)

- The greatest challenge is the accurate and complete description of complex systems

Resilience Thinking

- Fully recognizes complex dynamics and interdependencies between human and natural systems
- Looks at past behavior and historical systems patterns
- Focuses on resilience of what and to what, distinguishing between what can and cannot be managed
- Focuses on resilience of whom—most vulnerable parties
- Identifies critical and irreplaceable systems elements
- Emphasizes role of governance, institutions, and management in enhancing society's ability, commitment, and preparedness to manage systems for resilience; stresses adaptive comanagement

Holistic Science

- Interconnectedness and interdependence of all living and nonliving systems; social and ecological systems coevolve
- Emphasizes—complexity, surprise, nonlinearity and emergence and on the need for creative, intuitive, adaptive, integrative, normative, trans-scientific and pluralistic approaches; suspends the constraints of analytical thought
- Broadens the conception of the problem and of context; stresses ecological limits, equity, integration, and holistic perspective

Sustainability Science

- Economics, society, and nature—complex adaptive systems in a world of uncertainty
- Self-organizing systems exist in equilibrium; depend on feedback loops
- If destroy equilibrium push system to edge of criticality and perhaps chaos
- Need to understand biosphere from holistic-systems perspective
- Need to consider complexity and closely monitor feedback loops
- Seeks to foster adaptive capacity and resilience

Integrated Sustainability Assessment

- Applies an integrated systems approach to complex societal problems embedded in a process-based context
- Applies an interdisciplinary science perspective that utilizes complex systems theory, nonlinear knowledge generation, social learning, and systems innovation
- Seeks to capture nonlinear dynamics and adaptive behavior
- Seeks transformative outcomes
- Requires a participatory process, adaptability, reflection, evaluation, and learning
- Reinforces learning through organized evaluation, innovation, integration, and interaction

Sources: Alexander et al. (1987), Benveniste (1989), Clark et al. (2011), De Bono (1992), Dearden and Mitchell (1998), Friend and Hickling (1997), Gibson (1992), Gordon (1961), Grinde and Khare (2008), Haney and Power (1996), Hermans and Knippenberg (2006), Hodgson and White (2001), Hofstadter (1985), Homer-Dixon (2000), Iles (1996), Koestler (1964), Miller (1993), Mulvihill and Keith (1989), PCCRARM (1997b), Porritt (2000), Reckhow (1994), Rotmans (2006), Rowe (1991), Slootweg et al. (2010), Tuinstra et al. (2008), Wilson (1998, 2010).

Adaptive Management Adaptive management enables actions in the face of uncertainty (Feldman and Khademian, 2008). It allows decisions to be made notwithstanding imperfect information (Clark et al., 2011). Adaptive management can be active or passive (Kwasniak, 2010). It can serve as a follow-up tool within IA (Canter and Atkinson, 2010). It can facilitate cooperative resource management between indigenous peoples and other stakeholders (i.e., adaptive comanagement) (Landry et al., 2009). It can make it easier for environmental and IA policies to adjust in a rapidly changing institutional environment (Cherp and Antypas, 2003). Adaptive capacity refers to the ability to implement adaptation measures (Byer et al., 2011). It does not mean that those measures will be implemented. Examples of potential roles for adaptive management within IA include reducing cumulative effects uncertainties, informing decision makers of measures to reduce incremental effects, managing regional cumulative effects from multiple contributors, cooperative resource management, and adapting proposed actions to future climate change (Byer et al., 2011; Canter and Atkinson, 2010; Landry et al., 2009). IA good practice guidance has long called for IA to be adaptive (e.g., adjusted to changing realities, issues and circumstances, iterative, incorporating lessons as processes unfolds), while not compromising process integrity (IAIA, 1999).

AEAM is a form of adaptive management. It treats environmental management as a quasiexperiment (i.e., probing ecosystem responses to human actions) (Johnson, 1999; Lee, 1999). Managers learn while doing. Subsequent decisions are adjusted and enhanced from feedback (Reinke and Swartz, 1999; Wieringa and Morton, 1996). The AEAM process is an iterative cycle of planning, implementation, monitoring, research and reexamination (IEMTF, 1995). Each cycle facilitates the selection of more appropriate management actions, helps change stakeholder behavior, and provides a learning opportunity (Lal et al., 2001).

The process is structured around a series of workshops. An example AEAM process is depicted in Figure 11.2.

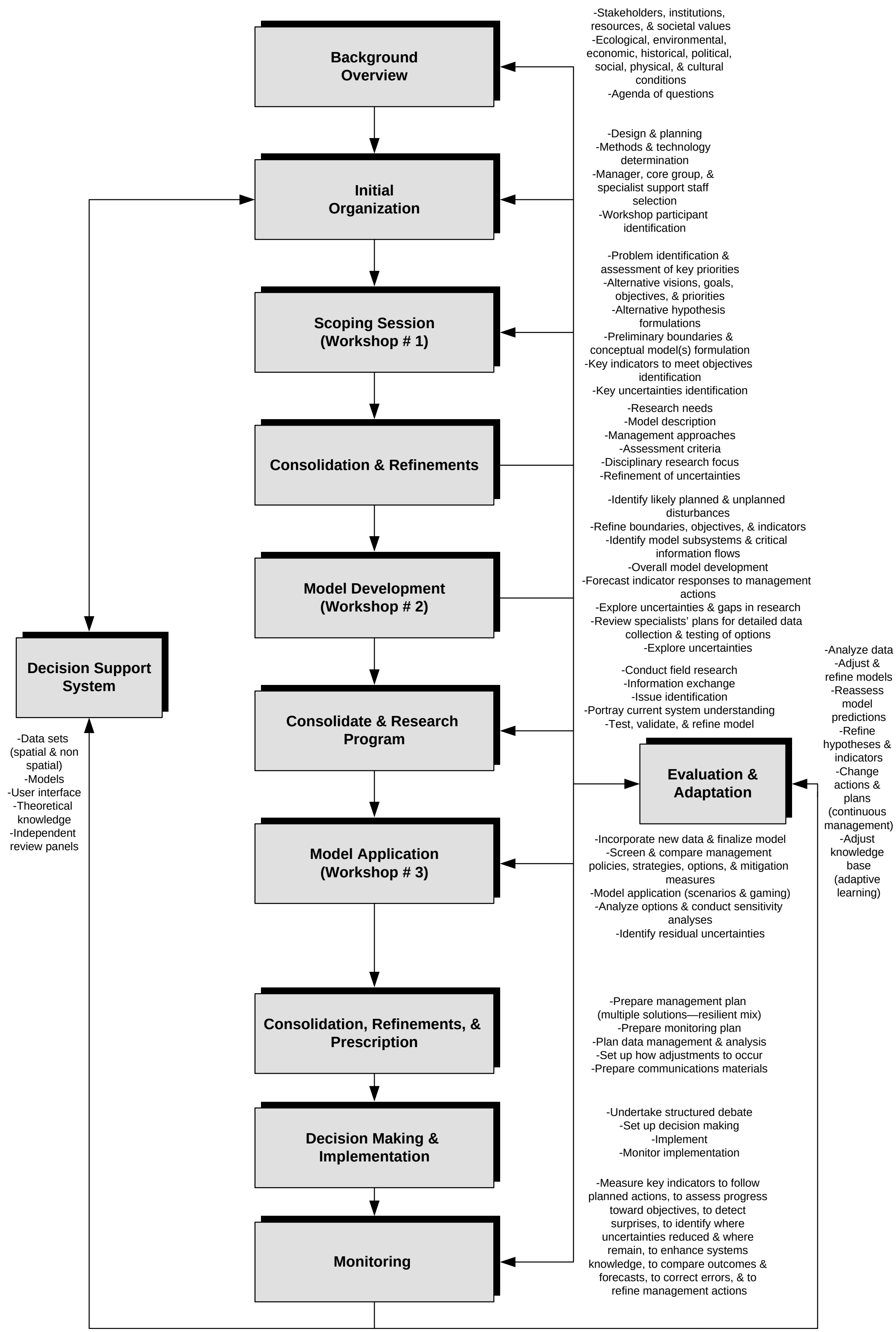

Figure 11.2 Example of an adaptive environmental assessment and management process.

AEAM has much to offer to IA, especially in actively adapting to and managing the uncertainties associated with complex problems and/or complex environments (Hyman et al., 1988; Johnson, 1999; Noble, 2000b). It is a useful tool for assessing mitigation and regional management measure effectiveness, and for assessing the likelihood of cumulative and large-scale effects (Canter and Atkinson, 2010; CEAA, 2009e). It recognizes the value of science in identifying and diagnosing surprise but acknowledges the limits of scientific methods, prediction, and control (Lee, 1999). It appreciates that the uncertain, the unexpected, and the unknown are normal facets of planning and management (Dearden and Mitchell, 1998). It facilitates rapid knowledge acquisition rates and rapid detection of changes (Canter and Atkinson, 2010; McLain and Lee, 1996; Smith, 1993). It recognizes that more information is not always desirable and can hinder decision making (Hyman et al., 1988). It permits learning by doing and underscores the value of monitoring (Morgan, 1998). It is able to handle indirect effects and cumulative effects (Hyman et al., 1988). It provides an integrative systems approach, which links and transcends disciplines and perspectives and helps alleviate the problems associated with fragmented research and coordination (Holling, 1978; Noble, 2000b). The workshop format, built around model building and testing, provides a potentially constructive and nonconfrontation approach for stakeholders to build a common understanding of the problem, to synthesize existing knowledge, to highlight key uncertainties, to clarify assumptions, to stimulate creativity, and to generate innovative options (GBC, 1999; McLain and Lee, 1996; Noble, 2000b; Smith, 1993).

The IA and AEAM processes are very similar, especially at the strategic planning level. The project level is potentially more problematic. Projects, particularly those involving large up-front costs, allow for contingencies but are often not amenable to midcourse corrections, which radically depart from original project objectives (Carpenter, 1997). Project-level EIA is largely oriented to obtaining data and to making specific predictions for decision-making purposes. AEAM is more focused on reaching a policy, resource, or environmental management strategy consensus (Morgan, 1998). Organizational resistance to AEAM will often occur because of a reluctance to admit uncertainty, to make mistakes or to try new solutions, a lack of interest in developing an organizational learning capacity, a perception that it will challenge bureaucratic self-interests, short-term perspectives, and an expectation that scientific research will be costly and of little administrative and political value (GBC, 1999; Gunderson, 1999; Lee, 1999; Walters, 1997). AEAM principles may be less applicable in unique situations where lessons are not transferable (i.e., no spatial replication), where impacts are curable rather than chronic, where uncertainties are limited and manageable, where reasonably accurate impact predictions can be formulated, where continuing surveillance of environmental systems is unwarranted, where ecological components and systems are not resilient, where stakeholders are inflexible (i.e., major value conflicts), where multiple systems are involved, and where there are potentially significant irreversible risks and impacts associated with experimentation (Gunderson, 1999; Johnson, 1999; Morgan, 1998; Noble, 2000b; Walters, 1997). The full application of AEAM modeling and field experimentation can be costly (Walters, 1997). AEAM is information dependent. The information needed to support AEAM may not be available and there may be no means to develop the information (IEMTF, 1995).

AEAM tries to cover multiple objectives by including representatives of various disciplinary backgrounds in the study team (Hyman et al., 1988). Since the process does not specify a systematic way of dealing with multiple objectives, the results are very sensitive to study team composition (Hyman et al., 1988). AEAM is largely based on applying ecological, often linear system models (McLain and Lee, 1996). Such models can have difficulty addressing cross-scale linkages (e.g., between physical–chemical and ecological processes), the nonadditivity of parameters and effects and difficult and emergent processes (Walters, 1997). Nonscientific and qualitative information, knowledge, and experiences are sometimes discounted (McLain and Lee, 1996). Such models may be unable to accommodate fundamental conflicts among scientists regarding facts and assumptions and among policy makers concerning community preferences (McLain and Lee, 1996). Most AEAM literature focuses on procedural elements (Smith, 1993). More attention could be devoted to social, cultural, and economic concerns and to substantial contributions to sustainability (Smith, 1993; UNEP, 1997). Methods of obtaining institutional support, the institutional structures required for AEAM to work, and the procedures for overcoming data inadequacies, model inadequacies, and misunderstandings about AEAM concepts and methods, all require additional attention (Jones and Greig, 1988; McLain and Lee, 1996).

11.4.3 Risks

Risks Risk is a combination of a frequency (in the past) or probability (in the future) and a usually harmful consequence for the human or natural environment (Eccleston, 1999b; Erickson, 1994; Whyte and Burton, 1980). Decision makers tend to know the alternatives but each alternative has several possible outcomes (i.e., outcomes are not certain) (US ACE, 1992). Adverse human outcomes or harm can include injury, disease (morbidity), death (mortality), impaired quality of life, financial loss, property damage or delay (Wiener and Rogers, 2002). Ecological harm can include damage to individual plants or animals, to species, to ecosystems, and to ecological diversity. There can be economic, health, and environmental risks (Grima et al., 1986). Risks can result from natural (e.g., natural disasters) and from human (e.g., human actions that result in exposures to chemical, microorganisms, radiation) sources. There can be high- or low-probability risks. There are best risk estimates and high value risk estimates (e.g., worst case, varying safety margins) (Kamrin, 1993). There are chronic (e.g., diseases resulting from persistent or repeated exposure) and acute (e.g., from abnormal events) risks. Levels of uncertainty and the magnitude of consequences can vary among risks. There are risks to the overall population and to sensitive or susceptible populations (e.g., asthmatics, fetuses, infants, young children, elderly). There can be objective (quantitative) or subjective (estimated or perceived) risks (US ACE, 1992). All risk estimates or calculations have an element of subjectivity. There are deterministic (exposure quantified as a point estimate) and probabilistic (probability distribution incorporated for each variable) risk estimates. Risk estimates can be based on scientific evidence (empirical), predictive models, or heuristic judgment and qualitative reasoning. Risks within a IA process can pertain to potentially significant adverse effects; risks to effective implementation associated with safety; natural hazard risks; security or political stability; risks for which data, process, or methods may be unreliable, invalid, or discredited; risks associated with information gaps, unknowns, major uncertainties; and risks connected to the ability to implement promptly and effectively (Catchpole and Moreno, 2012; Croal et al., 2010).

Table 11.5 outlines some major risk concepts. Risk assessment is concerned with how risks are characterized, described, and estimated. Perceived risks are subjective risk interpretations by individuals and groups. Risk communication involves the exchange of risk-related information and opinion between specialists and the public. Comparative risk assessment compares and ranks risk types. Risk evaluation determines the tolerance for, acceptability of, and desirability of options and proposals. Risk management is an umbrella term for all activities concerned with identifying, assessing, interpreting, communicating, and evaluating risks. It also includes measures to prevent and reduce risks, measures to take advantage of risk-related opportunities, decision-making, implementation, and monitoring. Integrated risk management includes organizational objectives and procedures. A hazard is an intrinsic property that can, under some circumstances, be harmful. A disaster is the realization of the hazard. Hazard identification determines

Table 11.5 Examples of Risk Concepts

Risk Estimation, Analysis, and Assessment

- Risk analysis—the systematic, scientific characterization of potential adverse effects of human or ecological exposures to hazardous agents or activities; performed by considering the types of hazards, the extent of exposure to the hazards, and information about the relationship between exposures and responses, including variation in susceptibility
- Adverse effects or responses could result from exposures to chemical, microorganisms, radiation, or natural events
- Distinction between chronic (diseases occurring as a result of repeated or persistent exposures) and acute (abnormal events) sources and effects; between human health and ecological risks
- Distinction between deterministic (quantifies exposures as point estimates) and probabilistic (incorporates probability distributions for each variable) risk assessment
- Distinctions among empirical risk assessment (based on scientific evidence), model-based assessment (uses predictive models in place of empirical evidence) and qualitative risk assessment (draws on heuristic judgment and qualitative reasoning)
- Need to consider risks to highly exposed populations (e.g., asthmatics, fetuses, infants, and young children, socioeconomic groups, elderly)
- Methods—relative risk indices, event trees and decision networks, environmental transport and fate models, dose response models
- Essential that limitations and negative tendencies of methods be acknowledged, avoided, and minimized

Perceived Risks

- The subjective perception of risk by members of society both individually and collectively; varies from individual to individual and group to group for the same risk and from one risk to another
- Recognizes that lay public knows something that the experts do not and have good reason not to be convinced of all expert evidence
- Public has deep emotional investment in beliefs (e.g., anomie, resentment, distrust, sabotage, stress)
- Public attitudes toward risks are real experiences that determine how people feed and act
- Perceived risk affected by person-related (age, sex, personality type, personal stake, sensitive populations), situation-related (e.g., beyond control of individual, involuntary, children at risk, scientific controversy, high media attention, victim identity), and risk-related characteristics (e.g., origin, immediate threat, consequences for health, dread hazard, catastrophic consequences, unfamiliar hazard, uncertainty, controllability, effects on future generations, reversibility, accident history)
- Also affected by public trust in institutions, fairness, media attention, benefits, and evidence
- Need to consider factors that contribute to outrage (e.g., involuntary exposures, lack of previous knowledge, dread of effects, severe consequences, inadequate or unclear benefits, outside personal control, artificial rather than natural risk, insidious dangers, unknown duration, associated with memorable events, unethical or unfair distribution of risk burden, managed by untrustworthy information sources, effects on children)
- Should be serious consideration in determining risk acceptability

(*continued*)

Table 11.5 (*Continued*)

Risk Communications

- An interactive process involving the exchange among individuals, groups and institutions of information and expert opinion about the nature, severity, and acceptability of risks and the decisions taken to combat them
- Involves providing citizens with scientific information about risk, making risk information genuinely meaningful, facilitating public involvement in processes where risk analyzed and managed and obtaining public conceptions of risk (risk perceptions); also serves to encourage risk reduction measures, to increase mutual trust and credibility, and to resolve conflicts and controversy
- Need for two-way interaction—learn about patterns of exposure, peoples' perceptions of risk acceptability, and peoples' concerns, values, and knowledge; should describe risks and uncertainties openly and understandably; must begin before important decisions made
- Risk communications strategies and methods adopted can either ameliorate or reinforce perceived risk concerns
- Distinction between informational (provides information necessary to understand characteristics and magnitudes of risk faced and methods for ameliorating) and persuasive (goal of changing people's behavior with respect to a particular risk)
- Need to explicitly consider uncertainty and public issues and to communicate with diverse ethnic and socioeconomic groups
- Elements of risk communications—objectives (why undertaken?), content (what is being conveyed?), form of communications (how should transmit?), feedback from audience (what is being received?)

