CHAPTER 12

# From science to policy: developing responses to climate change

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## Introduction

Climate change poses risks to human health, ecosystems, social and cultural systems, and economic development. It also provides opportunities. The goals of climate policy should be to reduce the risks and take advantage of the opportunities.

Adapting to the potential effects of climate change is a complex and ongoing process requiring actions by individuals, communities, governments and international agencies. In order to make informed decisions, policymakers will need timely and useful information about the possible consequences of climate change, people's perceptions of whether the consequences are positive or negative,[4] available adaptation options, and the benefits of slowing the rate of climate change. The challenge for the assessment community is to provide this information. Assessments must be made of the potential consequences of climate change, as well as of opportunities to adapt in order to reduce the risks, or take advantage of the opportunities, presented by change.

A policy-focused assessment[5] is an ongoing process designed to provide timely and useful information to decision-makers (*1*). Assessment products that address decision-makers' specific questions must be produced so that they coincide with decision points. Decisions will be made, including decisions to do nothing, whether or not the science is complete and the scientific community is prepared to provide input (*2*). Decisions made today might influence future opportunities to mitigate greenhouse gas emissions and to adapt to a changing climate.

Once policymakers have received information from the assessment community, their challenge is to integrate this information (where appropriate) to

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[5] Positive impacts from one person's perspective may be negative from another's.
[6] Scheraga and Furlow note that the term "policy-relevant" is more commonly used. "Policy-relevant" is defined as an iterative process that engages both analysts and end-users to evaluate and interpret the interactions of dynamic physical, biological, and social systems and communicate useful insights in a timely fashion. They choose to refer to this type of assessment as "policy-focused" because many types of research and assessment activities may, at some time, be relevant for policy, but are not focused on answering specific questions being asked by policy makers by a specific point in time. Policy-focused assessments are intended to inform in a timely fashion decision-makers asking specific questions. The terminology is intended to distinguish between these different types of assessment activities.

develop a policy portfolio consisting of a sensible mix of approaches for reducing the risks and taking advantage of the opportunities presented by climate change. An array of response options exists, including actions to mitigate greenhouse gas emissions in order to slow the rate of climate change; actions to adapt to a changing climate in order to increase society's resilience to change; communication strategies to increase public awareness of climate change; investments in monitoring and surveillance systems; and investments in research to reduce key policy-relevant uncertainties and increase understanding of the potential effects of climate change.

The challenge for decision-makers is complicated by the fact that climate change is only one of many factors that influence human health, ecosystems and social well-being. Climate change cannot be considered in isolation from other important stresses. Earth's ecological, socioeconomic and climate systems are closely linked (*3*). Human health is affected by a variety of social, political, economic, environmental, technological and demographic factors, including:

- urbanization
- level of economic development and availability of wealth (e.g. funds available for research, sanitation, surveillance and monitoring)
- technological innovation (can pose its own environmental and health risks)
- scientific breakthroughs
- individual behaviour
- environmental conditions (e.g. air or water quality).

Any public health programme should consider these factors holistically to identify the important stressors and the most effective remedial mechanisms. The resources available to the public health community need to be shared among a variety of public health problems (and other problems of concern to society), therefore the ideal situation is to direct resources to their highest valued uses for the greatest public good. Often it is said that public health resources are scarce, in the sense that a resource is scarce if it is desired but limited.

"Highest valued" is a value-laden concept and therefore a social choice, not a scientific decision. It may include equity considerations (e.g. a decision that leads to differential health impacts among different demographic groups), efficiency considerations (e.g. targeting those programmes that will save the greatest number of lives) and political feasibility. It may also include ethics considerations, which are particularly important in public health. The practice of public health is guided by four ethical principles (*4*): respect for autonomy, nonmaleficence, justice and beneficence. Beneficence, the principle of doing good, is the dominant ethical principle of public health—but may not be the dominant value for decision-makers faced with competing demands. Respect for autonomy means concern about human dignity and freedom, and the rights of individuals to make choices and decisions for themselves, rather than others deciding for them. Nonmaleficence is the principle of not harming, derived from the ancient medical maxim: first, do no harm. Justice in this sense means social justice—fairness, equity and impartiality.

Public health frequently is faced with situations where it is not possible to uphold each of these principles. For example, a decision to quarantine a group of individuals to prevent the spread of a communicable disease emphasizes beneficence over the respect for autonomy and justice. Public health places the need to protect society as a higher imperative than the rights of an individual. Public health practitioners believe that as long as the community perspective (driven by shared customs, institutions and values) and the perspective of a common good (including the desire to reduce disease, save lives and promote good health) remain intact, actions can be taken that limit individual autonomy and justice. Nevertheless, there isn't always consensus—even among public health officials—on the best way to promote the public's health and how to weigh individual liberties against the welfare of the whole.

Decision-makers outside the public health community are faced with similar challenges. Climate change affects multiple sectors and resources including (but not limited to) agriculture, forestry, water resources, air quality, ecosystems and biodiversity, and cultural resources. Stakeholders with an interest in each of these may have conflicting desires and conflict resolution is likely to be required. Policy-makers dealing with multiple social objectives (e.g. elimination of poverty, support for agriculture, promotion of economic growth, protection of cultural resources) and competing stakeholder desires must make difficult choices as they allocate scarce human and financial resources. For this reason, the Intergovernmental Panel on Climate Change (IPCC) suggested that it is helpful to view climate change as part of the larger challenge of sustainable development (*5*). Climate policies, including those intended to protect public health, can be more effective when consistently embedded within broader strategies designed to make national and regional development paths more sustainable. The impact of climate variability and change, climate policy responses, and associated socioeconomic development will affect the ability of communities to achieve sustainable development goals. Conversely, the pursuit of sustainable development goals will affect the opportunities for, and success of, climate policies.

This chapter addresses the health impacts assessment community's challenge to provide timely and useful information to decision-makers. We discuss the notion of policy-focused assessment and demonstrate how it can be a bridge between the research community and decision-makers. The key characteristics of a successful policy-focused assessment are identified. Case studies are presented to illustrate how actions and policy decisions already have been informed in a timely and useful way by policy-focused assessments.

A theme that pervades the entire chapter is that the existence of scientific uncertainty about climate change and its potential health impacts does not preclude policy-makers from taking actions now in anticipation of the health impacts of climate change. In fact, decisions are made every day where uncertainties about factors unrelated to climate are as high or higher than those associated with climate change (e.g. the financial markets). While there is uncertainty about some future climatic changes, also there are some for which there is relative certainty (*5*). The process of policy-focused assessment receives increased attention because of the need, the imperative, for scientists to provide timely insights to risk managers who must make decisions every day despite the existence of scientific uncertainties. A community building a drinking water plant in a coastal zone today cannot wait for projections of future sea level rise to be perfected. Decisions about plant location and investments in water purification equipment that may have a long lifetime will be made despite the existence of uncertainties. Policy-focused assessments analyse the best available scientific and socioeconomic information to answer questions posed by risk managers. They characterize and, if possible, quantify remaining scientific uncertainties and explain the potential implications of the uncertainties for the outcomes of concern to the decision-makers.

Ultimately, it is society's choice to decide whether a perceived risk (however large or small) warrants action. The existence of scientific uncertainties, by itself, is not an excuse for delay or inaction on the part of decision-makers.

## Boundaries between assessment and policy formation

Only society can decide whether or not particular risks and opportunities are of concern. The extent to which it is willing to expend resources to avoid the effects of climate change will depend in part on its perceptions of the risks posed, perceived costs of the effort and how much it is willing to risk possible negative consequences (*6*, *7*). Strategies to cope with or take advantage of climate change or to mitigate greenhouse gas emissions compete for scarce resources that could be used to address other societal problems (e.g. health care and poverty) that will be of varying degrees of concern to different individuals and groups.

Society is composed of individuals and groups that often have very different interests, motivations and levels of access to levers of power. The process by which society makes decisions to form and implement policy is complex. For this reason, care must be taken to respect the boundary between assessment and policy formation. Policy-focused assessment is an ongoing process, the goal of which is to inform policy decisions in a timely fashion. However an assessment should not make specific policy recommendations, unless commissioned by a deliberative, decision-making body that asks explicitly for these. In order to maintain the credibility, usefulness and effectiveness of the assessment process, a policy-focused assessment must be divorced from the actual process by which policy decisions are made. The process must be not only apolitical and unbiased, but also perceived as such by all parties participating in the assessment process, including decision-makers relying upon the results of the assessment.

