Health and Global Environmental Change
SERIES No. 1

WORLD HEALTH ORGANIZATION
EUROPE

Methods of assessing human health vulnerability and public health adaptation to climate change

WMO

Health Canada Santé Canada

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Abstract

The fact that climate is changing has become increasingly clear over the past decade. Recent evidence suggests that the associated changes in temperature and precipitation are already adversely affecting population health. The future burden of disease attributable to climate change will depend in part on the timeliness and effectiveness of the interventions implemented. In response to these changing risks, the Third Ministerial Conference on Environment and Health in London in 1999 recommended developing the capacity to undertake national assessments of the potential health effects of climate variability and change, with the goal of identifying: 1) vulnerable populations and subgroups and 2) interventions that could be implemented to reduce the current and future burden of disease. The need to facilitate the transfer of expertise among countries was recognized. This publication is designed to address this need by providing practical information to governments, health agencies and environmental and meteorological institutions in both industrialized and developing countries on quantitative and qualitative methods of assessing human health vulnerability and public health adaptation to climate change. An integrated approach to assessment is encouraged because the impact of climate is likely to transcend traditional sector and regional boundaries, with effects in one sector affecting the coping capacity of another sector or region. Part I describes the objectives and the steps for assessing vulnerability and adaptation and Part II discusses the following issues for a range of health outcomes: the evidence that climate change could affect mortality and morbidity; methods of projecting future effects; and identifying adaptation strategies, policies and measures to reduce current and future negative effects. The health outcomes considered are: morbidity and mortality from heat and heat-waves, air pollution, floods, windstorms and food insecurity; vector-borne diseases; waterborne and foodborne diarrhoeal diseases; and adverse health outcomes associated with stratospheric ozone depletion.

Keywords

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Foreword

Climate change is one of several unprecedented, large-scale, environmental changes that are affecting our planet. These changes reflect the overload of several of the Earth's biophysical and ecological systems caused by the combined impact of growing human population and economic activities. Environmental changes are now affecting the whole planet and disrupting earth's life-supporting mechanisms, but the extent to which this affects human well-being and health varies substantially in different parts of the world.

Many research activities have been carried out in recent years to improve understanding of climate change patterns as well as their effects on human health. Thanks to this extensive effort, these changes can now be better understood and scenarios for the future developed that allow the policy community to identify adequate strategies for response and adaptation.

In general, climate change does not and will not cause novel environmental exposure, but global warming and the increasing variability of weather patterns will tend to intensify the effects of climate-related environmental determinants of health. For instance, as Europe has experienced during the floods in 2002 and the heat-waves in 2003, climate change will increase the number and intensity of extreme weather events. This will cause excess death, injury, disability and disease. It is now time to identify these health effects on the population and to plan and take appropriate measures to prevent the effects, especially among the most vulnerable groups.

At the WHO Third Ministerial Conference on Environment and Health in London in 1999, countries recommended developing the necessary capacity to undertake national health assessment of vulnerability and adaptation to climate change with the aims of identifying the vulnerability of populations and subgroups and ensuring the necessary transfer of expertise among countries.

This publication is a response to this call. It is a result of an extensive consultation process involving many institutions. It provides an overview of the methods available to assess vulnerability to climate change and includes practical, real-life information for governments, health agencies and environmental and meteorological institutions in both industrialized and developing countries.
We hope that the world community will take the necessary steps to address the causes of climate change. In the mean time, we are confident that this work will help public authorities at all levels to identify and implement measures that will facilitate adaptation to climate change and protect human populations from the most serious and preventable health effects in each context.

Roberto Bertollini

Director
Division of Technical Support Health Determinants
WHO Regional Office for Europe

Foreword

There is growing evidence that global climate is changing and will have profound effects on the health and well-being of citizens in countries throughout the world. As the climate changes in Canada, we may experience more extreme weather events, an increase in contamination of our air, water and food and a greater number of emerging infectious diseases. Other countries may find themselves to be anticipating even greater risks than this. As a result, Health Canada, together with departments of health in other countries, will need to have a better understanding of the health effects expected from climate change and of those who may be the most vulnerable in our respective societies in order to be able to manage the risks.

For many countries, adapting to the effects of climate change will necessitate strengthening existing capacity and applying new approaches to examining the risks associated with a changing climate and increased climate variability. For health departments, this also means an increasing need to collaborate with other sectors of society that can play a critical role in managing the risks to health and well-being. Expanding national and international partnerships, particularly cross-sectoral ones, needs to be supported by a solid base of evidence and knowledge of the health effects and vulnerability resulting from a changing environment.

Health Canada is pleased to contribute to ongoing efforts aimed at adapting to climate change by providing a report that outlines the tools and methods available to conduct vulnerability and adaptation assessments in a manner that is adaptable to all levels of development. We hope that countries will find the content useful in their efforts to identify the health concerns that will require their attention in the coming years.

My Department looks forward to using the publication as we examine more closely the climate change related health effects which are of concern in Canada. Health Canada has appreciated the opportunity to work closely with WHO and other international experts in developing this publication and would like to thank all collaborators for their dedication over the past 2 years.