Comparative Risk Assessment

- The process of comparing and ranking various types of risks to identify priorities and to influence resource allocations
- Useful for ranking the social impacts of various forms of environmental degradation
- Analyzes several different hazards or sources of harm to the same individual, or valuable ecosystem site, in terms of relative risk
- Relative differences in risks are significant and can assist in settling priorities among alternative environmental programs so as to get the most risk reduction per unit expenditure; CRA can lead to risk-based strategic planning
- Examples (progressively less acceptable)—first class risk comparison (same risk/different occasions, risks against existing standards, different estimates of the same risk), second class (with and without activity, risks of different alternatives, same risks in other sites), third class (average risks against most serious risks, risk by source against risks by all sources producing same effects), fourth class (risk/cost ratios, risks vs. benefits, risks vs. risks from same source, risks vs. other causes of same illness or trauma), fifth class (unrelated risks)

Risk Evaluation and Acceptability

- Concerned with the desirability of options or proposals; value-full; expertise dispersed throughout society
- Need to consider all feasible options (modify wants, modify technology, prevent initiating event, prevent release, prevent exposure, prevent consequences, mitigate consequences)
- Risk evaluation—the determination of the importance of risks; risk is context dependent; need to consider cultural, social, and psychological factors; evolves; represents a subjective/political, value-full decision requiring the involvement of all sectors of society and often necessitating alternative dispute resolution
- Need to consider all major consequences (e.g., economics, environment, societal resilience, equity); need to compare against background, alternative actions, other familiar risks, and benefits of continuing the project and taking the risk
- Takes into account such considerations as predicted effects, public perceptions, risk–benefits, background and comparative risks
- Risk evaluation methods (e.g., professional judgment, cost–benefit analysis, cost effectiveness analysis, weight-scoring, decision analysis such as event tree)
- Acceptable risk is a risk whose probability of occurrence is so small, whose consequences are so slight, or whose benefits (real or perceived) are so great that a person, group or society is willing to take that risk; risk tolerance would be a more accurate characterization of the concept
- Risk acceptability of technology dependent on information people exposed to, information choose to believe, values held, social experience, dynamics of stakeholder groups, political process, and historic moment

Risk Management

- Risk management is a systematic approach to setting the best course of action by identifying, assessing, understanding, acting on, and communicating risk issues; integrated risk management—process for building into organizational objectives and procedures
- The process of identifying, evaluating, selecting and implementing actions to reduce risk to human health and to ecosystems; answers the question—what shall we do about it?
- Goal is scientifically sound, cost effective, integrated actions that reduce or prevent risks while taking into account social, cultural, scientific, technological, economic, ethical, political, and legal considerations
- Risk management—an umbrella term that encompasses risk analysis or assessment, risk evaluation (the determination of the importance of risk), risk mitigation, and monitoring
- Some argue should aggressively seek alternatives to command and control (e.g., environmental accounting, education, market-based, incentives, consensual decision-making approaches)
- Stages—define the problem and put it in context, analyze the risks associated with the problem in context, examine options for addressing the risks, make decisions about which options to implement, take actions to implement the decisions, conduct an evaluation of the actions; conducted in collaboration with stakeholders; uses iterations if new information is developed that changes the need for or nature of risk management

Table 11.5 (*Continued*)

- Examples of methods—education/information, incentives, substitution, regulation/prohibition, monitoring, surveillance, research, and risk compensation (for the anxiety created as a result of the hazard potential and for the consequences when a hazardous event occurs)

Disasters and Hazards

- Hazard is an intrinsic property of a substance, which is activated upon an event; a factor or circumstance that may under some circumstances be harmful or injurious; can produce a particular type of adverse health or environmental effect
- A hazard is a perceived event or source of danger that threatens life or property or both; a disaster is the realization of a hazard
- Hazard assessment seeks to recognize things that give rise to concern
- Hazard identification—addresses what can go wrong
- Examples of hazard identification methods (e.g., literature review, plant visits, brainstorming, hazard and operability studies, failure modes, effects and criticality analysis, safety audit)
- Hazard accounting or analysis—establishes boundaries of analysis and determines likelihood of events
- Examples of failure/risk assessment methods—preliminary hazard analysis (identifies hazards as early as possible), event tree analysis, fault-tree analysis, failure modes and effects analysis (attempt every possible way each component or interface among components could fail, then consider effect of failure on system), human reliability analysis (identifies how people interacting might cause to fail)
- Disasters include natural disasters and human induced (e.g., accidents, terrorism); emergency planning and management can be integrated into IA; potential for rapid environmental assessments in disasters
- Climate change a long-term disaster; can be addressed through climate change IA or through integration into other IA types; includes ecological, health, social and economic impacts, risks, and mitigation/adaptation measures; addresses impacts on and from climate change; emphasizes prevention; pertains to policies, plans, programs, and projects; systematically assesses and communicates uncertainties; and provides for adaptive management

Human Health Risk Assessment

- Assesses risk of cancer and from noncancerous (e.g., reproductive, neurotoxic, developmental, immunologic) health effects (alone and in combination); also from abnormal events (acute)
- Carcinogen risk assessment includes hazard assessment (whether agent poses carcinogenic hazard to humans and how might be expressed), dose-response assessment (evaluates potential risks to humans at exposure levels of interest), exposure assessment (the qualitative and quantitative determination of magnitude, frequency and duration of exposure), risk characterization (integrates risk assessment results in nontechnical discussion)
- Examples of issues (e.g., animal testing of potential carcinogens, modeling of carcinogenesis, overly conservative exposure assumptions, risk communications, perceptions and acceptability)

Ecological Risk Assessment

- A process used to estimate the likelihood of adverse effects on plants and/or animals from exposure to stressors
- Evaluates the probability and resulting adverse effects from one or more environmental hazards or stressors (nonendemic events or chemicals), which when introduced have the potential to accumulate, biomagnify, and genetically mutate species, poison, or in any other way impact a species or ecological system in an area
- Examines the extent of damage from a stressor (e.g., defined toxic agents and pollutants) or possible effects to a system or species as a result of a stressor; can be used to predict the likelihood of future adverse effects (prospective) or evaluate the likelihood that effects are caused by past exposure to stressors (retrospective)
- Tiered approach can be helpful—(1) descriptive risk assessment (simple qualitative data and/or comparative methods using literature); (2) semiquantitative (models and data collected to analyze priority issues); (3) site-specific data and predictive models
- Numerous methodological issues (e.g., ranking environmental problems and ecosystem sites, defining endpoints, selecting indicator species, determining scale, managing and quantifying uncertainties, extrapolations across scales, validating predictive tools, valuation, elements of a uniform approach) and areas requiring additional research (e.g., effects of multiple chemical, physical, and biological stressors)
- Extensive debate surrounding appropriate ecological risk assessment paradigm and whether same decision process should be used for human health and ecological risk assessment (e.g., no equivalent to lifetime cancer risk estimate)
- Example elements—problem formulation, receptor identification (partitioning assessment, biological characterization, system organization), hazard identification, endpoint identification (the target species or system that is subject to an environmental hazard), relationship, exposure characterization, ecological effects characterization, risk characterization, and uncertainty analysis

Sources: Agrawala (2010), Arquiaga et al. (1992), Baker and Rappaport (2009), Barrow (1997), Brown (2003), Burdge et al. (1994, 2004), Byer and Yeomans (2007), Byer et al. (2009), Byer et al. (2011), Canter (1993b), Carpenter (1997), Covello et al. (1988), CRAM (1993), Demidova and Cherp (2005), Dooley (1985), Eccleston (2008), EnHealth Council (2001a), Fischhoff et al. (1981, 1982), FPTCCCEA (2003), Furlow (2010), Gardner (2010), Grima et al. (1986), Health Canada (2000), Hood and Nicholl (2002), Hyett (2010), Kamrin (1993), Larsen et al. (2012), Kelly (2005), Lein (1992), Morganstern et al. (2008), Montague (2004), Powell (1984), Power and Adams (1997), PCCRARM (1997a,b), Rahm-Crites (1998), Sandman (1992), Slovic (1987), Spickett et al. (2011), Stackelberg and Burmaster (1994), Treasury Board (2000), US EPA (1998c), US NRC (1983, 1997, 2011a), Yoe (1996), Watson (2010), Weisner (1995), Wende et al. (2012), Weston (2010), WHOROE (2001c), Wilson (2010), Whyte and Burton (1980).

what can go wrong. Hazard assessment bounds the analysis and determines the likelihood of events. There are both natural and human-induced disasters. Human-induced disasters can be both accidental (e.g., spills, collisions) and deliberate (e.g., terrorist acts). Not all disasters are short term (e.g., climate change). Human health risk assessment estimates individual or cumulative risks to people from abnormal events, from cancer, and from noncancerous health effects. Ecological risk assessment estimates the likelihood of adverse effects on plants or animals from exposure to one or more environmental hazards or stressors. There are numerous methods and methodological issues associated with each risk concept.

Emergencies and Disasters There is a tendency in IA practice at the regulatory level to assume that IA requirements are not appropriate in emergency situations. The assumption tends to be that IA requirements are simply too time consuming, and would impede the prompt responses necessary in the event, for example, of a major flood, accident, or terrorist attack. IA requirements, for that reason, generally provide for exemptions to IA requirements for emergency situations. To the extent that major disasters are addressed in IA practice, there seems to be a propensity to “reinvent the wheel,” in terms of disaster planning, with each successive IA. Some jurisdictions have addressed, in part, the relationship between IA and emergency planning and management. In the United States, for example, NEPA-related guidance has been provided regarding the analysis of accidents and intentionally destructive incidents (Eccleston, 2003; Luther, 2007). In the wake of the Deepwater Horizon explosion in the Gulf of Mexico, a federal government report addressed policies, practices, and procedures related to outer continental shelf oil and gas exploration and development (US Administration of Barack H. Obama, 2010). The report addresses, among other matters, the role of programmatic and site specific NEPA analyses in assessing, mitigating, and managing potential impacts and risks. Europe requires specific reasons for exemptions (e.g., urgent and substantial need for project and inability to undertake the project earlier and inability to meet the full requirements of the Directive) (EC, 2006a). Guidelines for rapid environmental assessments in disasters also have been prepared in Europe (Kelly, 2005).

The relationship between IA and emergencies (whether natural or human induced), however, is more complex and subtle that either the blanket assumption that IA is not an appropriate instrument for managing environmental concerns during emergencies or the expectation that the merging of IA requirements and emergency planning/management can be limited to requirements/guidance for a few specific event types and proposal-specific emergency management follow-up procedures. Table 11.6 suggests a range of potential initiatives that would serve to more effectively link and integrate the two fields in a mutually beneficial manner. For example, rather than simply addressing potential risks and accidents on a project-by-project basis, specific requirements and guidelines could be formulated for a list of event types (e.g., terrorist attacks, nuclear material release, major train accident/explosion/chemical release, major flood, tanker sinking, major oil/gas release). Such requirements could be adapted for individual IAs and for emergency planning/management procedures. The event-specific requirements could be modified to suit a list of (GIS cross-referenced) physical/ecological and sociocultural setting types (e.g., arctic, continental shelf, river crossing, environmentally sensitive area, fishery, developing country). Requirements and guidance materials also are likely to be necessary for unique, highly sensitive, and highly valued settings. The matching of requirements and context would be greatly facilitated by regional planning and risk analysis zoning in conjunction with cumulative effects assessment.

IA requirements could be modified to include a rapid IA process stream to be applied in the event of a major incident (Kelly, 2005). IA requirements could be broadened to specify the types of conditions that would have to be met for emergency exemptions to be granted and for the rapid IA process stream to be applied. IA follow-up experiences and insights would inform the evolving set of event-related (generally, by setting types and for specific locations) requirements and guidelines. A general effort could be made to more effectively integrate natural disaster, accident, and intentionally destructive event considerations, together with insights from emergency planning and management, into IA requirements and good practices. Care should be taken to ensure that climate change; social, psychological, and cultural concerns; cumulative environmental effects; uncertainty in all its dimensions and from a precautionary perspective; and links to broader sustainability issues and imperatives are fully reflected in the requirements and guidance materials. Mutual learning among related fields (e.g., emergency planning and management, climate change IA, risk assessment and management, HIA, SIA, SEA, project-level EIA, SA)—all of which are concerned with natural and human-induced disasters—is essential. Resources should be pooled wherever practical, and readily available online. Given the time constraints when emergencies do occur, it is critical that stakeholders have already worked out and agreed upon the responsibilities for avoiding, minimizing, and managing the environmental consequences of major disasters. Research on disaster risk reduction could be coordinated and integrated with the aim of enhancing the capacity to address hazards and to make informed decisions on actions to reduce societal impacts (McBean, 2012). The long-term goal would be, consistent with sustainable development, to shift from response–recovery to prevention–mitigation–resilience building–risk reduction and learning from experience and past mistakes (McBean, 2012). IA could assume a key role in these efforts.

Table 11.6 Examples of Interconnections—IA and Emergencies/Disasters

- An abbreviated, rapid, or "fast-track" IA process track can serve to identify and manage environmental concerns during some types of emergencies and major disasters or during various postdisaster phases.
- The assessment of the effects of proposed actions and their alternatives should include the analysis and management of potential accident-related risks (i.e., emergencies induced by proposed actions).
- In many settings, the environmental baseline capacity is already highly prone/susceptible to emergencies/natural disasters (e.g., severe natural habitat loss, severe limits on ground or surface water supply, limited food supplies, decreased number of wild animal or plant species, near photosynthetic capacity, widespread use of toxic chemicals, spread of alien species, depleted fossil fuel, high level of atmospheric gas emissions). An IA analysis, in such settings, needs to consider the potential that proposed actions might push the environmental capacity beyond sustainability thresholds (i.e., emergency/natural disasters "tipping points"). Arguably, such analyses should be based on highly conservative–precautionary assumptions, and should seek to enhance sustainability rather than to operate within sustainability limits.
- Some environmental settings are highly sensitive and vulnerable to change. Debates regarding the acceptability of risks from accidents or spills in such settings (as part of IA processes regarding major pipelines, for example) often surround questions regarding whether such areas should be "off limits" (i.e., any limits unacceptable) or whether different standards (e.g., design, operations, contingency planning, risk acceptability) should be applied. An SEA approach (undertaken in concert with regional environmental planning), which defines the special "ground rules" concerning, for example, resource development and major projects such as pipelines in such settings, would bring such issues to the fore during the policy/planning stage rather than only addressing them at the project EIA level.
- The potential for terrorist attacks can be an issue for some types of proposed actions subject to IA requirements (e.g., nuclear facilities). Potential terrorist acts can be integrated into IA environmental analyses, wherever pertinent.
- Proposed actions and their alternatives should be designed, managed, and assessed to minimize vulnerability and maximize resistance/resilience in the event of natural disasters, accidents, and terrorist attacks (i.e., effects on proposed actions from emergencies).
- IA represents a decision-making instrument that can help shift the focus from response–recovery to prevention–mitigation, building resilience, reducing risks, learning from experience, and avoiding past mistakes.
- Part of the analysis of IA impacts and options should begin from the assumption that accidents and spills will occur. This suggests, for example, locational decisions that minimize the likelihood and severity of adverse environmental consequences and design-/operational/contingency choices (e.g., double-hulled tankers) premised on "worst-case" scenarios.
- There are close interconnections between acute human health risks analyses (as addressed through emergency planning and management) and both HIA and risk assessment and management.
- IA follow-up should include the monitoring of, for example, accidents and spills and associated contingency and clean-up measures. Part of follow-up planning should include measures to prevent and to minimize the incidence and severity of such incidents.
- The analysis of the likelihood and severity of effects from natural disasters and emergencies is likely to be altered, sometimes profoundly, when climate change considerations are integrated into the analysis.
- An important element of emergency planning and management concerns the division of responsibilities. This can be a problematic issue if it has to be worked out in the midst of the pressures of responding to an emergency or, perhaps years later, in legal proceedings. IA documents, and related follow-up and environmental management planning could clearly define the responsibilities (and associated protocols) of all parties in the event of, for example, an accident or spill.
- The social psychological impacts of natural disasters and deliberate actions can be severe. Emergency management and planning often is poorly equipped to anticipate, analyze, and manage such effects. SIA can make an important contribution to addressing such effects.
- An IA cumulative effects analysis (proposed actions considered in conjunction with other past, present, and likely future actions affecting the same environment) should address the potential for a significant increase in the likelihood of emergencies and/or the likelihood of severe environmental consequences in the event of emergencies or natural disasters.
- IA, because it seeks to predict and manage change well into the future, is fraught with uncertainties. The same could be said for emergency planning and management. The enhanced sharing of knowledge and experience between these two related fields would clearly be mutually beneficial.
- Research on disaster risk reduction could be coordinated and integrated with the aim of enhancing the capacity to address hazards and to make informed decisions on actions to reduce societal impacts. The long-term goal would be, consistent with sustainable development, to shift from response–recovery to prevention–mitigation–resilience building–risk reduction and learning from experience and past mistakes. IA could assume a key role in these efforts.

Sources: Diamond (2005), Eccleston (2003), Kelly (2005), Kumagai et al. (2006), McBean (2012), Utzinger et al. (2005).

Risk Assessment Process Figure 11.3 presents an example of a risk assessment/management process. The process begins by identifying and characterizing the problem and the proposed action. The problem is defined within the context of government requirements, policies and guidelines, and ecological, societal, and political systems (CRAM, 1993). A conceptual model is formulated to provide a framework for generating and evaluating preliminary hypotheses about how and why risk-related effects have or are likely to occur. An analysis plan is prepared describing risk management objectives, options to consider, the scope and focus of analysis, methods, and resource allocation (PCCRARM, 1997b; US EPA, 1998c). The proposed action is scrutinized to identify potential hazards (McCarthy and

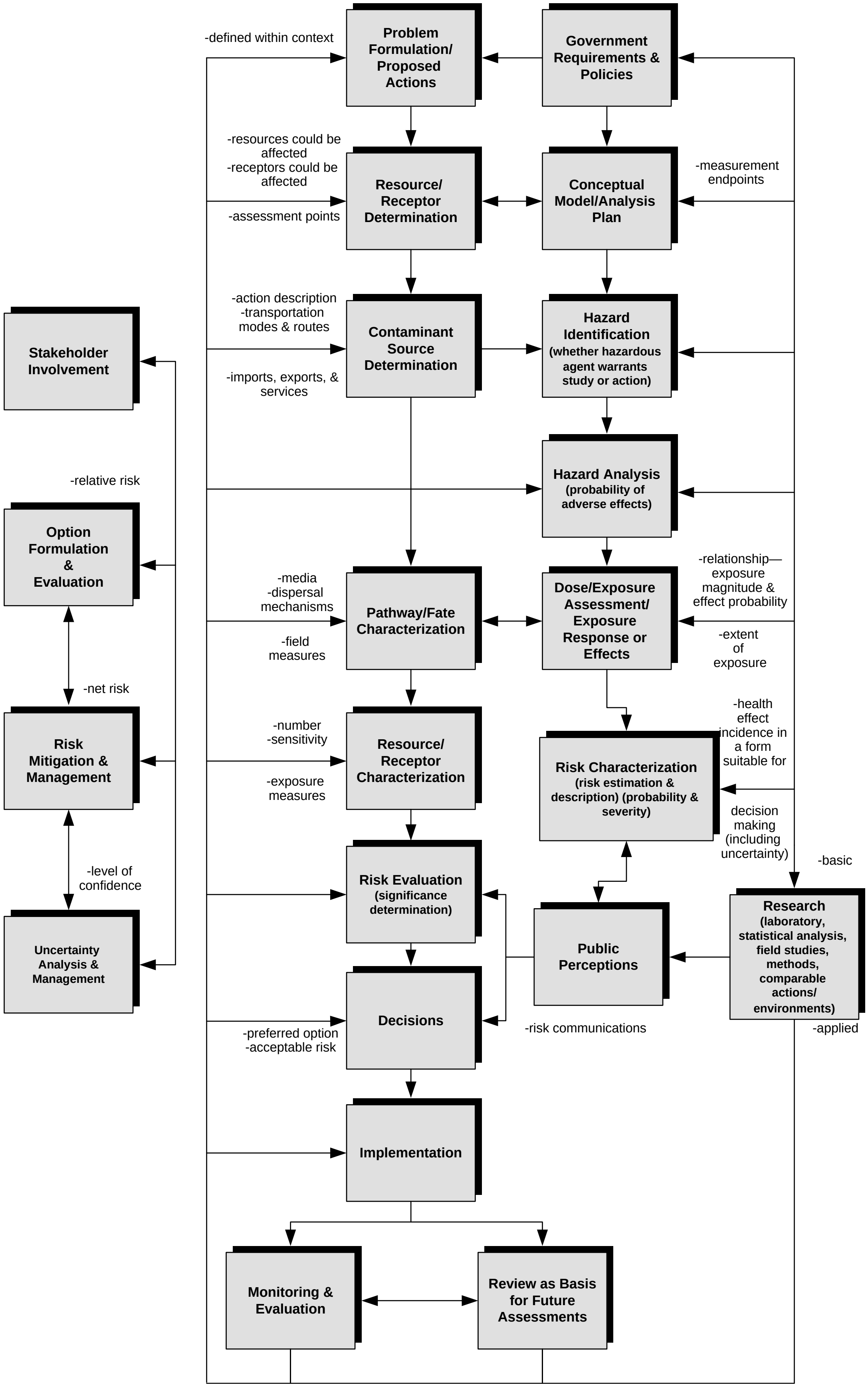

Figure 11.3 Example of a risk assessment management process.