It is the job of policy-makers, not researchers, to decide which criteria should be used. Such decisions are informed by the science but include other considerations that reflect societal values (e.g. equity considerations) and other factors affecting decision-making (e.g. political feasibility).

## Decision-making criteria

Many criteria and approaches exist for making decisions under uncertainty. One criterion that increasingly has been included in national legislations and international treaties is the precautionary principle. This is a risk management policy that is applied when a potentially serious risk exists but with significant scientific uncertainty (*8*). Like other approaches, it requires that decision-makers take into account the likelihood of a particular health hazard and the nature and scale of the consequences should it occur. The precautionary principle allows some risks to be deemed unacceptable not because they have a high probability of occurring but because there may be severe or irreversible consequences if they do. This was featured in the 1992 Rio Declaration on Environment and Development as principle 15 (*9*):

> *"In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation."*

The precautionary principle is one approach to risk management. There are other criteria and approaches for making decisions under uncertainty. One example is the “benefit-cost” criterion that weights the expected benefits and expected costs of an action taken to address an uncertain health risk. The benefit-cost criterion is straightforward: if the winners under a proposed policy value the change more highly than do the losers, it is said that the policy has positive net benefits and enhances efficiency (*10*). In calculating net benefits, allowance must be made for the possibility that benefits and costs may not accrue instantaneously, but over time. Discounting is the process by which measured future economic effects are transformed into their present values and compared. The weight given to benefits and costs at different points in time is critical and determined by the discount rate that is used. The evaluation of projects and their relative rankings according to a benefit-cost criterion is highly sensitive to the discount rate, particularly when the time-paths of benefits and costs are markedly different.

There are questions about how benefits and costs should be measured and how they should be compared among different societies. Often, benefits and costs must be measured using different metrics. Benefits frequently are measured in non-monetary terms (e.g. fewer hospital visits, fewer days of work/school missed, QALYs, DALYs) while costs are measured in dollar terms (e.g. the price of a smoke-stack or catalytic converter). These differences in metrics can lead to debate.

The benefit-cost criterion emphasizes the efficient use of scarce resources. It is not, however, a criterion for dealing with equity. As environmental issues (like climate change) become more complex, global and long-term in nature, policy analysts increasingly are questioning whether the process of discounting in benefit-cost analysis biases decisions against the interests of future generations. Such issues have the potential for catastrophic outcomes in the distant future that would be trivialized by the process of discounting. Despite these concerns benefit-cost analysis should not be dismissed completely. This would only deprive decision-makers of one set of insightful information. Further, advances have been made in the development of discounting approaches that account for situations in which the length of the stream of benefits from an environmental policy increases relative to the cost stream, and in which lags may exist between the time that costs are incurred and benefits are realized (e.g. health effects with latency periods) (*11*, *12*).

## Decision-support tools

Once society has made a decision to act, the choice of a “best” policy for coping with climate change is a decision inherently dependent upon social values and selection criteria that must be identified by decision-makers and stakeholders (not by researchers or assessors). Policy decisions often are complex because of the need to consider multiple social objectives and to assess the importance and relevance of these in some consistent way—which requires their own set of tools (*13*). Another important role for the assessment community is to develop decision-support tools that will help risk managers organize and visualize information, analyse potential trade-offs between social objectives as they make decisions under uncertainty and understand the implications of remaining scientific uncertainties for the outcomes they care about.

## Response options

An array of response options exist should society decide to expend resources to protect public health, ecosystems and social well-being from climate change. The

## **CASE STUDY #1** Hantavirus pulmonary syndrome in the southwestern United States of America

### Insights from this case study

The following case study illustrates how a policy-focused health-impacts assessment ultimately can lead to on-the-ground interventions to prevent disease and protect the public's health. Using information derived from an assessment of the environmental conditions associated with outbreaks of hantavirus pulmonary syndrome, decision-support tools in the form of risk maps have been developed that support public health officials trying to prevent outbreaks in the southwestern United States of America. This case study is based on the work of Glass et al (*14*).

### Motivation for the assessment

In 1993, a disease characterized by acute respiratory distress with a high death rate (>50%) among previously healthy persons was identified in the southwestern United States. Hantavirus pulmonary syndrome (HPS) was traced to a virus maintained and transmitted primarily within populations of a common native rodent, the deer mouse.

After the outbreak, researchers hypothesized that it was due to environmental conditions and increased rodent populations caused by unusual weather associated with the El Niño Southern Oscillation (ENSO) in 1991–92. It was suggested that a cascading series of events from weather (unseasonable rains in 1991 and 1992, mild winter of 1992) through changes in vegetation, to virus maintenance and transmission within rodent populations, culminated in changes in human disease risk from HPS. Public health officials wanted to understand the cause of the outbreak in order to develop effective techniques for intervention and prevention of the disease.

### Results of the assessment

A study at The Johns Hopkins School of Hygiene and Public Health, sponsored by the United States Environmental Protection Agency (EPA), explored this hypothesis by comparing the environmental characteristics of sites where people were infected with those sites where people were not. This research found that high-risk areas for hantavirus pulmonary syndrome can be predicted over six months in advance based on satellite generated risk maps of climate-dependent land cover. Predicted risk paralleled vegetative growth, supporting the hypothesis that heavy rainfall from El Niño in 1992 was associated with higher rodent populations that triggered the hantavirus outbreak in 1993. Landsat satellite remote sensing images from 1995, a non El Niño "control" year, showed low risk in the region: images from the 1998 strong El Niño again showed high risk areas as in 1992–93. Trapping mice in the field (collectors blinded to risk category) validated these satellite generated risk maps with mouse populations directly related to risk level, with a correlation factor of over 0.90. Risk classification also was consistent with the numbers of HPS cases in 1994, 1996, 1998, and 1999. This information was used to develop an early warning system, with intervention strategies designed to avoid exposure.

These strategies, developed in partnership with the centers for Disease Control and Prevention (CDC) and the Indian Health Service, already are being implemented for disease prevention in the south-west by the United States Department of Health and Human Services.

mitigation of greenhouse gases provides a mechanism for slowing, perhaps eventually halting, a build-up of greenhouse gases in the atmosphere. There is growing concern over the need to slow the rate of growth of atmospheric concentrations of greenhouse gases, particularly from anthropogenic sources. As noted in the 1995 Second Assessment of the Intergovernmental Panel on Climate Change: "with the growth in atmospheric concentrations of greenhouse gases, interference with the climate system will grow in magnitude, and the likelihood of adverse impacts from climate change that could be judged dangerous will become greater" (*15*). More recently, the IPCC 2001 Third Assessment concluded: "there is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities". The potential for unexpected, large and rapid climate changes (surprises) may increase due to the non-linear nature of the climate system. A slowing of the rate of warming could yield important benefits in the form of reduced impacts to human health and other systems.

Adaptation is another important response option (*6*). As discussed in chapter 11, adaptive responses are those actions taken to enhance the resilience of vulnerable systems, thereby reducing damages from climate change and climate variability. Adaptation in the form of adjustments in behaviours, practices, processes, or structures of systems is important for protecting human health from the risks posed by climate change and for exploiting beneficial opportunities provided by a changing climate. Actions may be taken in reaction to climate change as it occurs (reactive adaptation) or in anticipation of future climate change (anticipatory adaptation).

Adaptation strategies need to be considered as part of any policy portfolio. Some level of climate change is inevitable since the climate is already changing and mitigation efforts over the near future cannot stop climate change, only slow the rate of change. Some of this change will occur as the result of natural climatic variation, some as the result of human activities that already have altered the atmosphere and committed us to future climate change. Regardless of the source of change, systems that are sensitive to changes in climatic conditions will be affected, including human health. Failure to invest in adaptation may leave a nation poorly prepared to cope with adverse changes and take advantage of opportunities, thereby increasing the probability of severe consequences (*16*).

Communication of information about climate change, potential health impacts and response strategies is itself a public policy response to climate change. The development and implementation of monitoring and surveillance systems and investments in research, also are adaptive responses. All of these should be considered when developing portfolios of policies for responding to climate change.

Expenditures on adaptation and mitigation measures will likely not be politically feasible unless an informed public understands the potential consequences of climate change and decides that there is a need to respond. An informed public also is required to ensure the continued effectiveness of any adaptation and mitigation policies that are implemented.

Monitoring and surveillance systems are integral and essential to providing the necessary information and continuity in the data to support decisions by public health officials (*17*). Sustained investments in monitoring systems and their evolution are critically important for tracking changes in the environment, particularly those factors that affect human health. Monitoring systems also are required to track the effectiveness of adaptation and mitigation policies on an ongoing basis. Investments in public health surveillance systems are important for detecting changes in health status and the potential effects of climate change (*18*). Vital elements of such a system are:

- a rapid and comprehensive communications network
- accurate, reliable, laboratory-based diagnosis capabilities in host countries or regional centres
- a mechanism for rapid response.

The functioning of such systems would be aided by heightened cooperation among local, regional, national and international health organizations (*19*).

Ongoing investments in research are necessary to provide the scientific information required for the conduct of policy-focused assessments. Research and assessment activities are complementary. Regular interactions between assessment processes and research activities can help ensure that the ongoing production of scientific information will help to answer new stakeholder questions as they emerge. When successfully implemented, such interactions permit the research community (health, physical, biological and social sciences) to identify and communicate new information and data to the assessment and policy communities on a regular basis. At the same time assessments identify and prioritize research needs in order to better answer questions being asked by the stakeholder community.

## Building the bridge from science to policy: policy-focused assessment

Policy-focused assessment is a process that can help resource managers and other decision-makers to meet the challenge of assembling an effective policy portfolio. As noted earlier, it is a process by which the best-available scientific information can be translated into terms that are meaningful to policy-makers. A policy-focused assessment is more than just a synthesis of scientific information or an evaluation of the state of science. Rather, it involves the analysis of information from multiple disciplines—including the social and economic sciences—to answer the specific questions being asked by stakeholders. It includes an analysis of adaptation options to improve society's ability to respond effectively to risks and opportunities as they emerge.

Policy-focused health assessments should be designed to identify key stresses on human health within a particular region or community under current climatic conditions, and the extent to which society is vulnerable to these stresses. Formulation of good policy requires understanding of the variability in vulnerability across population sub-groups and the reasons for that variability. The vulnerability of a population is a function of the:

- extent to which health, or the natural or social systems on which health outcomes depend, are sensitive to changes in weather and climate (exposure-response relationships);
- exposures to the weather or climate-related hazards;
- population's ability to adapt to the effects of the weather or climate-related hazards.

Understanding a population's vulnerability to climate variability and change thus depends on knowing the baseline associations between specific health outcomes and specific weather and climate conditions. It also depends on the capacity of individuals and the population to adapt to changes in weather and climate conditions. The consequences are not just severe in countries with less adaptive capacity but also within specific communities and regions with less adaptive capacity. Individuals, populations and systems that cannot or will not adapt are more vulnerable, as are those who are more susceptible to weather and climate changes (e.g. consequences of storms and floods are more severe in countries with less adaptive capacity). Once current conditions are understood, the extent to which climate change may exacerbate or ameliorate health outcomes can be considered. Climate change should be considered in the context of the changes that may occur in other stresses: changes in these and in adaptive capacity can be expected to influence strongly the anticipated future benefits and costs of adaptation policies. Such a multiple stressor approach permits identification of the priority risks in a region or nation.

A complete health impact assessment goes beyond risk assessment. It also includes an adaptation assessment: an evaluation of society's capacity to adapt to change and of alternative risk management options. Once the risks have been identified, an assessment should identify and analyse appropriate adaptive responses to improve society's ability to respond effectively to risks and opportunities as they emerge. Barriers to successful adaptation and the means of overcoming such barriers need to be identified. Adaptive responses may have multiple benefits: reducing risks from climate change while, at the same time, addressing other risks to public health (also known as win-win strategies). Elimination of poverty in a community will not only reduce hunger but also facilitate improvements in sanitation, medical care and other public health systems, and thus increase resilience to climate change.

Earlier it was noted that stakeholders—both inside and outside the public health community—may have conflicting desires and conflict resolution often is needed to formulate and implement an effective policy response. Assessments of the potential health consequences of climate change can facilitate the process of conflict resolution and the allocation of scarce resources to their highest valued uses by considering multiple stresses on multiple systems and across multiple species that share interactive and interdependent relationships. Communities and sectors that share interactive and interdependent relationships also should be considered. Assessments that do not account for multiple interactions and feedbacks between systems and sectors may provide inadequate or inaccurate information for developing adaptive responses and may increase the likelihood of implementing ineffective or maladaptive strategies.

There are several key characteristics of a successful assessment of the health consequences of climate change (*1*):

- draws upon expertise from multiple disciplines;
- engages stakeholders throughout the assessment process to ensure timeliness and relevance of assessment results;
- analyses potential adaptive responses and options presented to decision-makers;
- identifies uncertainties and characterizes their implications for the specific decisions being made by policy-makers;
- produces a research agenda that identifies and prioritizes key knowledge gaps.

## Assessment as a multidisciplinary activity

Ideally, assessment teams are composed of researchers from a variety of disciplines working together to address complex research and assessment questions. By its very nature, assessment of the potential health consequences of climate change is a multidisciplinary activity. It includes an evaluation that engages the human health, biological, physical and socioeconomic sciences in order to understand health outcomes' sensitivity to changes in weather and climate, and the possible risks under different scenarios of climate change, economic growth and technological change. Assessment also entails consideration of how human behaviour might contribute to, or ameliorate, the risks.

The extent to which climate change may damage or harm human health will depend on the magnitude of the exposure and the ability of people to adapt successfully to new climatic conditions. The ability to adapt effectively may depend upon the social, political, economic, environmental, technological and demographic factors that may affect human health. Hence, to capture the full array of factors that may affect human health directly or indirectly, assessments also should include expertise from the social, political, environmental and engineering sciences. Researchers and modellers in all of these disciplines should be considered for inclusion in a health impact assessment team.

## Stakeholder engagement

Assessment of the potential health effects of climate variability and change should be guided by the priority vulnerabilities in a region or nation. The assessment should consider new or potentially evolving vulnerabilities that may or may not be climate driven. One way to determine priorities is through a stakeholder-oriented assessment process with involvement of stakeholders throughout the process.[1]

Sometimes it is difficult to identify all constituencies that might have an interest in a particular health impacts assessment. New stakeholders often are identified during the course of an assessment process, as understanding of the potential health consequences of climate change evolves. For this reason, the process of identifying and involving stakeholders is ongoing.

For an assessment to be informative, assessors must know the particular issues and questions of interest that the stakeholders and decision-makers want answered. This includes consideration of relevant questions suggested by scientists. At the outset of an assessment, the questions and outcomes of greatest concern (which may not be limited to health-related effects) should be elicited. The decision-makers who are clients for the assessment results often have multiple objectives and concerns, not necessarily limited to concerns about climate change—or even public health. Also, decision-makers may need very specific types of information in order to incorporate climate change into their decision-making and to formulate and implement new and effective adaptive responses. Stakeholders can be a source of this information.

An assessment begins with a framing exercise to determine process and goals. A multidisciplinary steering group established to agree upon the terms of reference for the assessment should conduct this exercise. This group also should be available to provide advice and support during the assessment process. The terms of reference will be specific to each assessment. Common elements should include detailed descriptions of the conduct and evaluation of the assessment, including such questions as the scope; timetable; budget and funding sources; methods used for identifying members of the team; methods used in the assessment and its review/evaluation; form and content; and the nature and frequency of feedback from the steering group and from stakeholders.

Stakeholders should be involved in the analytical process on an ongoing basis. Assessors and stakeholders are not necessarily distinct communities. In many

[1] Stakeholders in a health impacts assessment process might, for example, include public health officials, doctors, health insurance companies, drug companies, managers of public/private research programmes, disaster preparedness officials, concerned members of society and the decision and policymakers. They might also include agencies that fund priority research and the researchers themselves.

cases, stakeholder communities can offer data, analytical capabilities, insights and understanding of relevant problems that can contribute to the assessment. For example, stakeholders often can share traditional knowledge from their communities about the effectiveness of previous attempts to adapt to change.