Utley, 2004). Potential health effects associated with the proposed action are identified (Demidova and Cherp, 2005). Hazard identification determines possible sources of harm (usually based on experience with similar technologies, materials, or conditions), explores causal links, identifies the potential adverse effects, and decides whether the effects warrant further study or management action (Canter, 1993b; Carpenter, 1995; CRAM, 1993; Stackelberg and Burmaster, 1994; Yoe, 1996). Contaminant sources; pathways from contaminant sources to resources, receptors, and endpoints; and potentially affected resources, receptors, and endpoints are identified and characterized. A hazards analysis is undertaken to ascertain the probability of adverse events.

The exposure assessment quantifies (e.g., intensity, frequency, duration) the concentrations of contaminants (dose) in the environmental media at the point of human or ecological endpoint contact (Canter, 1993b; Carpenter, 1995; McCarthy and Utley, 2004; Stackelberg and Burmaster, 1994; Yoe, 1996). With ecological risk assessment, it describes the sources of stressors, their distribution in the environment, and their contact or cooccurrence with ecological receptors (US EPA, 1998c). The exposure response assessment determines the relationship of the magnitude of exposure and the probability of effects (Canter, 1993b; CRAM, 1993; Stackelberg and Burmaster, 1994). It involves, in the case of human health effects, evaluating how strongly contaminants elicit health response at various doses (McCarthy and Utley, 2004; Stackelberg and Burmaster, 1994). Ecological risk assessment evaluates stressor–response relationships or evidence that exposure to stressors causes an observed response (US EPA, 1998c). Exposure assessments and exposure response assessments are conducted in parallel and are highly interrelated (CRAM, 1993). Human health and ecological risks, including attendant uncertainties, are presented in a form suitable for public and decision-maker review (CRAM, 1993; Stern and Fineberg, 1996). Risk characterization summarizes the risk analyses, describes the available choices, addresses the implications of uncertainties, and integrates the perspectives and knowledge of interested and affected parties (PCCRARM, 1997b; Stern and Fineberg, 1996; US EPA, 1998c).

Risk evaluation draws upon the risk characterization and public perceptions and is aided by risk communications. It interprets the probability, severity, and significance of estimated and perceived risks (McCarthy and Utley, 2004). Risk acceptability or tolerance and option preference decisions are reached. The decisions are implemented (if approved, often with conditions) and monitored. Monitoring tests the validity of predictions, identifies additional research requirements, contributes to methodological advancements, and identifies the need for management actions (CRAM, 1993). Reviews of the process and of monitoring results are instructive for future assessments (US EPA, 1998c). The process is supported by basic and applied laboratory analyses, statistical analyses, field studies, and comparable actions/environments reviews (CRAM, 1993). Stakeholders are involved in each process activity. Options (e.g., regulatory, nonregulatory) and mitigation measures are formulated and evaluated in an ongoing effort to prevent and reduce risks and uncertainties to acceptable or tolerable levels. Implementation and monitoring are structured and guided by a risk management framework (PCCRARM, 1997b). The analysis and interpretation of qualitative and quantitative uncertainties is consolidated in an uncertainty analysis. The process is open and iterative (PCCRARM, 1997b). Good practice risk assessment and management principles, performance standards, and protocols are formulated, applied, and refined (Canter, 1993b; PCCRARM, 1997b; Steinemann, 2000).

Linking IA and Risk Assessment and Management Risk assessment application in IA practice tends to be confined to large, controversial (high levels of perceived risk) undertakings, usually involving nuclear materials or hazardous chemicals or wastes (Carpenter, 1995). Risk assessment and management has much more to offer. It can supplement regulatory standards and guidelines, which often address risks only partially, indirectly, and qualitatively. It recognizes the limits of deterministic knowledge and the value of probability analysis (Stackelberg and Burmaster, 1994). It provides a systematic, quantitative set of procedures for analyzing, interpreting, and comparing human health and ecological risks and uncertainties (Arquiaga et al., 1992; Suter, 1993). It systematically explores interrelationships that create exposure and effects (Canter, 1993b). It offers an effective bridge to scientific research and to the needs of regulators (Power and Adams, 1997). It appreciates the uncertainties associated with self-organizing and nondeterministic social and ecological systems (Carpenter, 1995). It provides a host of potentially relevant concepts, principles, distinctions, and methods (Canter, 1993b; Erickson, 1994; Grima et al., 1986; Hunsaker and Lee, 1985).

Risk assessment and IA are generally mutually supportive concepts (Grima et al., 1986; Erickson, 1994; Westman, 1985). Risk assessment inputs to IA can aid risk assessment (Barrow, 1997; Ratanachai, 1991). Risk assessment techniques can be incorporated into each IA stage (Demidova and Cherp, 2005). Risk assessment offers a holistic perspective; facilitates the integration of environmental, social, and economic issues; and assists in prioritizing management issues (Hyett, 2010). Principles have been formulated for selectively linking and integrating the two fields (Canter, 1993b). They share a common concern with human health and ecological risks. Both address uncertainty, the role of public perceptions, and the interconnections among science, regulatory requirements, environmental management, and public involvement. Risk assessment and cumulative effects assessment both systematically explore interrelationships. IA and risk assessment processes share many common elements (e.g., problem definition, baseline analysis, impact prediction, mitigation, monitoring) (Dooley, 1985). There are, however, differences also. Risk assessment and management only deal with probabilistic risks. IA addresses risks and impacts and considers certain, uncertain, and probabilistic effects (Dooley, 1985). Risk assessment tends to place less emphasis on alternatives (Barrow, 1997). It is more oriented toward internal management. It is less prone to consider opportunities as well as threats. It is more often applied to regulate industrial and other activities (Barrow, 1997). Enforcement with IA tests for compliance. Risk management determines whether the event probabilities are greater than those agreed to (Dooley, 1985).

Before strengthening the links between IA and risk assessment and management, the many criticisms of the latter must be considered. Some question whether available health and environmental risk data can support the assumptions, models, probability distributions, interpretations, and conclusions (i.e., the pretense of knowledge) (Gee and Stirling, 2003; Heiman, 1997; Montague, 2004; Power and Adams, 1997; SEHN, undated). Concern is raised about the adequacy of risk assessment methods to properly address complex environmental conditions, new technologies, synergistic relationships, latent, indirect and cumulative effects, exogenous events, vulnerable populations, interdisciplinary connections, processes with large geographical and temporal reaches, and carrying and assimilative capacity (Banken, 1998; Davies and Sadler, 1997; Power and Adams, 1997; Tickner and Raffensperger, 1998). The field is criticized for insufficient consideration of public concerns, values, perspectives and perceptions, cultural differences, the social context, nontechnological options, and ecological and biospheric limits (Davies and Sadler, 1997; Fischer, 1996; Kamrin, 1993; Raffensperger and deFur, 1997). It is portrayed as relying too heavily on inadequately supported technical and scientific interpretations and opinions (Hardstaff, 2000). It is described as biased in favor of quantitative scientific methods, rational and centralized decision making, technological "solutions," short-term and local effects, and the analysis of individual environmental components rather than whole systems (Fischer, 1996; Heiman, 1997; Montague, 2004; Raffensperger and deFur, 1997). It is criticized for its failure to warn users about inherent limitations and potential misuses and for not adequately considering cumulative and synergistic risks (Hyett, 2010; Montague, 2004). It is pointed out that it tends to consider only a single option, assesses the risks to others without obtaining their informed consent, ignores benefits or the lack thereof to exposed individuals, and gives people a false sense of safety (Montague, 2004). It is prone to jargon, an unsupportable "aura" of objectivity, and a reliance on the current distribution of power and resources (Heiman, 1997). These shortcomings, where valid, could inhibit democratic debate, heighten public fear and mistrust, exacerbate conflict, reinforce power inequities, undermine political legitimacy, detract from the authority and credibility of associated institutions and science in general, and divert attention and resources away from fundamental social and ethical questions such as acceptable levels of risk, uncertainty, and environmental disruption (Fischer, 1996; Gee and Stirling, 2003; Power and Adams, 1997; Raffensperger and deFur, 1997; SEHN, undated; Tickner and Raffensperger, 1998).

To respond to these concerns, IA practice could tightly circumscribe the application of risk assessment and management to proposals, settings and effects where technological and environmental databases are adequate. Risk assessment and management can be supplemented or combined with other approaches and methods (e.g., consequence analysis, semiquantitative hazards analysis, performance standards, the precautionary principle) (US NRC, 1994). The limitations of risk assessment need to be clearly acknowledged and appropriate steps taken to avoid and minimize its negative tendencies (Montague, 2004). Instances when risk assessment is inappropriate need to be acknowledged (e.g., cannot objectively determine risk acceptability, poorly suited for determining compliance, not well suited for addressing cumulative or synergistic impacts (Hyett, 2010). Governments and regulators could provide more good practice requirements and guidance (Hood and Nicholl, 2002; Hyett, 2010). Greater care could be taken not to oversimplify system interactions or to assume linear risk pathways (Hyett, 2010). More emphasis could be placed on defining and resolving the problem rather than on adapting a predefined set of methods (US NRC, 1994). Unnecessary exposures should be avoided whenever possible, exposures should be periodically reviewed with the aim of eliminating or reducing exposures to the lowest feasible levels, and human rights should be respected (Montague, 2004). More stress could be placed on integrating IA-related risk assessment and management efforts with organizational risk reporting, assessment, and management procedures and practices (Hood and Nicholl, 2002). Additional consideration could be given to risk–sustainability links (Hyett, 2010). Modifications and refinements could be made to minimize potential deficiencies. A greater effort could be made to link the treatment of risk in IA to other planning processes, requirements, and institutional arrangements (Watson, 2010).

11.4.4 The Precautionary Principle

Defining the Precautionary Principle Decision makers face a dilemma. Scientific knowledge of complex environmental and social systems is far from definitive. There will always be scientific uncertainties and varying interpretations of what represents adequate evidence to support a scientific conclusion. Scientists are understandably cautious in coming to firm conclusions. But serious, potentially catastrophic, environmental and health consequences have, and can occur as a result of individual and cumulative human actions. It may be too late to avoid such consequences if no actions are taken until scientific standards of proof are satisfied. In the meantime, decisions must be made on a host of proposed activities that have the potential for environmental and health harm. It is not sufficient simply to approve all activities except those where scientific evidence demonstrates the likelihood of serious or irreversible harm. Nor is it appropriate to automatically reject all proposed actions where there are uncertainties about harm potential and severity. Alternative or supplementary standards of evidence and decision rules are needed to provide a sound and consistent decision-making basis (CEC, 2000). The precautionary principle (PP) is one way to meet this need.

There is no commonly accepted definition of the PP or the precautionary approach. Most definitions begin with the *threat* or risk of harm from a proposed activity to the environment or human health. The threat is based on preliminary scientific evaluations that provide reasonable grounds for concern about the potential for dangerous effects on the environment or on human, animal, or plant health (CEC, 2000). Although possible harm is known, the probability of the harm is not known (WHOROE, 2001c). There may be *shortcomings* (e.g., lack of, inconclusive, or insufficient evidence), *uncertainties* (e.g., lack of certainty, some cause and effect relationships not fully understood) or *divisions* (e.g., lack of consensus) in the scientific knowledge base (CEC, 2000; Hardstaff, 2000; Wingspread Statement on the Precautionary Principle). The conclusion is drawn that scientific knowledge limitations should not preclude or postpone *actions* to prevent the harm when the failure to act would result in serious or irreversible environmental damage (Brown, 2003; Craik, 2008).

The PP shifts the burden of proof to the proponent to demonstrate that proposed action will not lead to serious or irreversible environmental damage, stresses prevention over mitigation, sees uncertainty as a threat (i.e., absence of evidence is not evidence of the absence of a threat), and seeks the elimination of harmful chemicals rather than risk management (Craik, 2008; Quijano, 2003; Tickner, 2004). The moral component of precaution is consistent with the common law obligation of due care and the duty of private actors to behave as society has a right to expect from reasonable people (Jasonoff, 2003). The PP accepts the uncertainty involved in assessing complex systems and challenges government and business to rethink their responsibility to society (Edwards, 2005; Tickner, 2003c). It demands a more dynamic and transparent interaction between science and policy, suggests that there are prudent ways to behave within the limits of available knowledge and experience, and requires an acknowledgement that decision making under uncertainty is often messy (e.g., precise point estimates may not be available) and value based (Jasonoff, 2003; Tickner, 2003c).

The PP is suitable for application when there exists considerable scientific uncertainty, when scientifically reasonable models or scenarios of possible harm are inappropriate, when uncertainties cannot be reduced without increasing ignorance at the same time, when the potential harm is sufficiently serious or even irreversible for present or future generations, and when delays make effective countermeasures more difficult (Kaiser, 2003). Claims of scientific certainty must be critically examined if the PP is to be effectively applied (Barrett and Lee, 2003). The PP is not relevant in cases of ignorance (impacts and probabilities are unknown) or when causal relationships are established (certain and preventable or probabilities can be estimated) (WHOROE, 2001c). Decisions pertaining to uncertainty and regarding when the PP is relevant and appropriate are strongly influenced by institutional, political, and scientific factors (i.e., the context within which knowledge claims are generated, contested, and accepted) (Barrett and Lee, 2003).

Interpreting the Precautionary Principle There are multiple interpretations regarding the harm that should trigger the PP (e.g., harm alone, serious or irreversible harm from proposed action, serious or irreversible harm from cumulative actions, varying interpretations of serious) (Tickner and Raffensperger, 1998). Opinions vary concerning scientific evidence standards. Action has been variously interpreted as (1) deciding that inaction to ameliorate harm is not justified by scientific uncertainty (i.e., action generally proceeds but with mitigation to reduce the threat of harm); (2) deciding that the proposed activity is unacceptable because the scientific evidence is inadequate or because the scientific evidence warrants rejection; (3) only proceeding with the proposed activity if it is proven safe scientifically (i.e., reversing the burden of proof and requiring a level of certainty); (4) only proceeding if a reasonably convincing case can be made that the action is safe (i.e., reversing the burden of proof, acknowledging uncertainties, requiring a weight of evidence argument); and (5) proceeding very carefully (i.e., balancing the burden of proof by adopting prudent decision-making criteria such as safety factors, no or least regrets, best available technology, stringent monitoring) (Gullett, 1997, 1998; Hardstaff, 2000; Wiener and Rogers, 2002). The standards of proof are generally greater if the proposed action is "a priori" hazardous or "new," as in a new technology. Qualifications can be added when applying any interpretation (e.g., proportionality, relative to alternatives, consideration of benefits, additional measures to cope with uncertainties) (Wiener and Rogers, 2002).

These varying interpretations imply thresholds or criteria for threat or risk of harm (which infers a combination of likelihood and severity), thresholds or criteria for deficiencies in scientific knowledge and rules, and principles and procedures for applying the thresholds or criteria. The PP needs to be supported by regulatory authority levels of protection and evidence standards of unacceptable harm (CEC, 2000; Gullett, 1997). Terms such as threat, harm, serious or irreversible, definitive, fully, lack, environment, health, and burden of proof require definition and interpretation, overall, for classes of situations or on a case-by-case basis. A mechanism for determining whether the PP is to be applied is required. Criteria, procedures, decision rules, and institutional arrangements for applying the PP are needed (CEC, 2000). The relationship of PP requirements to risk regulation (e.g., an overarching principle, a risk acceptability criterion applied after risk assessment), and to IA requirements needs to be addressed (Wiener and Rogers, 2002). Some argue that the PP also necessitates a reversed burden of proof from victims to proponents, an open, transparent, and democratic decision-making process, a systematic analysis of all alternatives for reducing (to acceptable levels) or eliminating the harm, a greater weight to "ignorance" in decision making, preventative anticipation or risk avoidance as decision norms, and a proactive effort to safeguard ecological space, to minimize serious or irreversible environmental damage, to avoid social deprivation, to operate within ecological and biosphere limits, to pay past ecological debts, and to protect the interests of future generations (O'Riordan and Cameron, 1994; Porritt, 2000; SEHN, undated; Raffensperger and deFur, 1997; Tickner and Raffensperger, 1998; WHOROE, 2001b,c).

An Example Precautionary IA Process Figure 11.4 is an example of a precautionary IA process. A decision is first made regarding whether the precautionary trigger applies to the proposed action. The PP is commonly triggered when there is a potential for serious or irreversible environmental or human health harm, a scientific evaluation, and a scientific uncertainty (CEC, 2000). The strength of the connection between harm and evidence ranges from significant risk, through likelihood of damage, to reasonable grounds for concern that harm may be caused, to potential for damage and no proof of harmlessness (Gullett, 1997). Very general PP requirements and guidelines maximize the ability to make commonsense adjustments to individual circumstances but increase the potential for arbitrary, biased, and inconsistent interpretations and judgments. A scientific evaluation identifies the potential threat, characterizes the problem, and assesses knowledge and uncertainty levels (CEC, 2000). Qualifications to the principle are added, where appropriate (CEC, 2000; EnHealth Council, 2001a; Government of Canada, 2001). Key terms are defined. Links to IA, to risk management (a framework for or a tool within), and to other environmental management requirements are identified (CEC, 2000; Government of Canada, 2001). Cross-disciplinary approaches and multiple lines of inquiry are favored (Guillette, 2003; Tickner, 2003b). Relevant implications are noted. A clear rationale is provided for each interpretation. The input requirements to apply the PP are specified. The overall precautionary approach is consolidated. Precautionary goals are set (Tickner and Raffensperger, 1998). The precautionary elements of the study design are prepared. A precautionary perspective is applied to the proposal purpose, to the assessment of need, and to the identification of alternatives (Gullett, 2000).

What is known (certainties) and what is not known (types and sources of uncertainties) are determined (Tickner and Raffensperger, 1998). Harm and scientific evidence thresholds and criteria are established. The harm criteria include such considerations as magnitude, temporal and spatial scale, reversibility, degree of complexity and connectivity, vulnerable environments and populations, error friendliness, catastrophic potential, and availability of alternatives to reduce or eliminate harm (Tickner, 1998). The scientific or causal inference criteria pertain to such matters as amount, strength, and consistency of evidence across a wide range of circumstances, knowledge coherence, plausibility of effect, consideration of all evidence and plausible hypotheses, study power to detect effect, statistically significant evidence, public health significance, and causal relatedness based on previous experience (Tickner, 1998). Qualitative and quantitative knowledge is fully and explicitly discussed (Tickner, 2003b). Precautionary decision rules, thresholds and criteria, and application principles and procedures are formulated. Prevention, not mitigation after the damage is done, is emphasized (Quijano, 2003). The decision rules determine what, for example, represents a basis for a moratorium on all actions: phasing out, action rejection, action deferral, additional study (e.g., a risk assessment), incremental approval and implementation, and specific approval conditions (Kaiser, 2003; O'Brian, 2003). Further refinements to the precautionary approach occur through the balance of the IA process.