In order to ensure that an assessment is timely and useful, assessors need to understand how stakeholders will use results of the assessment and the time frame within which the assessment is needed. When scientific uncertainties still exist research scientists often are reluctant to make statements that might be used by policymakers. Yet, policymakers frequently make decisions under uncertainty, whether or not scientists are prepared to inform those decisions. A decision to wait until the science is more certain is still a decision and opportunities may change during the waiting period. Assessors of health impacts strive to answer decision-makers' questions to the extent possible given the level of uncertainties of this science, in the belief that informed decisions are better than uninformed decisions. They also characterize the uncertainties and explore their implications for different health policy or resource management decisions in the belief that a better understanding of the quality and implications of scientific information leads to more informed decisions.

As an assessment process evolves and better understanding is gained of the potential consequences of climate change for human health, it is important to re-evaluate stakeholder concerns about issues previously identified and to identify new or evolving issues of concern as stakeholders are informed of assessment results.

## Evaluation of adaptation options

Chapter 11 provided a thorough discussion of the topic of adaptation. In this section, we discuss the challenges faced by assessors as they evaluate alternative adaptation options for responding to the risks and opportunities of climate change, as well as potential barriers to implementation.

The evaluation, design and implementation of an effective adaptation strategy are complex undertakings. Assessors and policymakers should not be cavalier about the ease with which adaptation can be achieved, or the expected effectiveness of any policies they implement. Not only must the potential health impacts of climate change and options for responding to these impacts be identified, but also barriers to successful adaptation and the means of overcoming them need to be evaluated. Consideration of barriers to successful adaptation, as well as potential for unintended negative consequences of adaptation measures, is critical to the translation of assessment results into effective public health policies. Also, sustaining adaptation needs to be considered, as well as the continued evaluation of effectiveness recognizing that climate, socioeconomic factors and other drivers continue to change. The effectiveness of an introduced adaptive response may need to be reconsidered over time.

The difficulties involved in ensuring the effectiveness of future adaptive responses are illustrated by existing efforts to cope with the effects of climate variability under current climatic conditions. Historical evidence demonstrates that societies have not always adapted effectively to existing risks. For example, exposure to extreme heat causes deaths in urban areas throughout the world, even during years with no heatwaves. During heatwaves these numbers can increase dramatically. Many of these deaths are preventable, yet they continue.

## **CASE STUDY #2** Preparing for a changing climate in the Great Lakes region

### Insights from this case study

This is another illustration of how a policy-focused assessment can be used to inform policy decisions, despite the existence of scientific uncertainties. It highlights the recent efforts by the Water Quality Board of the United States-Canada International Joint Commission to begin adapting to a changing climate in order to protect the beneficial uses provided by the Great Lakes system. These beneficial uses include agriculture, fish and wildlife consumption and other factors that can affect human health.

### Great Lakes Water Quality Agreement of 1978

The Governments of Canada and the United States entered into a Great Lakes Water Quality Agreement (GLWQA) in 1978. This committed both countries to restore and enhance water quality in the Great Lakes system (*20*). The GLWQA has been amended several times, most recently in 1987. Beneficial uses provided by the Great Lakes system are defined in the agreement. The Water Quality Board of the International Joint Commission (IJC) is responsible for fulfilling this goal. Among its responsibilities is the development of remedial action plans and lakewide management plans that embody a systematic and comprehensive ecosystem approach to restoring and protecting beneficial uses in geographical areas that fail to meet the objectives of the agreement, or in open lake waters.

### IJC focus on climate change

Each of the Governments of Canada and the United States recently completed policy-focused assessments of the potential effects of climate change on the Great Lakes system (*21*, *22*). These assessments demonstrated that climate variability and change would likely have important consequences for water supplies (both quantity and quality) and therefore human health in the Great Lakes region. Examples of the implications for human health include:

- changes in the availability and quality of drinking water
- potential spread of water-borne diseases
- impacts on habitat, leading to changes in fish and wildlife consumption.

Given the findings of these and other assessments, the IJC Water Quality Board is beginning to explore and assess opportunities to adapt to a changing climate in order to protect the beneficial uses derived from the Great Lakes system. Specific questions being addressed by the Water Quality Board as it develops recommended adaptation strategies include:

- What are the Great Lakes water quality issues associated with climate change?
- What are the potential impacts of climate change on the "beneficial uses" identified in Annex 2 of the Great Lakes Water Quality Agreement of 1978?
- How might these impacts vary across the region and across demographic groups?
- What are the implications for decision-making?
- What specific advice can the Board provide within the context of the agreement, that is, how can we adapt in order to mitigate?

It is anticipated that the Board will finalize a set of recommended adaptation options sometime in 2003.

There is a wide array of possible explanations for society's failure to adapt effectively to existing risks:

- failure to identify and understand factors that affect the risk and the ability of society and individuals to respond;
- limited resources available for adaptation;
- conscious decision by society not to invest scarce resources in adaptive responses;
- perceived lack of vulnerability or perceived elimination of the threat.

Regardless of the reasons for the limited effectiveness of existing adaptive responses, historical evidence suggests that one should not be over-confident about the effectiveness of adaptive strategies when making projections of future vulnerabilities to climate change.

In the assessment of adaptation options, a number of factors related to the design and implementation of strategies need to be considered, including:

- appropriateness and effectiveness of adaptation options will vary by region, across demographic groups, and with time;
- adaptation comes at a cost;
- some strategies exist that would reduce risks posed by climate variability, whether or not the effects of climate change are realized;
- the systemic nature of climate impacts complicates the development of adaptation policy;
- maladaptation can result in negative effects that are as serious as the climate-induced effects being avoided.

### *Adaptation varies by region and demographic group*

Policy-focused assessments must account for the fact that the potential risks, and human capacity to respond to these, vary by location and across time in scope and severity. In addition, the vulnerability of populations within and across regions will vary depending upon the health effect being considered. Consequently, appropriate adaptive responses will vary across geographical regions, demographic groups and with time.

Consider, for example, that climate change will likely increase the frequency and severity of very hot days and heatwaves during the summer. Studies in urban areas, mostly in temperate regions, show an association between increases in heat and increases in mortality (*23*). The risk of heat stress may rise as a result of climate change (*24*). The most vulnerable populations within heat-sensitive regions are urban populations. Within these vulnerable populations, the elderly, young children, the poor and people who are bedridden or on certain medications are at particular risk.

To be effective, adaptive responses must target these vulnerable regions and demographic groups, some of which may be difficult to reach (*25*). For example, the elderly are less likely to perceive excess heat (*26*); they may be socially isolated and physically frail (*27*, *28*). This may make it difficult to convince them to use air conditioning (because they do not feel the heat) or to travel to air-conditioned environments (e.g. they may have no one to take them and may be unable to travel on their own). The poor may not be able to afford air conditioning, and if they live in high crime areas may be afraid to visit cooling shelters. Finally, for infants and young children, decisions about how warmly to dress and how much time to spend

## **CASE STUDY #3** Hot weather watch/warning systems

### Insights from this case study

This describes the development of hot weather watch/warning systems intended to reduce the number of deaths due to extreme heat in urban areas. It illustrates several important aspects of an assessment process and the challenges faced in developing and implementing effective adaptation strategies.

The assessors drew together information from climatology, meteorology, medicine and public health to develop a city-specific system to alert the public to changing day-to-day health risks. The system is an example of a no-regrets adaptation that addresses a current problem and increases resilience in the future. Many strategies that would reduce risks posed by climate change or exploit opportunities make sense whether or not the effects of climate change are realized. Enhanced responses to urban heatwaves can save lives now.[1]

This case study also highlights the importance of assessing potential barriers to effective adaptation and the need to monitor performance over time. In particular, the critical importance of combining the watch/warning system with an effective communication strategy to provide advice on adaptive responses to limit the risk of heat stress is discussed. In some cases the watch-warning systems have been combined with communications strategies that may result in maladaptation.

### Heatwaves and human mortality

The watch/warning systems originated with a fundamental assessment question posed by stakeholders: what might be the impacts of climate change on deaths due to heat stress? Assessors analysed the relationship between various climatological variables (including temperature) and human mortality in order to answer this. They turned to the climatological research community to understand expected changes in the frequency and intensity of heatwaves as the climate changes, and evaluated the potential changes in numbers of deaths in particular urban areas as climate changes.

Heat and heatwaves are projected to increase in severity and frequency with increasing global mean temperatures. Studies in urban areas show an association between increases in mortality and increases in heat, measured by maximum or minimum temperature, heat index and, sometimes, other weather conditions (*23*). The elderly (65 years or older), infants and young children, the poor, mentally and chronically ill people, and those who are socially isolated, are at increased risk.

Several different methods for characterizing climate have been used to assess daily mortality associated with heat episodes. One such approach hypothesizes that humans respond to more than just temperature; rather, they respond to the entire blanket of air (or air mass) around them (*29*). Air masses were characterized for specific localities using statistical methods to separate the air masses into area-specific categories based on a number of meteorological variables (*30*). This synoptic approach has led to important findings about the effect of different types of air mass on mortality. For example, daily mortality in 44 United States' cities with populations greater than one million was analysed in relation to the frequency of particular air masses. Two types of air masses associated with particularly high mortality were identified (*31*).

After this initial research, assessments were conducted to identify potential adaptation strategies. Since people die of heat stress every year and many of these deaths are avoidable, strategies were

[1] In some cases, existing institutions and public policies may result in systems that are more rigid and unable to respond to changing conditions. Elimination of these institutions and policies—if it makes sense to do so under current climatic conditions—may increase resilience to change. For example, the existence of federal flood insurance in the United States of America provides an incentive for development in high-risk coastal areas. Elimination of federal flood insurance would reduce the inventory of private property that is at risk today, and in the future when sea level rises further.

considered that would reduce avoidable deaths today while increasing resilience to future climate change. Information from the public health community was used to identify the most vulnerable populations. From this emerged the concept of watch-warning systems that have been implemented in the United States, Italy and China to protect these populations (*32*). These systems are used to alert the public about the timing and severity of a heatwave and, more specifically, to the presence of air masses that are known to pose the highest risks to human health. This contrasts with other systems that issue alerts and warnings using arbitrary temperature thresholds. The systems are city-specific, using information about the population and air masses for a particular city. Once the alerts have been issued, the media provide advice about risk factors and beneficial response measures that can be taken by individuals.

Prototype systems were first established by the University of Delaware, in partnership with the U.S. Environmental Protection Agency (USEPA), in Philadelphia and Washington, DC, in the United States. Systems were then implemented in Rome and Shanghai by the United Nations Environment Programme (UNEP) in partnership with the University of Delaware, World Meteorological Organization (WMO), USEPA and World Health Organization (WHO).

The effectiveness of these systems is now being monitored and evaluated. Bernard (*33*) notes that when alerts and warnings are issued, media sources provide advice on adaptive responses to limit the risk of heat stress (e.g. limitation of outdoor physical activity; use of sun protection cream, hats and light-coloured clothing; increased hydration with non-alcoholic and non-caffeinated beverages). However, the effectiveness of this advice is questionable. In some cases, the most vulnerable populations are identified but limited information targeted at these specific groups is provided. For example, media advice rarely specifies that elderly people and others who might be confined to the home by illness should be visited in person, rather than simply contacted by telephone, because they might be unaware of either the elevated heat in their residence or of symptomatic heat-related health impairment. Even worse, advice that could lead to maladaptation sometimes has been provided. Some sources have provided potentially dangerous and confusing information by combining advice about poor air quality with advice about heatwaves, recommending that the elderly remain indoors.

These findings suggest that advisory messages should be revised in light of established information about risk factors. There must be further evaluation of the effectiveness of the weather watch/warning systems combined with media advice.

in hot environments often are made by adults, with the children and infants unable effectively to communicate their discomfort (*26*).

### *Adaptation comes at a cost*

The resources used to adapt to a changing climate may be diverted from other productive activities, such as reducing other stresses on human health, ecosystems and economic systems. This could mean reducing the resources available for remediation of public health problems unrelated to climate. Similarly, society may have to divert natural and financial resources from addressing social problems in other sectors. In the vernacular of economics, there are opportunity costs to using scarce resources for adaptation.

Once society has decided to invest in adaptation, having identified what and how it wants to adapt, it has the option of incurring the costs of adaptation at different times: either to invest immediately or to delay until a future time (assuming effectiveness of the adaptation is the same). In either case, there are costs associated with adaptation. It is a question of when the costs are incurred and what they buy. The decision of whether to adapt now or later should be based on a comparison of the present value of expected net benefits associated with acting sooner versus later.

Whenever incurred, adaptation costs must be weighed carefully when decision-makers consider the tradeoffs between alternative adaptation strategies, reducing the cause of the change and living with the residual impacts (*34*). It is therefore important that a health impact assessment evaluates the availability of the resources required to implement alternative adaptive strategies. A nation's ability to implement adaptation measures may be restricted by a lack of appropriate technology and trained personnel; financial limitations; cultural and social values; and political and legal institutions. Society's willingness to divert the required resources from other desired uses also must be evaluated.

### *Opportunities exist to adapt to multiple factors*

Assessments of adaptation options should consider no-regrets strategies that would reduce risks posed by climate change and are sensible whether or not the effects of climate change are realized. These measures result in human systems that are more resilient to current climate variability and hopefully to future climate change (depending on what happens with climate change, successful adaptation to climate variability may or may not prepare a community for the future). The public health community recognizes adaptation strategies such as heatwave early warning and vector-borne disease surveillance systems to be important to the protection of lives and health regardless of future climate change (*35*).

In some cases existing institutions and public policies result in systems that are rigid and have limited ability to respond to changing conditions. For example, as noted earlier, the existence of federal flood insurance in the United States provides an incentive for development in high-risk coastal areas, increasing the risk of injury and death to coastal populations. Elimination of the federal flood insurance today would reduce the size of coastal communities currently at risk (at a financial cost to those individuals already living in coastal communities), as well as in the future when sea level rises further.

### *The systemic nature of climate change complicates efforts to adapt*

Climate change will have wide-ranging effects that may occur simultaneously. Many of the effects are likely to be interdependent. The systemic nature of climate change and its effects poses unique challenges to resource managers developing adaptive responses (*34*). An adaptation strategy that may protect human health may, inadvertently, increase risks to other systems. In some cases it may be impossible to avoid all risks and exploit all opportunities. Society may have to choose between alternative outcomes.

Consider, for example, the increased risk of injury and death to populations in coastal areas due to more severe storm surges and flooding that may result from a rapid rate of sea level rise. If the only concern was protection of these coastal populations, one adaptive response might be to build sea walls: but the rise in sea level also threatens wetlands and the building of sea walls prevents new wetlands from forming. Destruction of wetlands can affect water quality, which in turn could have implications for the public's health. Destruction of wetlands can affect bird migration patterns and biodiversity too. Yet if the sea walls are not built, the rise in sea level could lead to salt water intrusion: threatening freshwater aquifers and drinking water, as well as fresh water required for other uses (e.g. irrigation).

A policy-focused assessment must identify for decision-makers the tradeoffs that society may have to make between future outcomes, effective risk reduction, exploitation of new opportunities presented by climate change and maximization of social well-being.

### *Maladaptation is possible*

Adaptive responses may have unintended secondary consequences that outweigh the benefits of undertaking the strategy. For example, one possible adaptive response is the use of pesticides for vector control (*36*). Pesticides' effects on human health and insect predators and on increased pesticide resistance need to be considered when evaluating new pesticides. Pesticides used to eradicate mosquitoes that may carry infectious diseases (e.g. dengue fever) may have their own adverse impacts on human health. These offsetting effects must be considered prior to implementation of an eradication programme. Programmes like mosquito eradication require long-term commitment; failure to keep that commitment may result in adverse consequences. In the 1940s and 1950s for example, the Pan American Health Organization (PAHO) undertook an *Aedes aegypti* eradication programme to prevent urban epidemics of yellow fever in south and central America. The programme was successful in most countries and was discontinued in the early 1970s. Failure to eradicate *Aedes aegypti* from the whole region resulted in repeated invasions by this mosquito into those countries that had achieved eradication. By the end of the decade, many countries had been reinfested. The reinfestation continued during the 1980s and 1990s (*37*). This is also a good example of how a perceived lack of vulnerability can have an impact on the perceived need for adaptation (or in this case, continued investment in an adaptive strategy).