The customary IA process activities are undertaken. The PP contributes to assessing need (need for reassessment); which alternatives are acceptable, which elements of the proposed action could pose an unacceptable harm; how uncertainties are to shape the application of the principle; which predicted risks and impacts could represent an unacceptable harm; which options are likely to be more harmless; whether mitigation and management measures are likely to reduce the harm to acceptable levels; whether the anticipated risks, impacts, and uncertainties are significant; and whether the proposed action is acceptable (Gee and Stirling, 2003; Gullett, 1997, 1998, 2000; Quijano, 2003). Precautionary measures to manage anticipated impacts, risks and uncertainties are integrated into management strategies (Gullett, 1998). The PP affects decision making (e.g., the taking of precautionary action, the weight of uncertainties in final decisions) (Gullett, 1999, 2000). It influences implementation, monitoring (e.g., early warning, contact protocols, precautionary actions), follow-up, and evaluation (i.e., precautionary measures to be followed unless compelling reason for not doing so) (Gee and Stirling, 2003; Gullett, 1998; ten Hallers-Tjabbes, 2003; Kaiser, 2003; Tickner, 2003a). Care is taken to ensure that the action stays within the precautionary acceptability levels. The PP application is evaluated, both to facilitate postapproval adaptations and to assist in future applications. The IA process is open, transparent, iterative, participatory, and democratic (Gullett, 2000; Quijano, 2003; Tickner, 2003a; Tickner and Raffensperger, 1998). The public and government agencies are involved in scoping, adapting, and applying the PP. The precautionary analyses draw upon multiple disciplines, sources of information, forms of expertise (including local, lay, and traditional knowledge), values, goals, and ways of reasoning (Harremoës et al., 2002). They

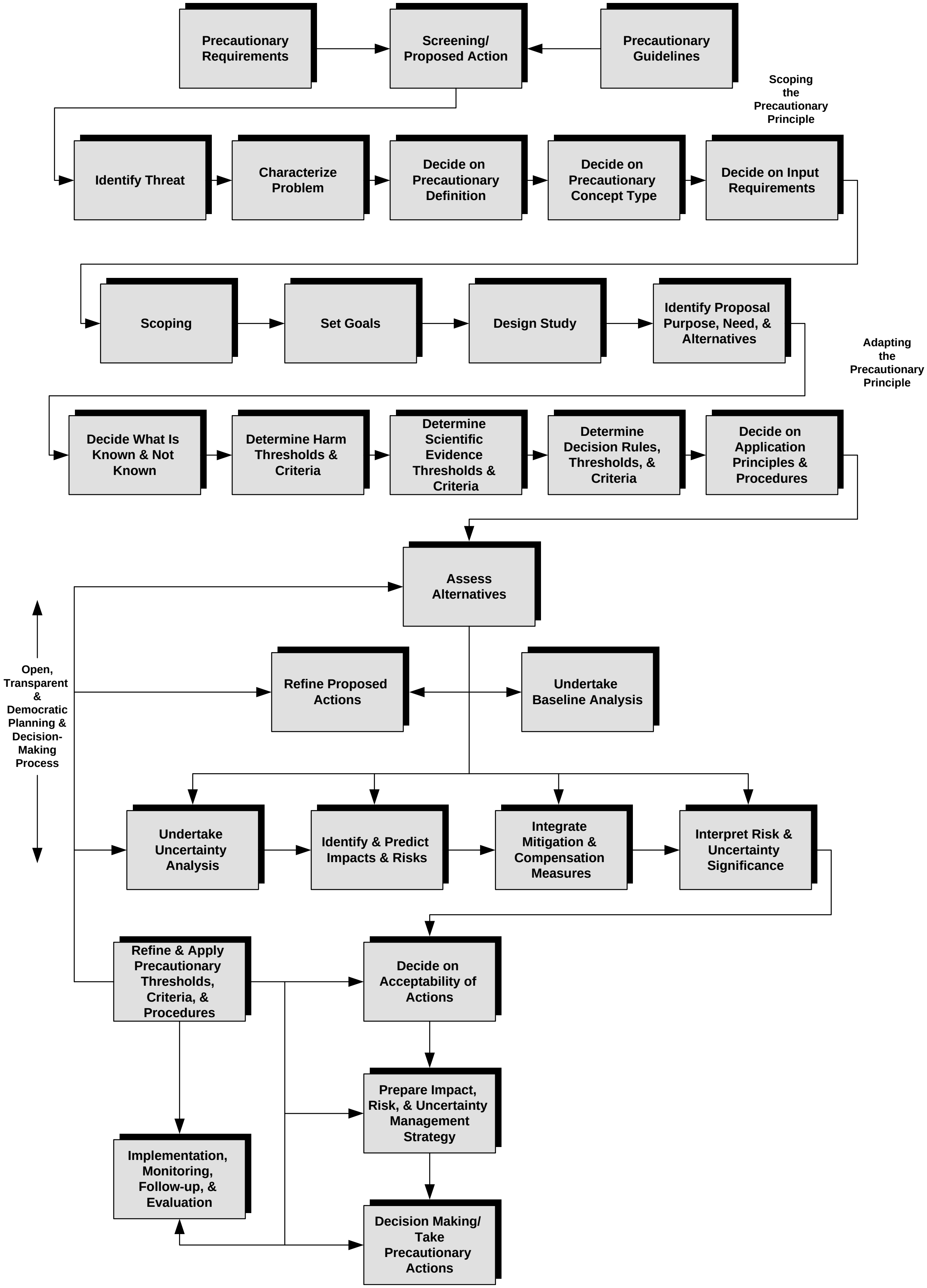

Figure 11.4 Example of a precautionary IA process.

also contribute to reducing and coping with uncertainties and errors (especially Type II errors) (Gullett, 2000).

Potential Contributions of the Precautionary Principle to IA Practice The PP can reduce the incidence and severity of serious, irreversible, and catastrophic environmental harm—a response to the "tragedy of the commons" dilemma, and facilitate the realization of positive public health and environmental goals (Gullett, 1997; O'Brian, 2003). It provides a philosophical framework and an operational guideline for consistently addressing uncertainties in decision making (Gullett, 1997; Seidler and Bawa, 2003). It tempers rational/synoptic IA approaches with corrective measures such as monitoring and feedback, favors the environmentally benign, links potential harm to uncertainty, permits a more careful consideration of available options, requires scientists and other analysts to clearly identify all the plausible effects of a proposed course of action, expands the range of participants in risk decisions, and recognizes the inherent limits in acquiring and applying scientific knowledge (Brown, 2003; Craik, 2008; O'Brian, 2003; Tickner, 2003e). It underscores the need to systematically consider all available options for avoiding harm, helps identify Type 3 errors (good research but the wrong problem), and necessitates the expanded use of science to monitor the integrity of health and the environment (Gullett, 2000; Kaiser, 2003; Thornton, 2003; Tickner and Raffensperger, 1998). It reshapes decision making by shifting the burden of proof from the public to the proponent, by seriously assessing proposal acceptability, by broadening decision making beyond science, and by contributing to more environmentally prudent decision making (Craik, 2008; Tickner and Raffensperger, 1998). It reinforces democratic and substantive environmental and social values and imperatives (Government of Canada, 2001). It is sufficiently flexible to adapt to varying contexts and to proposal and action-specific circumstances. It helps identify research and policy needs (e.g., integrative assessment frameworks, early warning funding, better methods for assessing technologies and activities, means of addressing the fragmented knowledge base, improved language for expressing conclusions and discussing science limits and uncertainties, education for interdisciplinary problem solving) (Tickner, 2003e).

The PP, depending on how it is interpreted and applied, can have serious drawbacks. There will always be risks and uncertainties when seeking to predict and manage environmental change. Few, if any, IA proposed actions would be acceptable if the lack of "proof" of safety or acceptable levels of environmental impact is sufficient grounds for rejecting or deferring a proposed action (Holm and Harris, 1999; Bailey, 1997a). A decision not to act creates risks of its own (Farber, 2003–2004). IA practice and the PP both operate somewhere between the two extremes of scientific certainty of no harm and scientific certainty of harm. Presumably, the goal of the PP is to place more weight on scientific uncertainty about harm potential and less on scientific uncertainty about no harm. Insisting on more decision-making weight for uncertainty, however, could oversimplify and distort an evaluation (Holm and Harris, 1999). Other, perhaps equally or more valid and compelling perspectives, values, and positions could receive no, minimal, or insufficient consideration (Bailey, 1997b). Decision making might be reduced to a hedging mechanism (Wildavsky, 1995).

The breadth of PP interpretations could be used to justify everything from minimal changes in conventional approaches (e.g., identify uncertainties and be careful) to rejecting almost any proposed action, many with significant environmental, social, and economic benefits (Appell, 2001; EnHealth Council, 2001a; Farber, 2003–2004; Whelen, 1996). Potential negative outcomes could include arbitrary, inconsistent, and distorted decisions; the stifling of innovation, application abuses (e.g., trade protectionism); the advancement of agendas of dubious validity and with limited public support; unwarranted public and private costs and delays; the neglect of legitimate risks; the exacerbation of unwarranted fears; the rejection of scientific knowledge; and the misuse of scarce environmental management resources (Appell, 2001; Bailey, 1997a; Foster et al., 2000; Government of Canada, 2001; Hardstaff, 2000; Holm and Harris, 1999; Whelen, 1996). These potential shortcomings point to the need to recognize the valid concerns underlying the principle while avoiding more extreme interpretations and being wary of overly vague and discretionary requirements and guidelines. A prudent, open, and democratic process for both formulating and applying the PP is essential. Vigilance is required to prevent and minimize abuses, distortions, and negative propensities (Wiener and Rogers, 2002). The risks and uncertainties of action and inaction both require consideration (Wiener and Rogers, 2002). Specific requirements and guidelines are needed concerning how to apply the principle within the IA process. The limited experience with the PP underscores the need to compile a good practice knowledge base (Gullett, 1997). More emphasis, when applying the PP, needs to be placed on generating and assessing alternatives, on facilitating greater participation and burden shifting, on reducing multiple risks over the long term, and on stimulating innovation toward sustainability (Tickner, 2004).

11.4.5 Human Health

Definitions and Distinctions A further major uncertainty approach is human health impact assessment. HIA considers human health effects resulting from certain, probabilistic, and uncertain risks and impacts from proposed actions (BMA, 1998; US NRC, 2011a). Health is defined as, "a complete state of physical, mental, and social well-being and not merely the absence of disease" (WHO, 1967). HIA is a combination of methods, procedures, and tools that can help decision makers identify the magnitude and distribution of public health consequences of proposed policies, plans, programs, and projects, together with appropriate actions to measure those effects (IAIA, 2006a; Kemm and Parry, 2004a; US NRC, 2011a). The demand for and practice of HIA has expanded dramatically in recent years, including the development and refinement of good practice standards (Bhatia et al., 2010; Cole and Fielding, 2007; Dannenberg et al., 2006; IAIA, 2006a; US NRC, 2011a).

HIA minimizes the negative and accentuates the positive impacts on the health and well-being of a specified population from a proposed action (Kemm and Parry, 2004a; McIntyre and Petticrew, 1999; NYPHO, 2001). It can be applied to a project, a policy, a program, or a plan. It encompasses the consideration of both the magnitude of health effects on a population and the distribution of effects within the population (Mackenbach et al., 2004). It provides a means by which health hazards, risks, and opportunities can be identified and addressed early in the policy/planning/development process (IAIA, 2006a). It can be a component of SEA or EIA or a "standalone" evaluation for an action subject or not subject to IA requirements. It is generally instigated when there is uncertainty or concern about possible health risks of a proposal or possible opportunities to increase health gain (Scottish Needs Assessment Programme, 2000). HIA overlaps with and is closely connected with SEA, SA, EIA, SIA, risk assessment, and management and health planning, management, and services (EnHealth Council, 2001a). It integrates knowledge and methods from psychology, sociology, economics, toxicology, and epidemiology (Erickson, 1994). It incorporates personal, social, cultural, economic, and environmental factors and considers the opinions, experience, and expectations of potentially affected parties (Davies and Sadler, 1997; EnHealth Council, 2001a; Lehto and Ritsatakis, 1999). It includes the consideration of individual (e.g., genetic, biological, lifestyle, behavioral, circumstantial), social/environmental (e.g., physical, community conditions, economic–financial conditions), and institutional/public policy (e.g., capacities, capabilities, jurisdictions, policies) health determinants (IAIA, 2006a). It recognizes that human health and environmental integrity are interdependent and essential for sustainability (Davies and Sadler, 1997).

Two broad HIA approaches, at the regulatory/legislative level, include (1) requiring, supporting, and promoting the use of HIA (e.g., required as part of IA processes, legislating health authorities to require an HIA at their discretion, legislating that potentially affected communities can request discrete HIAs and be involved in process, regulations or policies that support but do not require the use of HIA) and (2) health within government processes (e.g., requiring a health review or screening for all government policies, discretionary use of non-HIA processes to look at health issues) (Harris-Roxas et al., 2012). At the applied level, HIA can take the form of a quick screening, checklist, or audit (to determine if analysis is warranted), a rapid appraisal, desktop, or mini-impact assessment (available data, minimal quantification, single meeting, structured workshop), an intermediate or standard HIA (standard practice, limited literature review, largely reliant on routine data, impacts quantified, stakeholder participation, nonrigorous, sampling methods, threshold analyses), or a comprehensive or maxi-HIA (extensive literature search, primary and secondary data, rigorous with controlled populations where possible, extensive quantification, sampling and stakeholder participation) (Forsyth et al., 2010; Lehto and Ritsatakis, 1999; Mindell et al., 2004; Parry and Stevens, 2001; Scott-Samuel et al., 1998).

The level of HIA undertaken depends on the proposal timescale, available resources, the importance of the proposal, and the potential health effects (Mindell et al., 2004). HIA can be prospective (potential health impacts), retrospective (impacts after implementation), or concurrent (assessed during implementation) (NYPHO, 2001). It can adopt a broad (holistic view of health, sociological roots, democratic, general quantification, evidence from key informants and popular concerns, low precision) or a tightly defined (defined and observable aspects, epidemiology and toxicology roots, quantification, measurement evidence, high precision) perspective (EnHealth Council, 2001a; Mindell et al., 2004; Palmer, 2004). It can focus on health or disease, be based on a participatory process or on expert opinion, or can adopt a qualitative or quantitative approach (Ison, 2004; McCarthy and Utley, 2004). It can be part of policy preparation, an IA component, or independent from IA (e.g., voluntary, health advocacy) (Cole and Fielding, 2007; Lehto and Ritsatakis, 1999). It can be mandated, serve a decision-support role (voluntary or partnership) or represent a form of advocacy (Harris-Roxas and Harris, 2011). It can be proponent/government or community-driven (Cameron et al., 2011). It can occur at an international, national, subnational, regional, or local level (Birley, 2007; Gunning et al., 2011; Tugwell and Johnson, 2011). It can emphasize health equity or focus on the health impacts of climate change (Gunning et al., 2011; Simpson et al., 2005; Spickett et al., 2011). Often these varying approaches are combined in a complementary manner and are adjusted to suit the context (e.g., simple problems, complex problems, simple and complex problems) (Harris and Spickett, 2011; Harris-Roxas and Harris, 2011; McCarthy and Utley, 2004; Putters, 2005).

HIA Process Figure 11.5 is an example of a comprehensive HIA process. More abbreviated forms (e.g., screening and appraisal only) are also possible (Ison, 2004). The overall process is guided by principles such as democracy, equity, sustainability, the ethical use of evidence, and a comprehensive approach to health (IAIA, 2006a). Screening determines which actions require further review or more detailed health-related analysis, which actions have clearly negligible impacts or produce well understood and easily controllable health effects, and which actions require more information (Bhatia et al., 2010; EnHealth Council, 2001a; IPHI, 2001; Lehto and Ritsatakis, 1999). Particular emphasis is placed on the potential for substantial health effects, especially avoidable, irreversible, catastrophic, and unequally distributed effects (Bhatia et al., 2010). Scoping

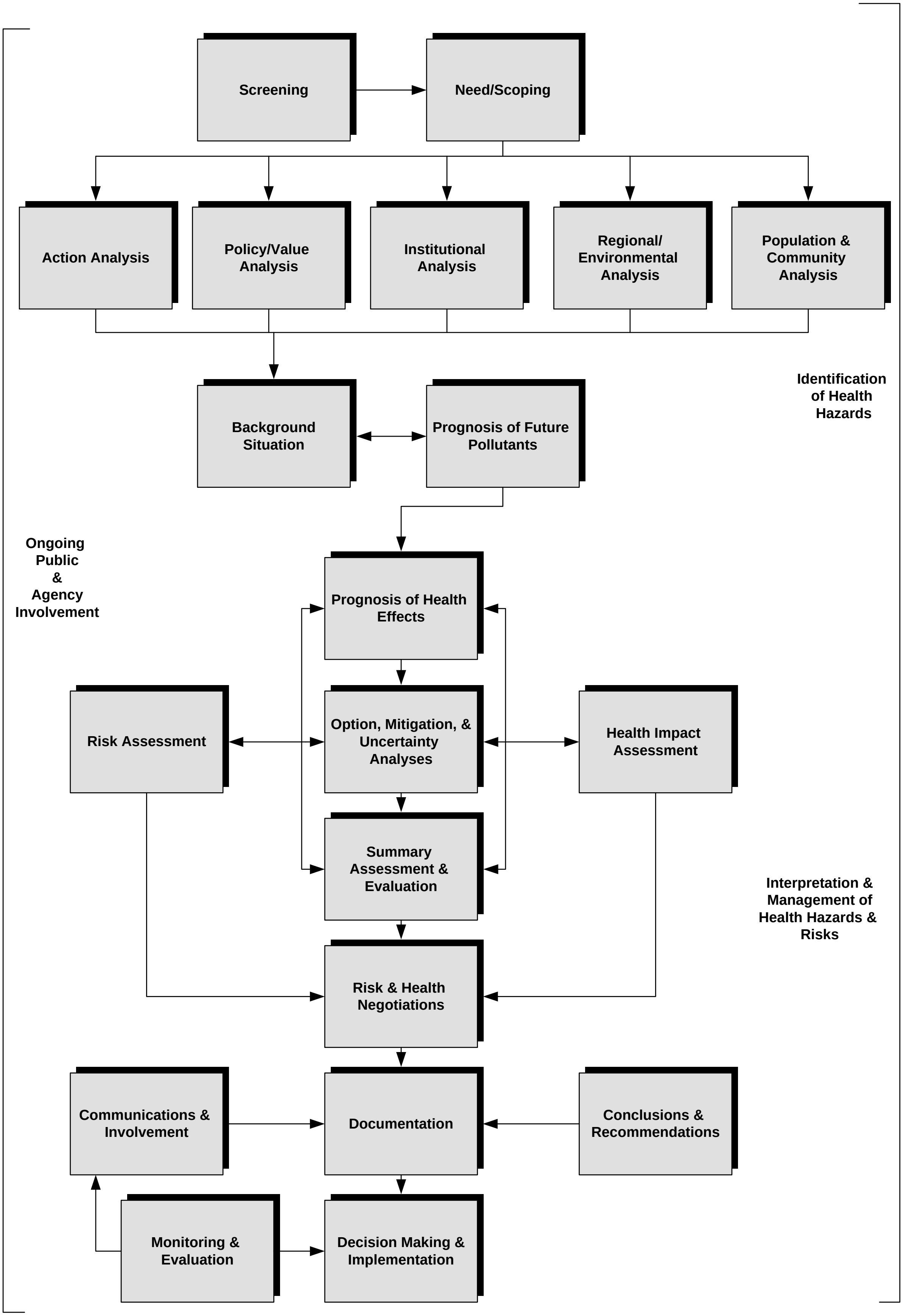

Figure 11.5 Example of a human health impact assessment process.