It is also important to assess in advance the risks to health from proposed technological adaptations to climate change. Increased use of air conditioning would protect against heat stress but also could increase emissions of greenhouse gases and conventional air pollutants, assuming the current proportion of coal-fired power plants (*15*, *38*).

A well-informed decision-maker, weighing the risks and adaptation options, may decide that the adverse effects of the adaptive measures are of greater concern than the risks posed by climate change itself.

## Characterization of uncertainties

Significant scientific and socioeconomic uncertainties related to climate change and the potential consequences for human health complicate the assessment process. Uncertainties exist about the potential magnitude, timing and effects of climate change; the sensitivity of particular health outcomes to current climatic conditions (i.e. to weather, climate and climate-induced changes in ecosystems); the future health status of potentially affected populations (in the absence of climate change); the effectiveness of different courses of action to address adequately the potential impacts; and the shape of future society (e.g. changes in socioeconomic and technological factors). A challenge for assessors is to characterize the uncertainties and explain their implications for the questions of concern to the decision-makers and stakeholders. If uncertainty is not directly

## CASE STUDY #4 Human dependence on food from coral reef fisheries

### Insights from this case study

This illustrates how research and policy-focused assessments have evaluated the linkages between global change (multiple stressors that include climate variability and change, UV radiation and other human-induced stresses on the environment), ecosystem change and human health. In particular it examines the effects of global change on the health of coral reefs, which among other uses supply a wide variety of valuable fisheries: an important source of food and animal protein in the human diet. Insights from policy-focused assessments are being used already to develop management options for protecting coral reefs around the world.

### Coral reefs and food supplies

Coral reefs are one of the most threatened global ecosystems and also one of the most vital. They offer critical support to human survival, especially in developing countries, serving as barriers for coastal protection; major tourist attractions; and especially as a productive source of food and trade for a large portion of the population (*39*, *40*). Coral reefs supply a wide variety of valuable fisheries, including both fish and invertebrate species (*41*). Some fisheries are harvested for food, others are collected for the curio and aquarium trades.

Reefs have been an abundant and productive source of food for millennia. In many nations, particularly those of the Pacific islands, reefs provide one of the major sources of animal protein in the human diet, with over 100 kilos of fish consumed per person per year. In the case of many small island developing nations, the majority of fisheries' harvest is small-scale and subsistence in nature; however, commercial fisheries have developed rapidly, for export markets as well as local sales. Target species include grouper, lobster, parrotfish, rabbitfish, emperors and snappers; and in areas with tourism, tourist preferences result in concentration on conch fisheries as well as grouper, snapper and lobster (*42*).

### Other uses of coral reefs

The aquarium trade serves approximately two million hobbyists worldwide who keep marine aquaria, most of which are stocked with wild-caught coral reef species. This industry has attracted controversy recently as opponents point out the damaging collection techniques that often are used and high mortality rates that result. Supporters point out that proper collection techniques can avoid major impacts to the reef and the industry involves low-volume use with very high value. Indeed, in developing countries, collectors can attain incomes that are many times the national average; recently, a kilo of aquarium fish from one island country was valued at almost US $500 in 2000, compared to reef fish harvested for food that were worth only US $6. Aquarium trade target species include not only fish but also a variety of hard and soft corals, clams and snails.

### Impacts of coral bleaching

Reef-building corals live in symbiosis with tiny single-celled algae (zooxanthellae) that reside in the corals' tissues and provide them with most of their colour and much of their energy (*43*). Coral bleaching occurs when, alone or in combination, stressors in the environment cause the degeneration and expulsion of zooxanthellae from the coral host, such that the white skeleton becomes visible through the transparent coral tissues. Depending on the intensity and duration, once the stress is removed corals often recover and regain their zooxanthellae (*44*). Prolonged exposure can result in partial or complete death of not only individual coral colonies, but also large tracts of reef. Bleached corals, whether they die totally or partially, are more vulnerable to algal overgrowth, disease and reef organisms that bore into the skeleton and weaken the reef structure (*41*). As reefs disintegrate, patterns of coral species diversity can alter dramatically and the reef community may be restructured (*45*, *46*), with consequent impacts on the diversity of fish and other organisms within the reef ecosystem.

Stressors that trigger bleaching include freshwater flooding (*47*, *48*), pollution (*49*, *50*), sedimentation (*51*), disease (*52*, *53*), increased or decreased light (*54*, *55*) and especially elevated or decreased sea surface temperatures (SSTs) (*44*, *56*, *57*). Elevated SSTs during the 1997/1998 El Niño Southern Oscillation (ENSO) triggered mass coral bleaching that resulted in extensive reef damage in many regions of the world. In severely impacted regions such as the Indian Ocean (where mortality of reef-building corals reached over 90% in some areas), some countries are now at serious risk of losing this valuable ecosystem and the associated economic benefits of fisheries and tourism (*58*, *59*). Furthermore, if average baseline temperatures continue to increase due to global climate change, then corals will be subjected to more frequent and extreme bleaching events.

### Designing effective management options

Small-scale, localized bleaching events that are due to direct anthropogenic stressors (e.g. pollution or freshwater runoff) can be addressed directly to minimize the threat at its origin. In contrast, coral reef managers cannot readily address large-scale bleaching events linked to global warming and ENSO events. Climate-related threats therefore must be tackled indirectly, through thoughtful planning and strategic care of reefs within existing and future marine protected areas (MPAs), to take advantage of natural properties of coral reef ecosystems and mitigate the impact of bleaching and related mortality.

The Nature Conservancy (TNC) and World Wildlife Fund (WWF) launched a joint initiative in 2001 to develop strategies for mitigating the impacts of coral bleaching through MPA design. They have since been joined by Conservation International (CI) and participating scientists from the Australian Institute of Marine Science (AIMS) and ReefBase, among others. The new MPA initiative seeks to identify for strict protection specific patches of reef where environmental conditions favour low or negligible temperature-related coral bleaching and mortality and to enhance reef recovery by ensuring optimal conditions for larval dispersal and recruitment among sites within a strategically designed network.

The approach is to develop a set of science-based, empirically testable principles to help managers identify, design and manage such networks, in order to maximize overall survival of the world's coral reefs in the face of global climate change. Though the intent may be to save the reefs for tourism, biodiversity or other reasons, the effort will also benefit human health by preserving an important source of protein.

addressed as part of the analysis, a health impacts assessment can produce misleading results and possibly contribute to ill-informed decisions.

A variety of methods is available to deal with the existence of scientific uncertainties, while still illustrating, analysing and providing useful insights into how climate change may influence human health. These methods also can be used to inform the design and implementation of effective adaptation options intended to increase resilience to change. The method chosen depends upon a variety of factors, including the type of question being asked by a policy-maker, public health official, or resource manager and the types of scientific uncertainties that exist.

## *Historical records*

Data and records from the past provide an essential perspective on how changes in climate affect human and natural systems. Gaining an understanding of present vulnerabilities and adaptive capacity of human populations, how those vulnerabilities are affected by variations in climate and other stressors, and which strategies have and have not worked to ameliorate the vulnerabilities, can be illuminating for understanding possible future vulnerabilities and adaptations to climate change (*60*).

Adaptive capacity, which will change over time, is determined by socioeconomic characteristics (i.e. non-climate variables). Different communities, regions and systems have different capacities to adapt. Understanding of the factors that presently contribute to health vulnerabilities that are sensitive to climate, and a sense of how these factors may change in the future, may enable effective actions to be devised even if there is uncertainty about how the climate drivers will change in the future. Also, one can ask the question: how bad would things have to be in order for the community to find itself outside the range of its ability to cope?

A word of caution is in order. It cannot simply be asserted that by increasing the capacity to cope/adapt to climate variability under current climatic conditions, future vulnerabilities to climate change will be reduced (i.e. increase resilience to change). Coping now does not always reduce future vulnerabilities to climate change. In fact, investments to increase current coping capacity may exacerbate the effects of climate change. A resource manager who knew with certainty what future climate would be might discover that planned investments would actually increase vulnerability to future climate. A completely different investment would increase resilience to change. Since the future cannot be known with certainty, scenario analysis (or some other approach) can help to reveal cases in which this might occur.

Two of the case studies presented in this chapter rely primarily on such assessments, not on the use of scenario analysis. In the case study that follows, Focks et al. (*61*, *62*, *63*) establish critical thresholds for dengue based upon past/present disease incidence. Adaptation responses that would reduce vulnerability to dengue can be evaluated from this, without relying upon scenario analyses. Similarly, the hot weather watch/warning system described in Case Study #3 is based largely upon analysis of health effects of weather events of the recent past and not on scenario projections of the future climate.

## Scenario analyses

Given the current state of climate science it is not yet possible to make predictions of the impacts of climate change, with the exception of future sea level rise. Nevertheless, useful insights that inform risk management decisions can be provided to decision-makers. One such approach is scenario analysis.

Scenarios are plausible alternative futures that paint a picture of what might happen under particular assumed conditions. Scenarios are neither specific predictions nor forecasts. Rather, they provide a starting point for investigating questions about an uncertain future and for visualizing alternative futures in concrete and human terms. The use of scenarios helps to identify vulnerabilities and explore potential response strategies.

Scenarios can be derived in a number of ways. Projections from sophisticated climate models (e.g. General Circulation Models [GCMs]) are one tool for understanding what future climate might be like under particular assumptions. Scenarios also can take the form of "what if . . ." or "if . . . then . . ." questions. These sorts of questions, together with sensitivity analyses, are used to determine under what conditions and to what degree a system is sensitive to change. Sensitivity analyses help to identify the degree of climate change that would cause significant impacts to natural and human systems, i.e. how vulnerable and adaptable these systems are.

There is a pressing need for the research and assessment communities to develop meaningful and credible scenarios of the potential health effects of global climate change in the context of other major risk factors for adverse health outcomes. This requires analysis of the relationships between health status and socioeconomic variables in order to develop a model that relates regional health status to potential changes in socioeconomic status over the next century. Once a health model has been developed successfully, the health risk model can be used to develop health scenarios based on future climate and technological change (e.g. scenarios derived from the IPCC's Special Report on Emissions Scenarios) (*64*).

For health outcomes where knowledge of the potential consequences of climate change is not sufficient to support modelling, assessors might rely upon expert judgment and existing peer-reviewed studies to provide qualitative insights to stakeholders.

## Describing uncertainties

Uncertainty can be expressed in a variety of ways. Because the types of uncertainty in a health impacts assessment are diverse, a multifaceted approach for characterizing uncertainties often is desirable.

Expressions of uncertainty can be categorized by the degree to which they are based on quantitative techniques versus qualitative techniques. Quantitative approaches have advantages because they enable uncertainty to be estimated when they propagate through a set of linked models, thus specific bounds on the outputs of an assessment model can be derived. The combined effect of many sources of uncertainty can be assessed formally. Uncertainties due to inherent randomness in the information base, and model formulations that use simplifying assumptions about that variability, tend to be easier to express quantitatively than uncertainties due to lack of knowledge. Uncertainty can be expressed quantitatively by probability density functions and summary statistics. Numerous sources of uncertainty can then be combined using either probability trees or Monte Carlo analysis to assess their overall uncertainty in a health impacts assessment. However, a shortcoming of this form of quantitative expression is that the propagation of uncertainty can become analytically impossible when many uncertainties are combined.

Qualitative approaches permit additional screening for potential biases and weak elements in the analysis that cannot be captured quantitatively. Either approach alone is insufficient in a complex analysis but overlaying the two provides more complete characterization of the issues. (It is noteworthy, however, that formal methods for combining qualitative information with quantitative estimates to aid decision-making have not yet been developed.)

## The benefits of uncertainty analysis

Arguably, the inclusion of uncertainties might create so much fuzziness in the results that distinguishing among policy alternatives is not possible. It should be noted, however, that many of the uncertainties might have similar effects on each of the health-related policy options being analysed. These dependencies should be taken into account in the uncertainty analysis by assessing the uncertainties on policy differences (under different climate scenarios) rather than the uncertainties of each individual policy outcome and subsequently examining the differences among them. If the uncertainty in the policy differences is built into the uncertainty analysis process, there is considerably less chance that the uncertainties will overwhelm any distinctions among types of policies.[1]

Careful and explicit assessment of uncertainties can lead to:

- better understanding of the limitations of the health impacts assessment itself;
- better understanding of the implications of the identified imprecision and biases for the makers of health policy;
- characterization of the robust properties of comparisons among types of health policies;
- identification of the most pressing areas for further research as selected health policies are implemented.

## CASE STUDY #5 Dengue simulation modelling and risk reduction

### Insights from this case study

This illustrates how decisions to make public health interventions can be taken despite the existence of uncertainties. This case study is based on the work of Focks et al. (*61*, *62*, *63*).

### Risk posed by dengue fever

It is estimated that dengue fever, and associated dengue haemorraghic fever, are responsible for the loss of over 20,000 lives and 653 000 disability adjusted life years (DALYs) annually (*17*). The dengue virus needs a mosquito vector for disease transmission to occur, the principal one being *Aedes aegypti*. A secondary vector is *Aedes albopictus*.

### Temperature, climate change and dengue transmission

Temperature affects the rate at which the virus develops inside the mosquito. The warmer the temperature, the faster the incubation and the faster the mosquito becomes infectious. Also, in higher temperatures the mosquito reproduces more quickly and bites more frequently. All of these factors increase transmission of dengue (*ceteris paribus*). It is expected that as global average temperatures increase, the risk of dengue epidemics will rise (*ceteris paribus*).

### Challenge faced by public health officials

Public health officials in developing countries usually have limited resources with which to protect the public's health. These must be targeted at the most serious health risks and needs. However, public health officials often are faced with significant uncertainties about the severity of a particular risk. An example of such a risk for many developing countries is dengue fever.

[1] Alternatively, as suggested earlier, in some cases vulnerability assessment can help to circumvent uncertainty about future climate for the purposes of developing adaptation strategies that are robust across climate scenarios. For example, whether or not climate change will increase breeding habitat for a disease vector, an adaptation strategy that succeeds in getting households to reduce breeding opportunities (e.g. eliminating standing water in and around their homes) will reduce health risks.

## Decision-support tool to aid public health interventions

Focks et al. have developed an effective computer-based decision-support tool that enables public health officials to make decisions about when and where to target public health interventions. Communities that are resource-constrained realistically can employ this tool (*65*).

Several factors must be present for a dengue epidemic to occur:

- the dengue virus;
- a sufficient number of *Aedes aegypti* mosquitoes to spread the virus effectively (entomologic factors);
- people who have not had that type of dengue virus before and therefore are not immune (seroprevalence).

Focks' computer simulation model uses these factors to determine a "threshold" number (pupae/person/area). Risk of dengue epidemic is low below the threshold; risk increases above the threshold.

Calculation of the threshold number requires an accurate survey to determine the number of pupae/person/area. To obtain this number, Focks has designed an inexpensive survey of households that uses the following steps:

- map out area to be surveyed;
- enter every fifth house to look for suspicious containers in which water accumulates and becomes a potential breeding ground for mosquitoes (e.g. tyres or buckets);
- record the number of people living in the house;
- empty the containers, pouring the water through a screen;
- rinse the screen with clean water, allowing the water to pour into a white basin so that any pupae can be seen;
- use a dropper to capture the pupae and place in a labelled vial;
- use a microscope to determine the type of mosquitoes present;
- count the number of pupae per person per area.

Once the household survey has been completed, Focks' computer model can be used to compute the threshold number using the survey data, current or anticipated temperature, and seroprevalence rate. The threshold number also is a function of the prevalence of containers of different types (e.g. tyres, drums, plant dishes, pools, vases) in a given area. Thus, the model can be used to conduct "what if" analyses to inform public health officials about how the threshold number changes as the number of containers of different types is varied. Officials can use this information to target specific types of containers to empty or scrub in order to reduce the number of pupae/person below the threshold number and avert an epidemic.