(a rapid appraisal process) is based on an overview analysis, the application of tools such as checklists and workshops, and extensive stakeholder discussions (Slotterback et al., 2011; Winkler et al., 2011). It confirms and refines need; identifies issues, priorities, alternatives, potential pathways, and standards; specifies potential health concerns and hazards; identifies data requirements and gaps; designs monitoring surveillance systems; and determines the type of HIA (Bhatia et al., 2010; EnHealth Council, 2001a; Winkler et al., 2011). It also bounds the analysis, determines the level of detail, establishes the schedule, selects the study team, designs the approach, decides on consultation procedures, determines documentation requirements, and allocates resources (Bhatia et al., 2010; IPHI, 2001; WHOROE, 2001a). Decision-making links are identified and clarified from the outset (Elliott and Francis, 2005).

Several analyses establish the basis for assessing health effects. Proposal characteristics (e.g., emissions, effluents) that could induce health effects in target populations (e.g., workers, nearby residents) are identified. Relevant policies are determined. Goals and objectives to guide the process are set. The capacity and capability of health protection agencies to prevent and ameliorate acute and chronic health concerns are determined (Arquiaga et al., 1994; Lehto and Ritsatakis, 1999). The physical, natural, resource, built environmental, and land use conditions (community profiling) likely to affect the incidence, dispersion, severity, and management of health effects are identified (Bhatia et al., 2010; Hansell and Aylin, 2003; Lehto and Ritsatakis, 1999). Population (e.g., levels, geographic distribution, food sources and eating habits, age distribution, socioeconomic status, health status, educational levels, genetic endowment) and community (e.g., social support networks, lifestyle and behaviors, community structure, working conditions) characteristics, likely to influence the incidence, severity, and distribution of human health effects, are determined (i.e., health determinants) (Ali et al., 2008; Bhatia et al., 2010; Davies and Sadler, 1997; EnHealth Council, 2001a; Health Canada, 2000; Kwiatkowski, 2004; Lehto and Ritsatakis, 1999). Preexisting health hazard sources (e.g., surface and groundwater water pollution, air pollution, soil and crop contamination, noise, odors, radiation) and health hazards (e.g., communicable diseases, noncommunicable diseases, inappropriate nutrition, injuries, mental disorder) are determined. Methods are justified; data gaps, quality, validity, and statistical stability are assessed; uncertainties are identified; sources of best available evidence are determined; and assumptions are established and substantiated (Bhatia et al., 2010; Hansell and Aylin, 2003).

The prognosis of future conditions establishes how health risks and hazards could change through the duration of the proposed action. It considers projected population levels and characteristics, planned and anticipated land and resource uses, expectations regarding the dispersion and dilution of pollutants, and projections of the exposure of the target populations to health effects from expected future background health hazards. The estimation of potential health effects from the proposed action involves a risk assessment (where probability distributions for health effects can be predicted), a health impact assessment (where potential health hazards and benefits are qualitatively and semiquantitatively described in terms of potential pathways and outcomes) and an uncertainty analysis (Bhatia, 2007; Tickner, 2003d). All three identify and assess options and mitigation measures as means for avoiding and reducing adverse health effects and for enhancing benefits. They also integrate stakeholder perceptions, knowledge, experiences, and perspectives (IPHI, 2001; WHOROE, 2001a). The risk assessment predicts the probability of acute and chronic (cancer-related and noncancer-related) health effects. The health impact assessment identifies and predicts direct and indirect health effects upon exposed segments of the target populations (Davies and Sadler, 1997). Potential chemical, radiological, biological, physical, and psychological health effects are considered (Arquiaga et al., 1994). Causal links between exposure or determinants and physical or mental health are traced (Harris, 2009). Links to physical, natural, social, economic, and service impacts are taken into account (EnHealth Council, 2001a). Hazard agents, exposure conditions, physical health effects, beneficial health effects, effects on health care services, social well-being, social and community health, and psychological well-being are all considered (Davies and Sadler, 1997; Health Canada, 2000). The equity in the distribution of positive and negative health effects is considered (Simpson et al., 2005).

The risk assessment and health impact assessment are combined in a summary assessment of individual and cumulative effects (Kreig and Faber, 2004). Changes caused by proposed actions and other societal changes are clearly differentiated (Kauppinen and Nelimarkka, 2004). Health risk acceptability and impact significance are evaluated, recognizing mitigation and enhancement potential (Davies and Sadler, 1997). Uncertainties, the limitations of the HIA, and methods for coping with uncertainties are specified (Ardern, 2004). A health impact management strategy is devised encompassing such matters as objectives, policies, tactics, priorities, roles and responsibilities, contingency and emergency response procedures, mitigation commitments, compensation criteria and procedures, research and information needs, resources for postproposal management, and monitoring requirements (EnHealth Council, 2001a; Winters and Scott-Samuel, 1997). Documents detail and summarize all aspects of the process, including conclusions and recommendations (WHOROE, 2001b). Decisions are made based on the documentation and on the consultation activities. Decision makers are fully involved in the process from the outset (Elliott and Francis, 2005). Public and agency involvement occurs in all HIA process activities. Agency involvement occurs through an agency steering committee and by means of contacts with individual agencies. Public involvement and participation is critical (Tamburrini et al., 2011). Measures employed include stakeholder and key informant interviews, surveys of potentially affected populations, a public liaison committee, and periodic consultation events (e.g., open houses). The desirability of reducing tensions and conflicts and of obtaining public acceptance by enhancing positive impacts is emphasized (Tamburrini et al., 2011). Opportunities to engage health professionals, policy makers, and affected communities are strengthened through working partnerships (Tugwell and Johnson, 2011). The proposed action is implemented (if approved) with environmental and health control conditions (EnHealth Council, 2001a; IPHI, 2001). Health indicators are identified. Key health conditions, hazards, consequences, and compliance with conditions are monitored for a predetermined period (WHOROE, 2001b). The HIA process, methods, consultation and communications procedures, and databases are evaluated. Adjustments are made to the proposed action and to post-approval procedures based on monitoring results (EnHealth Council, 2001a). The process evaluation is widely distributed to assist other HIA processes.

The typical IA can be broadened and reoriented to systematically address health impacts. This approach treats HIA as a subset of IA. HIA could, in turn, be either a subset of SIA or a field that partially overlaps with SIA (Lehto and Ritsatakis, 1999). Alternatively, the HIA process or process activities can be partially integrated, fully integrated, or simply linked with parallel IA activities (NYPHO, 2001). This approach treats HIA and IA as separate fields that have the potential for linkage, partial integration, or full integration, depending on the circumstances. Or a more targeted approach can be adopted where selective HIA activities or effects are integrated at key points in the IA process. This approach views HIA and IA as selectively and periodically partially overlapping fields. The final approach choice is to address health concerns through risk assessment and management (Arquiaga et al., 1994). The selected approach should suit the circumstances.

Potential Contributions of HIA to IA Practice HIA has many potential benefits for IA. It ensures greater prominence for human health concerns and benefits and responds to identified IA practice deficiencies and major public concerns (Erickson, 1994; IAIA, 2006a; NYPHO, 2001). An enhanced decision-making weight for health is valuable intrinsically, it avoids the transfer of hidden costs and contributes to broader social, equity, and sustainability objectives (Davies and Sadler, 1997; IAIA, 2006a; NYPHO, 2001). At the SEA level, it provides an opportunity to refine screening and causal pathways between policies and health impacts (Wright et al., 2005). HIA addresses more health effects and uncertainties than can be considered in risk assessment and management. The stress on health benefits counterbalances the IA and risk assessment preoccupation with minimizing the negative (Davies and Sadler, 1997; NYPHO, 2001). HIA provides a framework for integrating quantitative and qualitative health concerns. It helps bridge EIA and risk assessment and management, IA and health care planning and services, and EIA and SEA (NYPHO, 2001; WHOROE, 2001b). HIA provides a means of involving health professionals in IA practice (IAIA, 2006a). It helps place public health on the agenda, facilitates the consideration of health inequities, helps legitimize public and private bodies that incorporate health and social concerns, and potentially reduces the burden on the health services sector (IAIA, 2006a). It provides a mechanism for addressing the environmental and social determinants of health from a cross-sectoral perspective (Wernham, 2007). It fosters IA institutional capacity building for addressing health concerns. IA provides an established set of institutional arrangements for implementing HIA. HIA is an additional evaluation tool for the health care community and for public policy development. HIA (in common with IA) also contributes to more open, participatory, transparent, systematic, and substantiated planning and policy making.

There remains considerable room for improvement in HIA practice. More emphasis could be placed on identifying and selecting options rather than just on mitigating the effects of already determined developments (Fischer et al., 2010). Greater consideration could be given to social and behavioral health aspects, the equity of health-related consequences, the role of HIA in public policy making, the management of uncertainties, community-based participation in HIA research and analysis, and HIA capacity building (Bhatia and Seto, 2011; Fischer et al., 2010; Harris and Spickett, 2011; Harris, 2009; Kemm, 2005; Kwiatkowski, 2011; Kwiatkowski et al., 2009; Simpson et al., 2005; Utzinger et al., 2005; Wright et al., 2005). More attention could be paid to the refinement and testing of HIA methods under the umbrella of SEA and EIA (Cole, 2004). A more proactive effort could be made to address the concerns of IA professionals and government officials who have a tendency to resist the integration of HIA into IA practice (Wernham, 2007). Health professionals need to be engaged more effectively (Bond et al., 2011).

Further consideration, at the regulatory level, could be given to institutionalizing HIA either as part of IA (e.g., the nature and rationale for HIA triggers) or as a self-standing set of requirements (Birley, 2007; Bond et al., 2011; Fischer et al., 2010; Harris, 2009; Wright et al., 2005). There continues to be a lively debate concerning whether HIA is more effective when integrated (e.g., could help institutionalize HIA, shared resources, helps build constituency, ensures legitimacy, consistent health trigger, greater standing of EIA/SEA influences policymakers and proponents, helps promote awareness and analysis of social and health effects, action forcing, can build on IA procedural frameworks knowledge and guidelines, mutual learning and skills enhancement, greater transparency, encourages community involvement, facilitates the broader consideration of health determinants, separate HIA runs risk of marginalizing health issues) or independent (e.g., IA—laborious, gives health limited consideration, is project oriented, characterized by low effectiveness and weak implementation, and emphasizes legal defensibility, HIA as part of EIA/SEA will end up conforming to rather than expanding EIA/SEA, fear of losing focus on health and compromising health model, when independent HIA is more open-ended, flexible, and independent, provides opportunity to further develop methods and demonstrate value) from IA (Ahmed, 2004; Atkinson and Cooke, 2005; Bhatia, 2007; Cole and Fielding, 2007; Dannenberg et al., 2006; Harris-Roxas et al., 2012; Morgan, 2011; Slotterback et al., 2011; Wright et al., 2005).

Sometimes integration is clearly inappropriate (e.g., no statutory IA process, severe limitations with existing IA processes) (Morgan, 2011). Generally speaking, the most appropriate choice in terms of full, partial, or no integration is likely to vary depending on the context and could evolve over time. Regardless of the degree of integration, ultimate effectiveness will depend on such factors as government commitment to promoting public health; intersectoral linkages; HIA capacity building initiatives; clear criteria for initiating, conducting, and completing HIA; good practice guidance; and applied research that demonstrates HIA benefits (Cole, 2004; Cole and Fielding, 2007; Dannenberg et al., 2006; Krieger et al., 2003).

There are already numerous demands on hard-pressed health planning and management budgets. A desire to assess health impacts more systematically is of little value if necessary expertise and financial resources are not available. HIA must, therefore, be focused, practical, and realistic. Overlaps, duplication, coordination, and integration with related fields such as EIA, SEA, SIA, and risk assessment and management need to be addressed systematically, without diminishing the genuine need to more effectively address human health concerns (Davies and Sadler, 1997; IPHI, 2001). In some cases HIA may operate more effectively independently from IA (e.g., when health concerns are minor and secondary concerns, when institutional arrangements are too rigid) (McCaig, 2005). A stronger interface between health and other sectors is needed (Bond et al., 2011). Capacity building, networking, methodological development, refinements to theoretical frameworks, critical reviews of HIA approaches, applied research, education and awareness, quality assurance, the clarification of terminology and roles, measures to enhance awareness, measures to facilitate more inclusive participation, the revisiting of HIA governing values and standards, and the creative use of limited available resources are all required (Bhatia, 2007; Birley, 2007; Davies and Sadler, 1997; Harris-Roxas et al., 2012; IPHI, 2001; Krieger et al., 2003; Morgan, 2003b; US NRC, 2011a; WHOROE, 2001a,b). HIA could benefit from more comprehensive and readily accessible HIA information sources (e.g., gateway web sites, HIA good practice repositories) (Dannenberg et al., 2006; Quigley and Taylor, 2003). Greater attention needs to be paid to interactions between HIA and decision making (Becker, Putters, van der Grinton, 2005). A particular effort is needed to apply HIA at the policy (e.g., refining screening and causal pathways between policy and health impacts) and program/plan (e.g., addressing need/opportunity, identifying alternatives) levels (Fischer et al., 2010; McCaig, 2005; Wright et al., 2005). There is a continuing need to institutionalize HIA in many jurisdictions, especially in developing countries (Erlanger et al., 2008). This limitation reflects the tendency of government health agencies to view HIA as a novel activity rather than as a core capacity (Harris-Roxas et al., 2012).

Examples of emerging issues in HIA practice include broad social health determinants (e.g., gender), the role of HIA in facilitating sustainability, links between health threats/risk distribution and environmental justice/injustice, the role of health in cumulative effects assessment, connections between the politics of health and HIA, other forms of alternatives such as knowledge, institutional and goal alternatives, and the health effects of climate change (Harris-Roxas et al., 2012; Kreig and Faber, 2004; Pennock and Uma, 2011; Utzinger et al., 2005; Villani, 2011). The many uncertainties associated with HIA needed to be acknowledged and considered. Insight from related fields in uncertainty management will be essential.

Examples of other challenges facing HIA include defining health and HIA boundaries, balancing the need for valid, timely information with varying data quality realities, balancing the need for credible processes with the need to operate within budgetary requirements and to be responsive to decision making, producing quantitative health effect estimates, synthesizing conclusions on dissimilar health effects, enabling stakeholder participation, ensuring the quality and credibility of HIA, managing expectations, closing institutional gaps and removing institutional barriers, and integrating HIA and EIA/SEA (Becker et al., 2005; Harris-Roxas et al., 2012; US NRC, 2011a).

The continuing resistance to the integration of HIA and EIA/SEA (including the reluctance of IA professionals) underscores the need to better understand the reasons for resistance (e.g., methodological complexities, resource limitations, data controversy or confidentiality, lack of legal framework, professional bias) and to develop and refine strategies for ameliorating resistance, facilitating stakeholder ownership, and illustrating the added value, costs, and negative impacts of including and not including HIA (e.g., demonstration projects that test, refine, and demonstrate different models and methods to maximize utility and acceptance, applied research that shows how decision making is informed and affected, evidence of the predictive validity of HIA, case studies and evidence of health benefits/disbenefits and reduced/increased health inequities, organizational partnership approaches, HIA support systems and capacity building) (Atkinson and Cooke, 2005; Becker et al., 2005; Cole, 2004; Elliott and Francis, 2005; Harris and Spickett, 2011; Harris-Roxas and Harris, 2011; Harris-Roxas et al., 2012; Quigley and Taylor, 2003; Tugwell and Johnson, 2011; Wright et al., 2005; Petticrew et al., 2007).

11.5 INSTITUTING AN ADAPTIVE IA PROCESS

11.5.1 Management at the Regulatory Level

The four jurisdictions address uncertainty. Table 11.7 summarizes positive and negative regulatory level examples in

Table 11.7 Positive and Negative Adaptive Examples at the Regulatory Level

United States	Canada	Europe	Australia
(+) Necessary to identify when information is incomplete or unavailable, together with its relevance and implications	(+) Reference to precautionary principle and to considering in a careful and precautionary manner	(+) Proposed Project Directive (PPD) addresses environmental issues such as resource efficiency, biodiversity, climate change, and disaster risks; links to disaster (natural and man-made) risk prevention and management concerns	(+) Requirement that each IA document describe information timeliness, reliability, and uncertainties
(±) Provisions for emergency and major disaster exemptions; more explicit criteria needed	(+) If responsible authority concludes not sufficient information may require collection	(±) PPD includes provisions for exclusions in cases of civil emergency compliance; case by case exemption—civil emergencies and national defense; question of criteria and potential for abbreviated process	(+) Reference is made to indicating whether relevant impacts are likely to be unknown, unpredictable, or irreversible
(+) NEPA refers to risk to health or safety; regulations identify unique or unknown risks, from both natural hazards and accidents, as significance determination factors	(±) Provisions to exclude projects in event of national emergency or would prevent damage to property or environment or in interest of public health or safety; important that explicit criteria; preferable if abbreviated process rather than no process	(+) PPD include health and climate change effects	(+) The administrative guidelines on significance identify degree of confidence with which impacts are known or understood as a significance factor
(+) Regulations refer to impacts with catastrophic consequences and to a requirement for a reasonably foreseeable analysis	(+) Effects must take into account environmental effects of malfunctions or accidents	(+) PPD—required to consider exposure, vulnerability, and resilience of factors to natural and man-made disasters	(+) General references made to the relationship of risk, especially regarding accidental events, and significance determination; several general health and environmental risk assessment and management guidelines have been prepared
(+) NEPA-related requirements and guidelines address such risk-related matters as intentionally destructive acts, the relationship of NEPA and emergency actions, floodplain management, the protection of children from environmental health and safety risks, offshore oil and gas minerals management, the analysis of accidents, pollution prevention, nuclear activities, emergency response actions, and disaster response, recovery, and mitigation (US CEQ, 2010c; US EPA, 1999)	(+) The probability or predictability of an impact occurring is a significance determination criterion	(+) PPD—monitoring requirement—part of role of monitoring to identify any unforeseen adverse effects	(±) Provisions included for exempting actions for defense or security reasons or when dealing with a national emergency
(+) Federal agencies have issued a host of guidelines, research reports, case studies, and forum reports on human health and ecological risk assessment	(+) Follow-up a requirement; identified as a means of verifying the accuracy of an EA and determining the effectiveness of mitigation measures	(+) PPD—competent authority to verify whether information up to date, especially regarding mitigation measures	(−) The independent review of the Australian IA legislation recommended the inclusion of a greenhouse trigger; not accepted
(+) Accident and intentionally destructive acts analysis guidance (US DOE, 2002b, 2006)	(+) Provision for compliance enforcement, including fines ranging from $100,000 to $400,000.	(+) PPD—Annex IV refers to describing forecasting methods and accounting for main uncertainties, assessing natural and man-made risks and accident risks (and, where appropriate, measures to prevent), indicating difficulties (technical deficiencies or lack of know-how) encountered by developer in compiling information, sources used and main uncertainties and their influence on effects estimates and selection of preferred alternative	(+) Health effects considered as part of effects on people
(+) Social and cumulative effects guidelines refer to managing uncertainty by monitoring, mitigation, and adaptive management, and to the importance of communicating uncertainties (US CEQ, 2011)	(+) The EA Agency is responsible for monitoring and facilitating compliance with the Act, promoting and monitoring EA quality, and taking the lead regarding EA quality assurance	(+) SEA directives refer to risks to human health or the environment from accidents and reversibility of effects and requires monitoring and the consideration of human health effects	(+) HIA, including equity-related HIA and health effects from climate change, have been addressed through an Australian and New Zealand collaboration, and through various state, regional, and local level initiatives
(+) Uncertainty management is addressed in individual agency guidelines	(+) Adaptive management guidance and research (CEAA, 2009e; ESSA, 1982)	(+) EIA guidance documents refer to projects involving unique or unknown risks, to environmental damage and risks from natural disasters, to actual or perceived human health risks, to risks of accidents and abnormal events, to the occurrence of disease or	(+) There have been numerous strategies, partnerships,
(+) Climate change is addressed through regulations and draft guidance on the effects of climate change and reducing	(+) Reference is made to follow-up, mitigation effectiveness, and follow-up implementation when determining assessment equivalency		
	(±) SEA guidance refers to considering the need for follow-up but not a requirement		