The Focks decision-support tool is attractive for several reasons. First, it uses as input household survey data that can be obtained at reasonable cost. Second, it enables public health officials to minimize intervention costs by targeting those breeding ground containers that are most important. Certain types of containers have been found regularly to harbour a greater number of pupae in a particular area. In fact, in some areas, less than 1% of the containers have been found to produce more than 95% of the adult mosquitoes. The Focks method of targeting especially productive breeding containers has been found to be more cost effective than mosquito eradication programmes that use insecticides that also can have undesirable health and ecosystem side-effects (i.e. maladaptation).

## Formulating a research agenda

Assessment is an ongoing, iterative *process* that yields specific assessment *products* (e.g. reports) at various points in time. Given the extensive scientific and socioeconomic uncertainties surrounding the issue, it is unlikely that any particular assessment report will answer all of the questions posed by decision-makers. It is therefore important that each assessment report identifies and prioritizes remaining key research gaps. Also, the assessment should include science/policy linkage gaps, gaps in those things needed to inform the process (e.g. implementation and adaptation evaluation gaps such as monitoring and surveillance) and communication gaps. Key gaps are those that must be filled to answer current stakeholder questions.

It is not a simple matter to identify and prioritize key research gaps because stakeholder needs change over time. At the end of any assessment, some questions will remain unanswered that stakeholders may wish to be addressed in the next phase of the assessment. Stakeholders also may have new questions, either because of the insights gained from the assessment process or because of changes in other factors unrelated to the assessment process. Some of the unanswered questions may be no longer relevant given evolving stakeholder needs. For this reason, stakeholder needs and concerns should be elicited for every phase of the assessment process.

Identification of stakeholder questions is only one step in formulating a research agenda. There are often many alternative research projects that could be undertaken to try to fill the remaining knowledge gaps. Unfortunately, limited resources are available for conducting research, so investments in research needs must be prioritized. Research resources should be invested in those activities that will most likely yield the greatest amount of useful information, that is information that will provide the most useful insights to stakeholders in the timeliest fashion. This requires value of information calculations that yield insights into the incremental value to stakeholders of information anticipated from an investment in a particular research activity. The results of these calculations depend on changing stakeholder needs and values, and the timeliness and relevance of information. Value of information exercises may be costly to undertake but are essential to any assessment process.

Integrated assessment is one approach for conducting value of information exercises. This includes stakeholder involvement as an integrating mechanism rather than sole reliance on a model. It is also a valuable approach that has wider applicability than relying solely on an integrated assessment model (which is not always available). Integrated assessment has been defined as "an interdisciplinary process of combining, interpreting, and communicating knowledge from diverse scientific disciplines in such a way that the whole set of cause-effect interactions of a problem can be evaluated from a synoptic perspective with two characteristics: it should have added value compared to single disciplinary oriented assessment; and it should provide useful information to decision-makers" (*66*). As noted by Bernard and Ebi (*35*), integrated assessment is a synthesis of knowledge across disciplines with the purpose of informing decisions rather than advancing knowledge for its intrinsic value. The outcome can be used to prioritize decision-relevant uncertainties and research needs. The multidisciplinary nature of this research challenges the more traditional, single discipline focused research.

Assessment and scientific research are ongoing activities. To ensure that they are complementary, an ongoing feedback process between assessment activities and research activities is essential. When successfully implemented such a process permits scientific research—whether in the health, physical, biological or social sciences—to identify new risks or opportunities and provide information and data required for an assessment. At the same time, assessments identify and prioritize research needs that must be filled in order to better answer questions being asked by the stakeholder community.

## Increasing public awareness: importance of communicating assessment results

Communication with stakeholders should be an ongoing process that keeps stakeholders engaged throughout an assessment process. Also, once an assessment has been completed, the results must be communicated to stakeholders in a timely and meaningful fashion to inform decision-making (the communication of results at the end of an assessment also can be useful in engaging more stakeholders in future assessments). This requires the development of a communication strategy that is part of the assessment process.

A communication strategy must ensure access to information, presentation of information in a usable form and guidance on how to use the information (*67*). Risk communication is a complex, multidisciplinary, multidimensional and evolving process. It is most successful and efficient when focused on filling knowledge gaps and misconceptions that are most critical to the decisions people face (*68*). Often, information has to be tailored to the specific needs of risk managers in specific geographical areas and demographic groups in order to be effective (*69*). This requires close interaction between information providers (e.g. researchers, assessors) and those who need the information to make decisions.

Good reporting of assessment results can enhance the public's ability to evaluate science/policy issues and the individual's ability to make rational personal choices. Poor reporting can mislead and disempower a public that increasingly is affected by science and technology and by decisions determined by technical expertise (*70*).

Assessments are a valuable source of information for risk managers, decision-makers and the public: the results can be used to promote education, training and public awareness of the potential health impacts of climate change. Maintaining the credibility of the assessment is central to maintaining the confidence of decision-makers. The degree of oversight and other procedural features of assessment, such as public participation or access to data and reports and the weight accorded to formal assessment in policy-making, may vary from culture to culture (*71*). Yet, most successful and effective assessments will contain communication strategies that possess the following key characteristics (*72*):

- assessment process is open and inclusive. Representatives of all key stakeholder groups invited to participate, regardless of their views;
- non-threatening atmosphere is created at the consultation table: all parties are encouraged to be candid, respectful and supportive;
- information about the assessment is shared early, continuously and candidly. Any perceived refusal to share information will be interpreted negatively by stakeholders and destroy trust in the assessment process;
- principal focus of the assessment process is on issues of concern to stakeholders. In this sense, they should control the consultative process. Assessors should not prejudge what those issues are;

- stakeholders are consulted even about the design of the consultative process;
- cooperative approach to the collection and interpretation of project-related data from the outset of the assessment process;
- expected "deliverable" is clearly identified, and public's role in the final decision is clarified;
- project-design options provided wherever possible;
- ongoing communications with grass roots constituencies maintained through the stakeholders' representatives in the public involvement process.

Information about the assessment, including assessment results, are disseminated through a variety of mechanisms, including:

- workshops and seminars;
- electronic systems that provide decision-makers with data and information, including metadata which summarizes the data;
- tools for the decision-making process;
- different formats and contents of information (videos, printed materials, CD-ROMs, etc.) designed for different target audiences.

## Conclusions

Policy-focused assessment is a valuable process for providing timely and useful information to decision-makers, resource managers and other stakeholders in the public health community. To be successful on an ongoing basis, an assessment process must have the following characteristics:

- remain relevant by continually focusing on questions and effects of concern to stakeholders;
- assessment team and approach should be multidisciplinary;
- entail constant interactions between research and assessment communities to ensure key research gaps are filled;
- carefully characterize uncertainties and explain their implications for stakeholder decisions;
- provide relevant information in a useful format that has meaning to stakeholders. Risk management options should be explored, including cost, effectiveness, and potential barriers to implementation;
- an interactive process that builds on previous assessments to provide information required to support decisions and policy development;
- models and tools to support decision-making should be developed, wherever possible.

It has been argued that the existence of scientific uncertainties precludes policymakers from taking action today in anticipation of climate change. This is not true. In fact policymakers, resource managers and other stakeholders make decisions every day, despite the existence of uncertainties. The outcomes of these decisions may be affected by climate change or the decisions may foreclose future opportunities to adapt to climate change. Hence, the decision-makers would benefit from information about climate change and its possible effects. The entire process of policy-focused assessment is premised on the need to inform risk managers who must make decisions every day despite the existence of uncertainties. It is also noteworthy that policy-focused assessments already have influenced policy and resource management decisions of interest to the public health community.

Care must be taken to respect the boundary between assessment and policy formation. Policy-focused assessment's goal is to inform decision-makers, not to make specific policy recommendations or decisions. Policy decisions depend on more than the science, and involve societal attitudes towards risk, social values and other factors affecting decision-making. But the information provided by policy-focused assessments is invaluable. An informed decision is always better than an uninformed decision.

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