Table 11.7 (*Continued*)

United States	Canada	Europe	Australia
greenhouse gas emissions, in policy, program, and planning initiatives for better climate impact preparation, and in requirements for addressing energy requirements and conservation potential (+) Climate change adaptation task force (progress reports, crosscutting strategies, agency climate change adaptation planning) (+) Guidance for GHG emissions and for carbon capture and storage (+) Courts increasingly require that NEPA documents address climate change (Draper, 2010; Eccleston, 2010; Smith, 2010) (±) HIA, as a tool for identifying and managing health effects, has received considerable attention, in terms of both guidance and good practice examples; less evident in project-level EIA documents (Cole, 2004) (±) Precaution is not explicitly mentioned, although reference is made to dealing with unknown information and uncertainties; selective adoption of precautionary approaches by Federal agencies (Graham, 2002) (+) Guidance—EIA and EMS links (US CEQ, 2007c) (+) Adaptation addressed through EIA/EMS and climate change guidance (US ICCATF, 2011)	(+) The relationship of EIA and climate change, follow-up, and adaptive management have been addressed through procedural guidance and through EA Agency sponsored research (±) Changes caused to the health of aboriginal people and health effects directly or indirectly linked to projects, or resulting from the exercise of federal powers must be considered, if they result from project-induced environmental changes (i.e., indirect health effects only) (+) EIA and SEA guidelines refer to health effect type, to cumulative health effects, to the role of health effects, uncertainty and risks as significance factors, and to measures to mitigate significant adverse health effects (+) Mention is made in guidance documents to Type 1 and Type 2 statistical errors; the differences among certain, reasonably foreseeable, and hypothetical future actions; uncertainty sources; and methods for addressing uncertainty (+) Health Canada has prepared an HIA handbook	disease vectors, and to especially vulnerable groups of people (+) Individual European states have sought to integrate health considerations into SEA and into spatial and community planning (+) IA guidelines elaborate on types of potential health effects (+) Ensuring a high level of health protection is prominently featured in European legislation (+) The World Health Organization (WHO) Regional Office for Europe has assumed a lead role in developing and promoting HIA as a policy measure to facilitate health protection (WHOROE, 1999, 2001a,b,c) (+) The European Public Health Strategy also identifies HIA as a means to promote health protection (+) Several European countries (e.g., Netherlands, Ireland, Britain, Sweden) have prepared HIA guidelines (+) The precautionary principle is endorsed in the 1992 Maastricht Treaty of the European Union, the European Court of Justice has defined the conditions for applying precautionary measures in community law and has explained the rationale for precautionary measures, and The Commission of the European Communities has issued a Communications on the Precautionary Principle (+) The Habitats Directive adopts a precautionary approach by ensuring that strategic actions do not exceed limits beyond which irreversible damage can occur (+) Guidelines for European Commission actions and guidance for individual jurisdictions refer to the precautionary principle, HIA, and to risk and uncertainty assessment (EC, 2009a; UK Department of Health (DH), 2007)	committees and research, and guidance documents, at the national/state/territorial level, directed toward progressively integrating (broadly defined) health-related concerns into public policy (Harris and Spickett, 2011) (+) IA legislation includes a definition of the precautionary principle; the Act specifies the decisions for which the Minister must take account of the precautionary principle (+) The government, in response to the independent review of the Australian legislation, committed to produce guidelines regarding the application of the precautionary principle (Australian Government, 2011d) (+) The Minister has the authority to require an environmental audit; provision is made for the preparation of environmental management plans (framework, mitigation, monitoring program, responsibilities) (+) The Hawke report called for the development of foresight reports to help governments manage emerging environmental threats

the United States, Canada, Europe, and Australia. Numerous general and specific references are made to uncertainty and adaptation in the four jurisdictions. More extensive references are made (a different combination in each jurisdiction) to risk assessment and management, to the precautionary principle or approach, to human HIA, to climate change impact assessment, to emergency planning and management, and to AEAM. The only difficult problems specifically referred to are transboundary effects, terrorist attacks, and catastrophes. Minimal references are made to chaos and complexity.

The four jurisdictions collectively address many aspects of uncertainty and uncertainty management. All the jurisdictions provide for follow-up as a means of managing uncertainties. All sponsor research and provide for effectiveness analysis, auditing, and quality assurance to enhance practice and as means of more effectively managing uncertainties. All stress the need to substantiate methods and assumptions and to explain the implications of uncertainties and data gaps. A more systematic effort could be made to identify relevant uncertainty forms and sources, to describe key uncertainty concepts, to identify where and how uncertainties arise in the IA process, and to provide examples of uncertainty management methods. Further direction and advice could be provided regarding documenting uncertainties and concerning the role of uncertainty in IA-related decision making (e.g., screening, scoping, significance determination, option rejection and comparison, the triggering of mitigation, and monitoring requirements). Each jurisdiction could consider the specific sources of uncertainties in IA requirements and guidelines (from the perspective of stakeholders) that have led to unwarranted inconsistencies.

All jurisdictions refer to health risks in IA requirements. More attention is devoted to human health risks and to risks from accidents and natural disasters than to chronic health risks, ecological risks, and perceived risks. The United States provides detailed human health and ecological risk assessment and management requirements and guidance. The other jurisdictions concentrate more on risk management. All jurisdictions could devote more attention to potential risk assessment and management roles in the IA process. Risk assessment and management strengths and limitations, the measures introduced to ameliorate limitations, and similarities and interconnections between IA and risk assessment and management should be addressed. All jurisdictions provide for emergency exemptions from IA requirements. A greater effort could be made to develop and apply abbreviated IA forms for emergency situations and to integrate lessons and insights from emergency planning and management into IA risk management requirements and guidance.

The four jurisdictions have all gradually moved toward the greater integration of climate change considerations and IA requirements. So far, the focus has been on general guidance, applied research, and institutional capacity building. This may lead, over time, to a refinement of general and proposal specific IA requirements to more fully integrate climate change considerations, and to more closely link climate change and sustainability requirements and limits. IA jurisdictions and other stakeholders could benefit, along the way, from sharing experiences and insights (IAIA, 2010). There is likely to be considerable resistance to possible climate change requirements if they could lead to the rejection of major resource development proposals. It is likely that progress in this area will be incremental and tentative at best.

Health effects are mentioned in the IA requirements of all four jurisdictions. But the treatment of health effects is general and fragmentary. The numerous recent HIA initiatives and guidelines are correcting this deficiency. Experiences at the national, subnational, and local level in all four jurisdictions could be instructive. There remains considerable ambivalence regarding whether HIA can operate more effective on its own or under the IA umbrella. More attention needs to be devoted to the interrelationships between HIA and risk assessment and management. The role of the health community in HIA also requires additional consideration. The effectiveness of HIA requirements and guidelines needs to be monitored and evaluated. The many uncertainties associated with identifying, predicting, and managing human health effects should receive particular consideration.

There is considerable variation among the jurisdictions in if and how the precautionary approach or principle is addressed in environmental requirements. When the precautionary principle is inappropriate, IA regulations and guidelines should explain how other mechanisms are to address the relationship of uncertainty and potentially severe consequences. If the principle could be applied, IA requirements should define the principle and specify which harmful effects, uncertainties, and actions trigger its application. Conditions for applying the principle and the decisions to which it applies should be indicated. Guidelines can provide more specific advice regarding roles within the IA process, possible criteria, thresholds, and decision rules, and links to risk assessment and management, human health impact assessment, and uncertainty analyses. The principle's strengths, potential drawbacks, and means of avoiding and reducing potential shortcomings should be assessed. Additional applied research would be helpful.

IA requirements could more explicitly provide for AEAM, appreciating the differences between IA and AEAM. IA guidelines could address potential AEAM and IA interrelationships. The potential role of AEAM in identifying and coping with uncertainties should receive particular attention. More consideration could be given to AEAM strengths, limitations, and measures to reduce limitations. Applied research could explore AEAM adaptations for addressing social and economic concerns, AEAM roles in assessing nonresource management proposals, and steps to ameliorate organizational resistance and inflexibility.

Aside from catastrophic and climate change effects, IA requirements and guidelines in the four jurisdictions largely do not refer to other types of difficult problems or to chaos and complexity. There are scattered references to unusual and complex interactions and effects. Such conditions can affect impact significance interpretations. IA guidelines could devote more attention to other types of difficult problems (e.g., trans-scientific, latent time bombs) in IA practice. Guidelines and applied research could identify insights and implications from chaos and complexity theories for IA practice. At a broader level, risk assessment and management, adaptive management, climate change assessment, HIA, and the precautionary principle collectively represent tools and perspectives for analyzing and coping with uncertainty. They clearly overlap, and they should be complementary. This suggests that there is a need, at the regulatory level, to integrate these individual elements within broader uncertainty management strategies. These strategies, in turn, could guide and bound overall uncertainty-related adaptive public policies, plans, and programs, and provide the foundation for the treatment of uncertainty within IA requirements and guidelines. Mutual learning among IA jurisdictions represents an important knowledge source for enhancing IA uncertainty management capacity.

11.5.2 Management at the Applied Level

Designing an Uncertainty Management Approach This chapter presents a range of concepts and processes dealing with uncertainties—problem types, environment types, uncertainties, general adaptation strategies and tactics, risk assessment and management, health impact assessment, the precautionary principle, adaptive environmental assessment and management, emergency planning and management, and climate change impact assessment. An adaptive IA process could, as illustrated in Figure 11.6, combine elements from some or all of these concepts and processes.

The process first determines whether a risk and uncertainty management framework is warranted. An analysis of the problem is undertaken next. A conventional IA approach is applied if the problem and environmental conditions appear simple and manageable. If the problem and/or environment are determined to be short-term crises, then abbreviated versions of or alternatives to IA are instigated. Uncertainties are considered regardless of the approach adopted. Uncertainty is a central feature of the process if a complex or metaproblem are involved and/or if environmental conditions are complex or chaotic. Pertinent uncertainty forms and sources are identified and analyzed. Uncertainty concepts are applied, where appropriate. An adaptive IA process is designed. Uncertainties are considered for every IA activity and for every interconnection among activities. The process is iterative, flexible, heuristic, open, continuous, cyclical, interactive, and boundary spanning. Institutions are modified and reformed to facilitate and accommodate adaptive IA processes.

Consideration is given to whether one or more of (1) risk assessment and management (RAM); (2) the PP; (3) HIA; (4) AEAM; (5) emergency planning and management; and (6) climate change impact assessment also should be applied. RAM is more suited to situations where human health and/or ecological risks are major concerns and uncertainties are conducive to probabilistic analyses. The PP is usually instigated when there are potentially severe or irreversible adverse environmental impacts, a need for action and significant scientific uncertainties. HIA is undertaken when significant positive and/or negative health effects are likely, there are adequate health-related resources available, and other approaches are unlikely to adequately address health concerns. AEAM is more commonly applied in environmental and resource management situations involving complex but not unique situations, where ecological systems are resilient and conducive to modeling and where stakeholders are willing to engage in workshops. Emergency planning is appropriate when proposed actions could induce environmental hazards and/or are susceptible to adverse environmental effects if natural or human-induced (accidental or deliberate) disasters could occur. Climate change impact assessment is appropriate if proposed actions could have a significant effect on climate change and/or are susceptible to climate change effects.

The characteristics, variations, procedures, methods, IA links, strengths, limitations, and measures to reduce limitations of each approach are considered before it is decided if it should be applied. A clear rationale is prepared for whether the approach is to be applied and, if so, how it is to be linked to or combined with IA. A rationale also is provided for how uncertainty management approaches are combined when more than one approach is used and how the approach(es) are matched to the relevant problem, environment, and uncertainty types. The overall uncertainty management approach integrates all elements into a coherent whole. The approach is applied, monitored, and adapted as needed. Several iterations are required before the approach is finalized. Provision is made for early and ongoing stakeholder involvement in the host of uncertainty management interpretations and judgments.

11.5.3 Adaptive IA Practice by IA Type

Crosscutting Characteristics Table 11.8 provides examples of adaptive IA practice characteristics for various IA types (SA, SEA, EIA, EcIA, SIA, and HIA). All of the IA types recognize the inevitability of risks and uncertainties, the limits of knowledge and the need for an adaptive IA process that can effectively identify, interpret, and manage risks and uncertainties. All acknowledge the need to explain and interpret assumptions and limitations; to justify methods, interpretations, and conclusions; and to seek resilient, robust, and adaptable solutions to complex problems. All emphasize the importance of monitoring and feedback, the need for a plurality of approaches and methods, and the necessity of designing and adapting the process to a complex, uncertain, and fluid context. All stress the importance

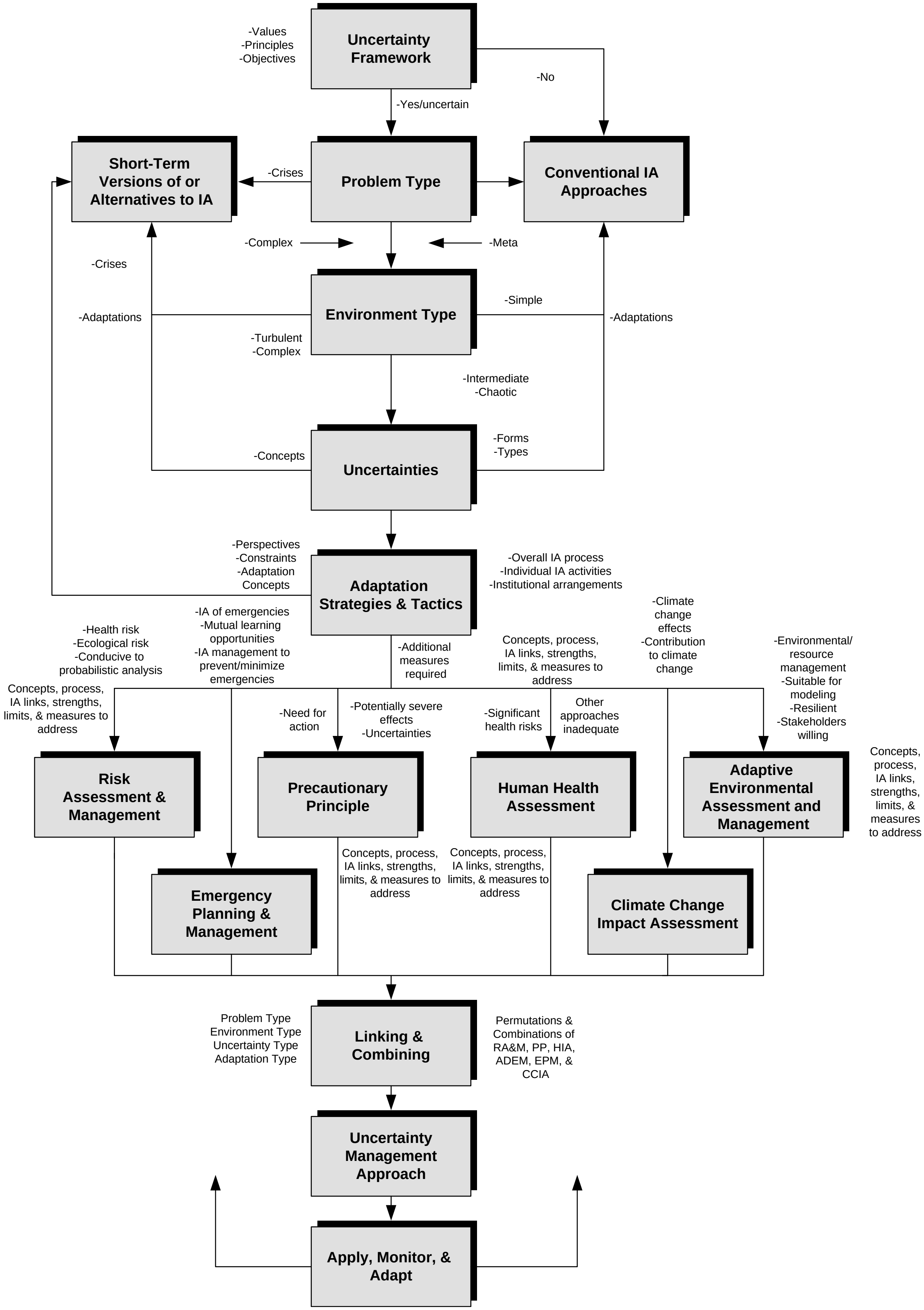

Figure 11.6 Designing an IA uncertainty management approach. Adapted from Lawrence (2005a).

Table 11.8 Adaptive IA Practice by IA Type

Adaptive SA Practice	Adaptive SEA Practice	Adaptive EIA Practice
Emphasizes the importance of continuous learning, feedback, and coordination; process open to critical discussion and local knowledge	Seeks an SEA that is as robust as possible; a process that is iterative, flexible, adaptive, dynamic, open, creative, iterative, resilient, communicative, inclusive, continuous, and learning based	Process adapted to realities, issues, and circumstances of proposal without compromising environmental interest
Sees world as complex, adaptive, self-organizing systems in equilibrium	Sees SEA as a diverse family of approaches that can be adapted to a variety of decision-making settings; no one way or even one best way, at times chaotic; recognizes that many actors with multiple goals in a “messy” reality	Employs uncertainty assessment methods (e.g., probability analysis, sensitivity analysis, confirmatory analysis)
Stresses flexibility, innovation, adaptability, diversity, resilience, and search for creative and pluralistic opportunities and learning	Combines adaptive management with policy making; is sufficiently flexible that decision makers can take useful elements and apply them	Applies the precautionary principle and risk assessments where needed
Acknowledges and accommodates uncertainties (e.g., sensitivity analyses, scenario analysis)	Is conscious of and sensitive to the influence of context on aims and outcomes	Locates uncertainty blind spots and vulnerabilities in predictive models; assesses ramifications
Recognizes many change elements cannot be measured; brings together best of qualitative and quantitative	Clearly states assumptions and related predictions, addresses probabilities and confidence levels, carries out sensitivity analyses, uses different scenarios, and predicts in ranges	Assesses alternative future scenarios and reversibility
Recognizes interdependencies; seeks mutually reinforcing gains; seeks to preserve and enhance adaptive capacity and human capabilities	Role for SEA in protecting and improving health, in preventing ill health and in addressing health inequities; consults with health organizations/experts	Combines multiple information sources
Recognizes limits and dangers of reductionist science and planning	Integrates HIA; treats health as a separate element	Integrates consideration of natural and human-induced disasters, spills, and accidents
Applies precautionary approach	Acknowledges and exposes uncertainties, risks, and ambiguities; recognizes must deal with an uncontrolled and unpredictable environment	Emphasizes prevention over mitigation
Sustainability definition tailored to context; ensures not so flexible that manipulated or unsustainable outcomes; protects future	Data collection incremental and spread through SEA process; takes care in data and scale choices	Tests sensitivity of alternatives ranking and conclusions
Integrates climate change concerns	Recognizes that policies, plans, and programs only partially influenced by environmental analysis; focuses on producing and communicating strategic knowledge	Estimates the uncertainty factors affecting the impact evaluation and implications; fosters risk aversive decisions
Gradually and progressively defines complex and collective vision of what to sustain	Addresses both emergent and deliberate strategies	Seeks lasting gains and resilient projects and environments; seeks to build desirable and resilient futures
Seems transformative outcomes (e.g., radically different futures, desirable, resilient, and lasting futures)	Recognizes that need for flexibility at policy level with limited role for detailed regulation	Stresses the effective communications of uncertainties
Employs systems–holistic–dynamic perspective; constant sustainability improvements	Employs a preventative/precautionary approach	Seeks to build to more lasting options with proposed action as catalyst
Health an imperative	Takes care to ensure that environmental protection and sustainability not compromised	Seeks positive results
Characterized by methodological pluralism	Integrates comparative risk assessment	Designs for surprises and manages for adaptation
Integrates postnormal science and complexity theory; transcends individual disciplines	Assesses effects on and from climate change	Assesses effects on and from climate change; addresses the links between climate change mitigation measures and climate change adaptive capacity
Fosters nonlinear knowledge generation, social learning, and system innovation	Emphasizes effective monitoring; specifies organizations responsible for monitoring; monitors outcomes of similar actions; adapts to setting	Recognizes that effectiveness only meaningful in socioeconomic, political, and cultural context of country or countries concerned
Stresses follow-up, verification, and adaptive management; connects monitoring to adaptive design and management	Clearly identifies risks and uncertainties; manages rather than trying to eliminate	Integrates mitigation strategies for managing unanticipated outcomes
	Integrates climate change concerns, stresses systems resilience and determinants, emphasizes monitoring rather than certainty, utilizes adaptive management and governance, and prioritizes early warning	Arranges for monitoring and evaluation; adapts protocols to local needs
	Integrates resilience thinking to address uncertainty and complexity	Recognizes that need for follow-up greatest when inherent uncertainty; employs adaptive management as part of follow-up to address highly unpredictable uncertainties; community fully engaged
	Fosters adaptive SEA systems; designs for resilience and adaptability in the face of uncertainties and risks	Tracks cumulative effects
	Prepares uncertainty report, detailing sources and means to reduce, different viewpoints, contingency plans, and postponed decisions	Incorporates lessons throughout the project’s life cycle

(*continued*)

Table 11.8 (*Continued*)

Adaptive EcIA Practice	Adaptive SIA Practice	Adaptive HIA Practice
Seeks to foster flexibility, diversity, and resilience of ecological components and systems	Recognizes that knowledge of social world and social processes incomplete; social processes constantly changing and vary over space and time	Recognizes that IA is about decision making in the face of uncertainty and complexity
Recognizes complexity of contemporary ecosystems; more complex than we think or can think	Acknowledges that social impacts cannot be precisely defined or quantitatively valued, and that SIA cannot provide definitive answers	Broadly defines health aspects (e.g., social and behavioral aspects)
Recognizes that ecosystem processes and functions are complex and variable; level of uncertainty increased by social constructs	Acknowledges the gulf between information and knowledge	Flexibility a guiding principle
Recognizes that change inevitable	Employs holistic research methods	Clearly explains and substantiates models, assumptions, and limitations; data quality, validity, and statistical stability are assessed
Adaptive management a key element of ecosystem approach	Aware of differential distribution of impacts among groups and burden on vulnerable	Recognizes the complexity of multiple levels and causal pathways; acknowledges prediction limitations and implications
Estimates uncertainty factors and their effect on interpretations of results and decision-making implications	Incorporates scientific and local and indigenous knowledge, experience, and epistemologies	Differentiates between changes caused by program and other societal changes
Tests sensitivity of results	Integrates uncertainty, prevention, and precautionary principles	Precautionary approach: reduces and prevents significant exposures before occur
Acknowledges limits of understanding	Develops a rich picture of the local community context, including relationship of local community values to planned intervention	Seeks robust predictions; experimental and adaptive
Integrates precautionary principle; assesses biodiversity threats, and seeks to avoid irreversible biodiversity loss	Addresses impacts from multiple perspectives using multiple methods (e.g., literature, surveys, interviews with community leaders, public consultation events, analyses of comparable actions/environments)	Assesses health impacts of disasters and climate change
Addresses climate change and disaster impacts on biodiversity	Acknowledges complexities and limits	Identifies controlling and coping strategies
Assesses cumulative effects	Assesses change with and without proposed action against control study	Develops a range of adaptation responses
Sees ecosystem management as a learning process that adapts methods and practices to ways in which systems are managed and monitored	Recognizes that impact pathways cut across domains, are iterative, and are direct, indirect, and cumulative	Sees health and sustainability as inextricably linked
Recognizes need for flexibility in implementation and policy making	Addresses risk perceptions/attitudes and risk communications	Employs methodological triangulation (statistics and literature, stakeholder inputs, direct observation)
Recognizes ecosystem management as a long-term experiment (learning as doing)	Recognizes and preserves diversity and seeks to build social resilience and sustainable livelihoods	Includes an uncertainty analysis; identifies confidence levels
Includes detailed monitoring and follow-up plans	Promotes health and safety; broadly defines health and health determinants	Identifies, reduces, and manages uncertainties
	Provides for monitoring and managing intended and unintended consequences and social change processes invoked by interventions	Stresses the importance of monitoring, evaluation, and follow-up
	Addresses uncertainties through contingency planning, adaptive management, and capacity building	Includes follow-up plan, goals, roles, triggers, reporting, and resources
	Provides for social follow-up surveys and research	Employs retrospective validation to assess predictions and effectiveness

Sources: Adelle and Weiland (2012), Ahmed (2004), Ali et al. (2008), Ardern (2004), Ayre and Calloway (2005), Bhatia (2007), Bhatia and Seto (2011), Bhatia et al. (2010), Bond (2010), Bond and Morrison-Saunders (2011), Bond et al. (2011, 2012), Burdge (2003b, 2004), Byer et al., (2009), Canter (1993a), Cherp et al. (2007), Clark et al. (2011), Croal et al. (2010), Dannenberg et al. (2006), Devlin (2011), Donnelly et al. (2007), Dovers (2005), Duncan (2008), Duncan and Hay (2007), EC (2009a), Esteves et al. (2012), Faber et al. (2010), Feldman and Khademian (2008), Fischer et al. (2010), Fischer (2003, 2007b), Gardner (2010), Gasparatos et al. (2007), Geneletti (2002, 2003, 2005), Gibson (2006a, 2011), Graham (2002), Grinde and Khare (2008), Hacking and Guthrie (2008), Hanna (2009b), Hermans and Knippenberg (2006), Hindling-Rydevik and Bjarnadóttar (2007), Hodge (2004), Hunsberger et al. (2005), IAIA (1999, 2003, 2005, 2006a), ICPGSIA (2003), João (2007); Khera and Kumar (2010); Kumagai et al. (2006); Kauppinen and Nelimarkka (2004); Kemm (2005); Kørnøv (2009); Kørnøv and Thissen (2000), Krieger et al. (2003), Lane et al. (2003), Mandelik et al. (2005), Morgan (2011, 2012), Morganstern et al. (2008), Marshall (2005), Lobos and Partidário (2010), Meynell (2005), Nilsson and Dalkmann (2010), Noble (2009a), Partidário and Coutinho (2011), Persson and Nilsson (2007), Rajvanshi et al. (2011), Rotmans (2006), Seidler and Bawa (2003), Shepherd (2008), Spickett et al. (2011), Slootweg et al. (2010), Steinemann (2004), Stoeglehner and Wegerer (2006), Storey and Jones (2003), Tetlow and Hanusch (2012), Thérivel et al., (1992); Thérivel (2010), Thompson (2002b), Tickner (2003b,d), Tuinstra et al. (2008), Utzinger et al. (2005), Vanclay (2003, 2010), Wiek and Binder (2005), Winkler et al. (2011), Wilson (2010), Wlodarczyk and Tennyson (2003), Wright et al. (2005).

of enhancing system capacity to adapt to and manage positive and negative change, as interpreted from multiple perspectives. All point to the need for flexibility, creativity, openness, and inclusiveness. All suggest the desirability of an IA process that is iterative, dynamic, innovative, transformative, precautionary, and learning oriented. All emphasize the need for approaches and methods that are holistic, transcend individual disciplines, and systematically address indirect and cumulative effects. There is a general recognition of the overlaps and interdependencies among IA types, the need to systematically explore interconnections and to assess the merits of various integration approaches, and the necessity of integrating and contributing to the IA knowledge base. Many substantive themes (e.g., health, emphasis on the most vulnerable, climate change, contribution to sustainability) are shared among IA types. Differences among the process characteristics for the various IA types are largely a question of degree, emphasis, and orientation.

Adaptive EIA, EcIA. and HIA practice tends to place more emphasis on rational, scientific, quantitative, and technically oriented approaches to uncertainty and risk management. Adaptive SA, SEA, and SIA practice tends to stress nonrational, trans-scientific, qualitative, and collaborative approaches to uncertainty and risk management. Given the many shared themes, overlaps, and interconnections among the adaptive IA process type characterizations, the sharing of knowledge and experiences would seem highly desirable, appreciating the implications of differences among the IA types and in terms of context.

Adaptive SA Practice Adaptive SA practice emphasizes the search for transformative change and the realization of substantive sustainability outcomes. It is context dependent. It fosters methodological pluralism, nonlinear knowledge generation, social learning, and system innovation. It stresses follow-up and adaptive management. It recognizes the limits of reductionist science, applies a precautionary approach, and acknowledges and accommodates uncertainties. It is flexible, innovative, and creative. It employs a holistic systems vision, recognizes interdependencies, and seeks pluralist and resilient solution to complex and uncertain environmental problems.

Adaptive SEA Practice Adaptive SEA practice recognizes the need for a plurality of approaches that can be adapted to and evolve in concert with changing decision-making needs and requirements at multiple levels. It focuses on the search for proposal options and mitigation/enhancement measures that are resilient, contribute to lasting positive change, avoid and prevent significant negative, especially catastrophic change, and can adaptively respond to and manage surprise. It is highly conscious of contextual variation; acknowledges and exposes risks, uncertainties, and ambiguities; and recognizes the limits of knowledge and control. It fosters adaptive SEA systems, designs for resilience, and employs a preventative–precautionary approach.

Adaptive EcIA Practice Adaptive EcIA practice focuses on fostering diverse and resilient ecological components and systems, and on adaptive and effective ecosystem management. It recognizes the complexity of ecosystem processes and functions, acknowledges and estimates uncertainties and associated implications, and tests the sensitivity of results. It fully integrates the precautionary principle, assesses biodiversity threats, and seeks to avoid irreversible biodiversity loss. It appreciates the limits of knowledge, the importance of flexibility and resilience, and the critical role of follow-up.

Adaptive SIA Practice Adaptive SIA practice stresses the limits of knowledge and control, the importance of bottom-up participation, and the value of local and indigenous knowledge and perspectives. It emphasizes the need to differentiate the distribution of impacts among population groups and to ameliorate the burden on and enhance the lives of the most vulnerable. It appreciates the necessity of a sound understanding of community context. It emphasizes the importance of preserving and enhancing social diversity, resilience, and sustainable livelihoods. It employs holistic research methods; integrates the uncertainty, prevention, and precautionary principles; and addresses impacts from multiple perspectives. It seeks to recognize and preserve diversity, build capacity, promote health and safety, and build social resilience and sustainable livelihoods.

Adaptive HIA Practice Adaptive HIA practice emphasizes the importance of broadly defining health and health determinants and the need to explore the complex web of causal pathways that stretch across multiple levels. It fully substantiates methods and assumptions. It acknowledges the inevitability of limits in the ability to predict changes and to differentiate impacts from other health-related societal changes. It appreciates the importance of robust predictions and management approaches that facilitate resilience. It employs multiple and effective coping strategies. It seeks to systematically integrate retrospective analyses.

11.6 CONTEMPORARY CHALLENGE—CLIMATE CHANGE

11.6.1 Definitions and Distinctions

Climate change is a change in the climate that is directly or indirectly attributable to human activity that alters the global atmosphere composition over observed time periods, and is in addition to natural variation (IAIA, 2012). It can be identified by changes in the mean of variability of its properties and persists over an extended period (IAIA, 2012). Climate change is a multidimensional issue (e.g., development, security, equity) (IAIA, 2012; IAIA and World Bank, 2010). IA can help integrate climate change considerations into policies, plans, programs, and projects in a manner that reduces the contributions to, impacts from, and vulnerability of natural and human systems against actual and expected climate change.

Climate change IA (CCIA) addresses the climate change implications of greenhouse gas (GHG) emissions from a proposed action and the effects on a proposed action and the environment from climate change (FPTCCCEA, 2003; US CEQ, 2010a). CCIA integrates climate change considerations into each IA activity (e.g., scoping, alternatives analysis, mitigation, follow-up). Related concepts include (1) adaptation (initiatives and measures to reduce human and natural system vulnerability against actual or expected climate change effects), (2) resilience (capability to anticipate, prepare for, respond to, and to recover from climate-related threats), (3) adaptive capacity (ability of system to adapt to climate change, moderate potential damages, take advantage of opportunities, or cope with consequences), (4) risk (combines magnitude of consequences from climate change impacts with likelihood of occurrence), (5) vulnerability (degree system is susceptible to or unable to cope with climate change adverse effects including climate variability and extremes), (6) mitigation measures (measures such as technological change and substitution that directly or indirectly reduce resource inputs and greenhouse gas emissions and enhance sinks), (7) adaptation measures (measures that increase resistance to withstand, recover from and adapt to climate change), and (8) uncertainty (degree to which a future value such as the future state of the climate system is unknown) (IAIA, 2012; US NRC, 2011a).

11.6.2 Climate Change and the IA Process

Integrating climate change into the IA process has, as summarized in Table 11.9, implications for every IA activity. A basic distinction is drawn, in IA process design and management, between impacts on (avoided and minimized through mitigation) and from (avoided and minimized through adaptation) climate change. Often, proposed actions entail both mitigation and adaptation. The integration of climate change operates at both the SEA and project EIA level. SEA tends to be especially important in integrating climate change considerations into public decision making and in framing the treatment of climate change considerations in public and private EIA project-level decision making (IAIA, 2012).

The effective management of uncertainties and risks, the importance of adaptability and resilience, and the need to fully consider vulnerability and equity are central features of CCIAs. Other key aspects of the IA process, when addressing climate change, include the importance of linking climate change effects and sustainability principles, the need to draw upon applied climate change research, resources and good practice guidance, and the need to place climate change predictions and management measures within the context of cumulative effects on resources and biodiversity, larger scale inventories, targets and thresholds, and a range of climate change scenarios.

11.6.3 Climate Change Good Practices

The integration of climate change and IA practice is arguably still in its infancy (Yi and Hacking, 2012). Although the role of climate change in IA practice has been an issue for more than a decade, good practice examples are still limited in number and scope. As summarized in Table 11.10, considerable work remains to build the capacity to undertake and effectively participate in CCIA. Major gaps and deficiencies remain regarding key data sources, especially at the subnational and regional levels. A considerable effort is needed to enlarge the level of climate-related expertise and to foster communications, mutual learning, and networking among stakeholders. Education and the building of political will and support are essential, given the likelihood that resistance to change will be significant. As the capacity to undertake and participate effectively in climate change impact assessment is enhanced, requirements and guidelines can be refined, harmonized, and more broadly and systematically applied.

Good practice climate change impact assessment guidance still remains quite general. Pilot projects, applied research, and the refinement of frameworks and methods can help extend such guidance, with due allowance for regional and sectoral variations. Standard protocols and guidance should help to reduce the gaps and inconsistencies in the treatment of climate change in IA practice (Yi and Hacking, 2012). Particular care should be taken to fully, explicitly, and systematically address risks, uncertainties, and adaptive capacity, to thoroughly address issues related to the vulnerability of natural and human systems, to favor mitigation, enhancement, and adaptation measures that can flexibly respond to a range of potential future conditions, and to systematically integrate equity-related concerns into all aspects of climate change impact analysis and management. CCIA should not be viewed as an expert-driven procedure. Community and indigenous knowledge, understanding, and support are crucial. The assessment of individual proposals is unlikely to be effective if not framed within broader scale climate change databases, strategies, goals, requirements, initiatives, and policies.

11.7 SUMMING UP

This chapter addresses how IA processes adaptively anticipate and respond to the uncertainties associated with difficult problems in chaotic and complex environments. The three stories address uncertainty in different ways. The first story describes a strategic cumulative environmental assessment that adaptively evolved in response to unanticipated methodological challenges and the changing needs and expectations of the major partners in the process. The second story illustrates the risks associated with a technically driven IA process that does not appreciate or mitigate potential sources of proposal failure, does not recognize changing institutional arrangements, is insensitive to varying stakeholder perspective and

Table 11.9 Climate Change and the IA Process

Activity	General	Impact on Climate Change (GHG)	Impact from Climate Change
Screening and scoping	Establish boundaries and focus assessment Scope uncertainties Identify proposal and climate variables that should include Determine who to conduct assessment	Determine if GHG considerations an issue and should be addressed in greater detail; provide rationale Determine whether qualitative or quantitative assessment appropriate Identify GH-related policies, plans, programs, and targets	Determine if impact from climate change an issue (proposal or environment vulnerable to climate change, beneficially or adversely affected); provide rationale Decide approach for addressing climate change impact
Baseline analysis	Cross-reference research Consider links between climate change and resources Identify a reasonable and credible range of climate change scenarios (e.g., minimum, intermediate, maximum) Consider current and future climate with and without climate change	Link to national, subnational, and regional GHG inventories Determine if GHG emissions have already breached a cumulatively significant level, could manifest in regional or local geographic area, and could be affected by proposed action	Describe how global climate changes could manifest in regional or local geographic area and could affect proposed action Clarify changing climatic parameters (magnitude, distribution, rate of change) Assess impacts of current land use and policies
Proposal characteristics	Identify how climate change and GHG can be integrated into proposed action (e.g., reason for action) Identify proposal characteristics potentially linked to climate change	Identify and quantify (if possible) direct and indirect GHG emissions (composition, magnitude, intensity) Design/operate to avoid and minimize GHG emissions Determine if medium to high emissions and if diverges from industry or government best practices and from reduction targets or objectives	Identify proposal characteristics potentially vulnerable to climate change impacts Assess adaptive capacity Design for resilience
Alternatives analysis	Explore combinations of climate scenarios and options At SEA level, seek to develop and evaluate climate friendlier policy, planning, and program alternatives	Identify alternatives that meet need and reduce GHG emissions Compare alternatives under climate scenarios Select preferred alternatives	Identify avoidance, reduction, and compensations options Identify alternatives that facilitate adaptation to/resilience from climate change Assess options and selected preferred options
Impact identification and prediction	Assess social, economic and, environmental impacts Capture and combine impact ranges Consider inter- and intragenerational equity Identify urgent large risks to determine whether impact management is necessary	Clarify magnitude, intensity, and timing of proposal emissions Analyze climate change effects on environment (individual, cumulative, direct, indirect, large-scale impacts on carbon sinks) Determine possible consequences of accidents or spills Assess degree policies, plans, programs, and projects promote reduction in GHG emissions	Identify climate change risks Analyze cumulative climate change effects on proposed actions (positive or negative, feasibility, viability, sustainability) Analyze effects of climate change on impacts resulting from proposal Analyze extent areas, water resources, land use types, communities, and socioeconomic groups vulnerable or at risk to climate change
Significance determination	Cross-reference government (international, national, subnational, regional) standards and policies Identify impact significance	Set threshold for GHG emissions Assess whether the change in cumulative impact is significant Assess whether net emissions consistent with industry/government best practices and reduction targets or thresholds	Assess significance of climate change impacts on proposed actions and on impacts resulting from proposal
Mitigation, enhancement, and adaptation	Identify mitigation, enhancement, and adaptation objectives	Determine whether additional GHG management necessary Identify additional measure to prevent/reduce GHG emissions (e.	Identify mitigation measures to reduce proposal vulnerability and increase resistant to extreme circumstances and resilience to

(*continued*)

Table 11.9 (*Continued*)

Activity	General	Impact on Climate Change (GHG)	Impact from Climate Change
	Distinguish between adaptation (anticipated and potential) and adaptive capacity Ensure broad range of mitigation and adaptation strategies (e.g., pricing, technology, behavioral change, ecosystem management)	g., design, operations, energy efficiency measures); directly or indirectly Address how to enhance or impede attainment of GHG targets, policies, goals, and regulations Identify compensatory mitigation (e. g., carbon offsets)	recover quickly after extreme conditions Identify adaptation opportunities; adjustments in human and natural systems to climate stimuli and effects Clarify adaptive management plan to reduce climate change risks Identify measures to enhance resilience
Uncertainty management	Explicitly identify uncertainties (e. g., regarding proposed actions, modeling, future state of climate, and effects) Incorporate ongoing information gathering and risk assessment Apply precautionary principle Identify uncertainty decision rules (e.g., maximin, minimax regret)	Apply methods to address uncertainties (e.g., sensitivity analyses, scenarios, probabilistic analyses, simulation studies) in GHG emissions forecasts	Apply methods to address uncertainties in climate change forecasts and related impacts on proposals and environment (e.g., scenarios, story lines) Identify how adaptive planning can be used to address uncertainties Seek to make actions more adaptable and flexible
Public participation	Identify questions for public review; integrate public concerns, preferences, and knowledge Ensure scenarios credible and acceptable to stakeholders Communicate results and uncertainties to stakeholders	Integrate public concerns and preferences regarding options and proposal acceptability Integrate public concerns and preferences regarding measures to avoid, minimize, and offset GHG emissions	Integrate public concerns and preferences regarding options and proposal acceptability Integrate public concerns and preferences regarding climate proofing measures and climate resilience enhancement measures
Decision making	Explain and justify how results obtained and degree of confidence Confirm consistency with jurisdictional requirements and initiatives Decide based on precautionary principle (do no harm) and sustainability principles Determine if proposed risks and impacts acceptable Identify conditions of approval	Address GHG emissions through established jurisdictional policies or regulations Determine conditions that ensure acceptable GHG emissions Determine if GHG emission levels, after mitigation, acceptable	Determine if proposed action too vulnerable to climate change to proceed Determine if adaptive strategies and methods acceptable Determine conditions that ensure acceptable climate proofing and resilience
Follow-up and management	Monitor, evaluate, manage, and communicate Identify management responsibilities; distinguish between public and private sector risks and responsibilities Incorporate lessons learned Address evolving proposal and climate change knowledge, technology, policy, and legislation (pre- and postapproval) Include adaptive management plan	Clarify how design/operations takes GHG considerations into account Identify performance measures to monitor GHG emissions and links to climate change Verify GHG emissions forecasts and mitigation effectiveness Implement remedial actions as needed	Monitor status of proposal and effectiveness of mitigation measures Monitor climate change and climate proofing Implement remedial actions as needed

Sources: Agrawala (2010), Byer and Yeomans (2007), Byer et al. (2011), CDFAIT (2002), CEAA (2003c), CFTPC (2003), Draper (2010), Eccleston (2008), Farber (2003–2004), FPTCCCEA (2003), IAIA and World Bank (2010), Smith (2010), Spickett et al. (2011), US CEQ (2010a).

Table 11.10 Examples of Climate Change Good Practices

Institutional Arrangements and Capacity Building	Requirements and Guidelines	IA Process Design and Management
Institute or supplement GHG inventories at national, subnational, and regional levels	Establish GHG targets, policies, and goals at national, subnational, and regional levels	Consider vulnerability of human and natural systems and groups; consider potential health effects
Institutionalize climate change integration into policies, plans, programs, and projects at multiple levels; ensure adequate resources	Clarify legal requirements (e.g., required monitoring of carbon emissions)	Use latest credible scientific information and projections
Supplement climate change expertise (e. g., education, training) and climate science capacity	Close decision-making gaps	Link time horizons to national and international climate scenarios
Institute/supplement climate monitoring network	Foster political will	Explore synergies between negative and positive climate and environmental interactions
Institute pilot program to demonstrate how to achieve greater climate protection	Seek government and business commitments to address climate change before making decisions	Place within context of international agreements and national and subnational strategies
Enhance links to related planning processes and legislation	Strengthen legislation and regulations	Look at climate change in context of other pressures on food, water, and biodiversity
Support climate-related information and good science	Provide updated and improved guidance for addressing and managing climate change at SEA and project EIA levels, and for different proposal types, sectors, and regional settings	Link to broader inventories and targets
Foster climate-related education, networking, and communications between scientific community and IA practitioners	Provide climate change guidance on methods, significance determination, mitigation, and adaptation	Distinguish between adaptation and adaptive capacity; importance of flexibility regarding future changes
Foster cross-disciplinary and cross-sectoral coordination	Promote use of guidelines	Explicitly identify uncertainties (e.g., methods, future conditions, impacts, mitigation effectiveness) and implications
Facilitate public access to climate change information	Ensure adequate monitoring of current emissions	Embrace complexity, give more serious attention to worst-case scenarios, always cope with uncertainty, and clearly explain uncertainties
Structure and post climate change information on line in searchable ways; linked to GIS	Emphasize role of monitoring and adaptation	Ensure indirect negative impacts of secondary proposal activities addressed with, for example, renewable energy projects
Document best case examples of addressing climate change in different settings (e.g., developing countries) and at different levels (e.g., SEA)	Require consideration of sustainability at all levels	Integrate uncertainty considerations into each IA activity (e.g., scoping, alternatives, impact management)
Foster private sector capacity for companies to understand and integrate climate change impacts	Harmonize protocols for analysis and for incorporating climate change into IA	Use risk management frameworks to understand implications of climate change impacts and uncertainties for planning, investments, and operational decisions
Seek to develop and refine spatially specific climate change scenarios	Harmonize climate change data gathering through regulations	Consider equity (sociocultural, socioeconomic, inter- and intragenerational), vulnerabilities, and adaptive capacities
Use and promote sustainability principles as a means of framing consideration of climate change		Link climate change IA and sustainability
		Seek no regrets measures that generate net social, ecological, and economic benefits regardless of extent of climate change
		Utilize assistance from experienced communications specialists to help inform decision makers of relevance and implications of climate change to proposal
		Integrate local and indigenous knowledge
		Assess interactions between mitigation and adaptation measures and consequences
		Integrate climate change considerations into life cycle of infrastructure and business investment/performance
		Develop and test different planning, policy, and program options against different climate scenarios
		Explain and justify how results obtained and degree of confidence
		Draw upon IA and climate change information and resources including literature, guidelines, and best practices

Sources: Brown (2003), Byer et al. (2009, 2011), Burdge (2008), Draper (2010), Farber (2003–2004), FPTCCCEA (2003), Furlow (2010), Gardner (2010), IAIA (2012), IAIA and World Bank (2010), Larsen (2012), Larsen et al. (2012), Smith (2010), Spickett et al. (2011), US CEQ (2010a), Watson (2010), Wende et al. (2012), Wilson (2010), Yi and Hacking (2012).

interests, and is unwilling or unable to adapt to an evolving regional context. The third story describes how a proponent learned from past mistakes and built on past successes. The three stories underscore the need for IA processes to be open and adaptive if they are to operate effectively in complex, rapidly changing decision-making environments fraught with uncertainty.

The problem is a combination of confusion regarding the nature of uncertainty, risk and health effects, and ambivalence concerning the most appropriate approach, or combination of approaches, for managing IA process uncertainties. The direction involves an enhanced understanding of uncertainty, difficult problems, chaotic and complex environments, and adaptation, coupled with a selective blending of general adaptation strategies and tactics, risk assessment and management, the precautionary principle, human health impact assessment, emergency planning and management, adaptive environmental assessment and management, and climate change impact assessment.

Problems are triggered by a question or a situation, are negative, and need to be addressed. Problem-solving processes identify, define, bound, and state the problem. The problem is then progressively refined and addressed. There are simple or tame problems, compound or semistructured problems, complex or ill-structured problems, and crises or metaproblems. Simple and compound problems can be addressed by routine and conventional IA procedures, respectively. Complex and metaproblems are more difficult. They are real, complex, messy, transcend boundaries, and disciplines, are prone to dilemmas, impossibilities, and crises, and require ingenuity. An adaptive IA process is needed to properly cope with difficult problems.

IA processes should suit the *environment* or context. There are many environmental components or systems (e.g., ecological, social, economic, institutional, technological). There are simple, moderately complex, and highly chaotic and/or complex environmental systems. Command and control and conventional IA processes, respectively, operate effectively in simple and moderately complex environments. Chaotic or complex environmental systems are more problematic. They exhibit such properties as self-organizing, emergent, turbulent, nonlinear, irreducible, random, incoherent, unpredictable, interdependent, resilient, and unstable. Adaptive IA processes and organizations can operate more effectively in chaotic or complex environments.

Uncertainty, broadly defined, is any situation where we are not absolutely sure. There are many uncertainty forms (e.g., quantitative, qualitative, objective, subjective, methodological, perceived, knowledge, values, past, present, or future conditions). Uncertainties can pertain to any IA process activity. There are many possible uncertainty sources (e.g., data or knowledge deficiencies, theoretical or methodological deficiencies, resource limits, poor communications, natural variations, novel situations). Several uncertainty-related concepts are potentially relevant (e.g., ignorance, errors, indeterminism, vagueness, ambiguity, doubt, confusion, surprise, deep/extreme).

There are many ways of addressing *uncertainty in the IA process*. A perspective change is first required (e.g., uncertainty as a fundamental attribute of the process). Measures can be introduced into each IA activity to anticipate, cope with, learn from, and manage uncertainties. Uncertainty management measures can be integrated into problem definition, scoping, proposed action determination, option identification and evaluation, individual and cumulative impact identification, prediction and interpretation, mitigation and compensation, impact and uncertainty management, public and agency consultation, study team management, decision making, monitoring, and IA institutional arrangement reform. Uncertainty management is facilitated by insights and lessons from design, ingenuity, creativity, strategic choice, consilience, and holistic science.

Adaptive environmental assessment and management treats environmental management as a quasiexperiment (i. e., probing ecosystem responses to human activities). The AEAM process is an iterative cycle of planning, implementation, monitoring, research, and re-examination. AEAM processes are typically built around a series of workshops. The workshops construct and apply a model that characterizes critical environmental conditions and interactions and tests possible management actions and alternative assumptions. The periods between workshops are devoted to consolidation and refinement. The process is guided by a core group and by specialist support staff. Workshops involve policy people, managers, and a diversity of stakeholders. Key indicators are monitoring throughout implementation. Data obtained during monitoring are analyzed, documented, and fed into each process activity. The process is open, continuous, cyclical, evolving, and highly iterative. AEAM has much to offer IA but there also are important differences between the two fields. These differences and AEAM strengths and shortcomings should be carefully considered when connecting or integrating IA and AEAM.

Risk combines frequency or probability with a harmful environmental consequence. There are many risk types (e.g., economic, health, environmental, from natural or human sources, chronic, acute, for overall and for sensitive populations, deterministic, and probabilistic). Potentially relevant risk-related concepts include risk assessment, perceived risks, risk communications, comparative risk assessment, risk acceptability or tolerance, risk management, disasters and hazards, human health risk assessment, and ecological risk assessment. Risk assessment processes include, for example, problem and analysis plan formulation, receptor determination, pathway and receptor characterization, hazard identification and analysis, exposure assessment and response, risk characterization, risk evaluation, decision making, implementation, and monitoring. Risk assessment processes integrate research, public perceptions, stakeholder concerns and preferences, option analyses, mitigation measures, and uncertainty analyses. There is considerable potential to more effectively link and integrate IA and emergency planning and management. There are many similarities but also important differences between IA and risk assessment and management. Similarities, differences, and risk assessment and management strengths, deficiencies, and measures to address deficiencies, all should be considered when linking and integrating IA and risk assessment and management.

The *precautionary principle* responds to the dilemma of what to do when there is a need to take action because of potentially severe environmental consequences but shortcomings in the scientific knowledge base. There are multiple interpretations of what represents severe harm potential, inadequate scientific evidence, and the basis for action (e.g., inaction not justified, rejection of proposal, only proceed if proven safe, proceed if reasonable case can be made, proceed with caution). Applying the precautionary principle requires thresholds, criteria, decision rules, definitions for key terms, and institutional arrangements. Some argue that the principle also requires a reversed burden of proof, open transparent and democratic decision making, systematic alternatives analyses and greater decision-making weight on prevention, risk avoidance, ignorance, and environmental values. A precautionary IA process involves screening (whether the principle is to be applied), scoping, goal setting, study design, an analysis of need and alternatives, adaptations to the principle to suit the situation, refining, and applying precautionary thresholds, criteria, and procedures, precautionary decision making, the taking of precautionary action, implementation, monitoring, follow-up, and evaluation, all within an open, transparent, and democratic IA process. The precautionary principle is highly controversial, but addresses a valid concern. Ascribed strengths and drawbacks need to be carefully considered. A clear rationale should be presented for if and how the principle (or an alternative approach) is applied in IA practice.

Human health impact assessment is concerned with positive and negative, certain and uncertain human health effects. HIA is closely connected with other types of IA, draws upon an interdisciplinary knowledge base, and can contribute to sustainability. It assumes many forms (e.g., quick screening, rapid appraisal, standard HIA, comprehensive HIA). It can be prospective, retrospective, or concurrent. It can be broadly or narrowly defined. HIA processes tend to begin with screening, scoping, a background analysis, and a prognosis of future health-related environmental conditions. Health effects associated with options and before and after mitigation are predicted, summarized, and evaluated. HIA is supported by quantitative (e.g., risk assessment) and qualitative (e.g., health impact assessment) procedures. The health and risk analyses provide the basis for management measures, documentation, conclusions, recommendations, and decision making. Results are monitored and evaluated. Agencies and the public are heavily involved in the process. Health effects are addressed by HIA being undertaken independently, broadening IA, merging IA and HIA, selectively integrating IA and HIA, or broadening risk assessment and management. HIA is a newly emerging and rapidly expanding field of IA practice. It has many attributes, strengths, and limitations that should be carefully considered, especially its uncertainty management procedures.

The *four jurisdictions* (United States, Canada, Europe, Australia) address many aspects of uncertainty. IA guidelines could devote more attention to difficult problems (e.g., trans-scientific, latent time bombs) in IA practice. Guidelines and applied research also could identify insights and implications from chaos and complexity theories for IA practice. A more systematic effort could be make to identify relevant uncertainty forms and sources, to describe key uncertainty concepts, to identify where and how uncertainties arise in the IA process, and to provide examples of uncertainty management methods. Further direction and advice could be provided regarding documenting uncertainties and concerning the role of uncertainty in IA-related decision.

All jurisdictions refer to health risks in IA requirements. More attention could be devoted to chronic health risks, ecological risks, and perceived risks. All jurisdictions could devote more attention to potential risk assessment and management roles in the IA process. A greater effort could be made to develop and apply abbreviated IA forms for emergency situations and to integrate lessons and insights from emergency planning and management into IA risk management requirements and guidance. The four jurisdictions have all gradually moved toward the greater integration of climate change considerations and IA requirements. IA jurisdictions and other stakeholders could benefit from sharing experiences and insights.

Health effects are mentioned in the IA requirements of all four jurisdictions. But the treatment of health effects is general and fragmentary. The numerous recent HIA initiatives and guidelines are correcting this deficiency. The role of the health community in HIA requires additional consideration. The effectiveness of HIA requirements and guidelines needs to be monitored and evaluated. The many uncertainties associated with identifying, predicting, and managing human health effects should receive particular consideration. There is considerable variation among the jurisdictions in if and how the precautionary approach or principle is addressed in environmental requirements. If the principle is to be applied, IA requirements should define the principle and specify which harmful effects, uncertainties, and actions trigger its application. Conditions for applying the principle and the decisions to which it applies should be indicated. IA requirements could more explicitly provide for adaptive management in general and AEAM in particular, appreciating the differences between IA and AEAM. IA guidelines could address potential AEAM and IA interrelationships. The potential role of AEAM in identifying and coping with uncertainties should receive particular attention.

At a broader level, risk assessment and management, adaptive management, climate change assessment, HIA, and the precautionary principle collectively represent tools and perspectives for analyzing and coping with uncertainty. They clearly overlap, and they should be complementary. This suggests that there is a need, at the regulatory level, to integrate these individual elements within broader uncertainty management strategies. Mutual learning among IA jurisdictions represents an important knowledge source for enhancing IA uncertainty management capacity.

Uncertainty management at the applied level involves selectively combining concepts (related to problem types, environment types, and uncertainties) and approaches (general adaptation strategies and tactics, risk assessment and management, health impact assessment, the precautionary principle, emergency planning and management, adaptive environmental assessment and management, climate change impact assessment), within an adaptive IA process. Designing an IA uncertainty management approach entails formulating an uncertainty framework (to identify relevant values, principles, and objectives); identifying the applicable problem and environment type (to determine the appropriate IA approach); characterizing uncertainties; formulating and applying general adaptation strategies and tactics; determining whether and how risk assessment and management, the precautionary principle, health impact assessment, emergency planning and management, climate change impact assessment, and adaptive environmental assessment and management could be used to manage risks, uncertainties, and health effects; linking and combining the concepts and approaches; formulating an overall uncertainty management approach; and applying, monitoring, and adapting the approach.

All the IA process types (SA, SEA, EIA, EcIA, SIA, HIA) recognize the inevitability of risks and uncertainties, the limits of knowledge, and the need for an adaptive IA process that can effectively identify, interpret, and manage risks and uncertainties. All suggest the desirability of an IA process that is iterative, dynamic, innovative, transformative, precautionary, and learning oriented. Many substantive themes (e.g., health, emphasis on the most vulnerable, climate change, contribution to sustainability) are shared among IA types. Differences among the process characteristics for the various IA types are largely a question of degree, emphasis, and orientation. Given the many shared themes, overlaps, and interconnections among the adaptive IA process type characterizations, the sharing of knowledge and experiences would seem highly desirability, again, however, appreciating the implications of differences among the IA types and in terms of context.

Climate change is a change in the climate that is directly or indirectly attributable to human activity that alters the global atmosphere composition over observed time periods, and is in addition to natural variation (IAIA, 2012). It can be identified by changes in the mean of variability of its properties and persists over an extended period (IAIA, 2012). Climate change addresses both the climate change implications of greenhouse gas emissions and the effects on a proposed action and the environment from climate change.

Climate change considerations can be integrated into each IA process activity. It tends to operate more effectively when applied at both the SEA and project EIA levels. Climate change impact assessment incorporates and applies such concepts as adaptation, adaptive capacity, risk, vulnerability, mitigation measures, adaptation measures, equity, resilience, and uncertainty. The uncertainties with climate change predictions and management and links to sustainability need to be fully and systematically considered. Consideration should be given to climate change IA good practices, appreciating the need for contextual adjustments.