Paul Glover

Director General
Safe Environments Programme
Health Canada

Preface

This publication provides practical information to governments, health agencies and environmental and meteorological institutions in both industrialized and developing countries on how to assess vulnerability and adaptation to climate variability and change at the regional, national and local levels. Flexible methods and tools are described to achieve better understanding of the current and future vulnerability of specific populations. This will help institutions and agencies to identify appropriate and effective adaptation strategies, policies and measures.

The proposed methods and tools are designed to fit into current international frameworks for assessing the potential impact of environmental change on sectors other than health. This includes the guidance provided by the Intergovernmental Panel on Climate Change (IPCC) for assessing the impact of and adaptation to climate change, developing scenarios and dealing with uncertainty. The proposed adaptation assessment method is also consistent with the Adaptation Policy Framework developed under the auspices of the United Nations Development Programme. The methods will be further developed and adapted in pilot testing in countries in the next two years.

In presenting this publication, WHO, Health Canada, UNEP and WMO offer governments and their health agencies an opportunity to join a wider collaborative effort to identify and develop strategies for reducing the potential health impact of an emerging worldwide environmental problem that will profoundly affect all of us.

Carlos Corvalan, Hiremagalur Gopalan, Buruhani Nyenzi and Jacinthe Seguin

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We dedicate this publication to the memory of David Le Sueur.

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Sari Kovats (Centre on Global Change and Health, London School of Hygiene and Tropical Medicine, United Kingdom), Kristie L. Ebi (Global Change and Health, WHO Regional Office for Europe; currently Exponent Health Group, USA) and Bettina Menne (Global Change and Health, WHO Regional Office for Europe) were the main authors.

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PART 1. CONTEXT

1. Introduction

2. Vulnerability and adaptation to climate change: key concepts

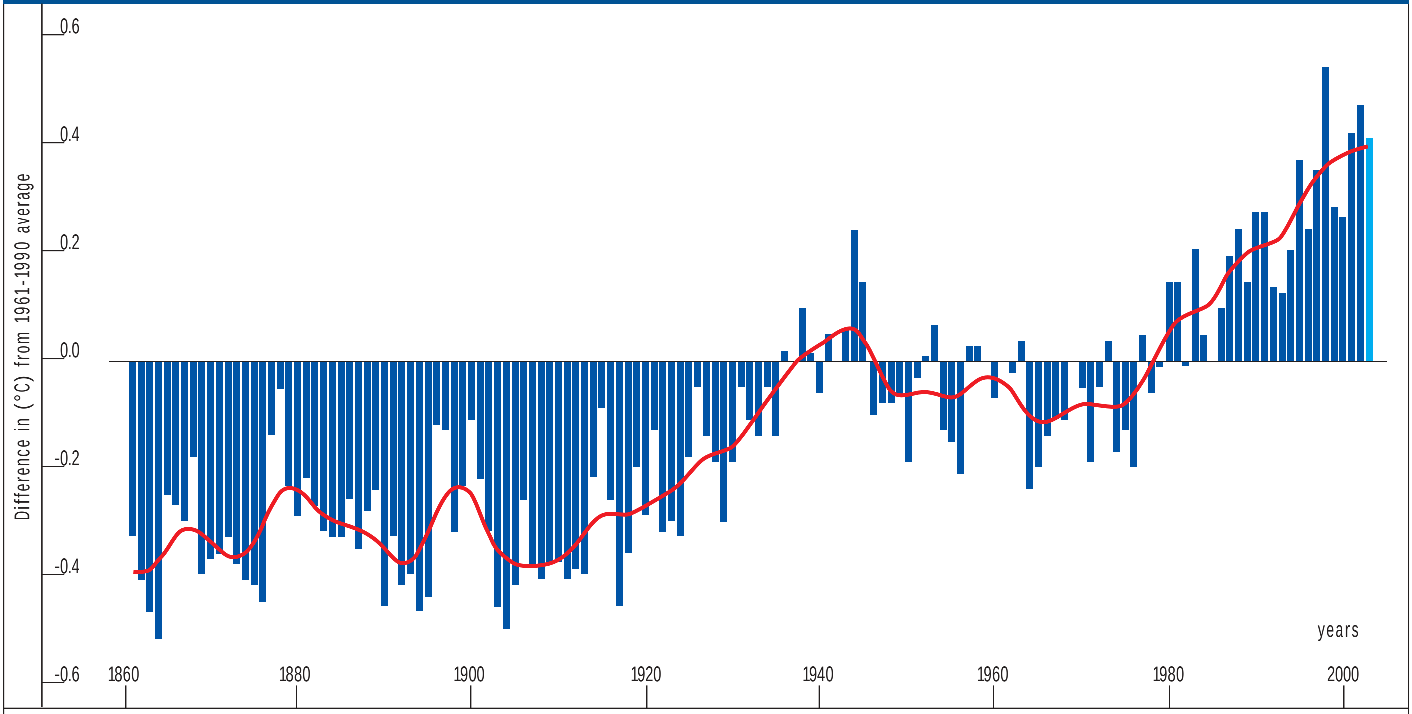
3. The framework for the assessment

1. Introduction

Over the past decade, the fact that the world's climate is changing has become clear. The assessment activities undertaken by the Intergovernmental Panel on Climate Change (IPCC) have found an increasing body of observations giving a collective picture of a world that is warming and is experiencing other changes in the climate system. The global average surface temperature has increased since 1861, and new analyses of proxy data from the Northern Hemisphere indicate that the increase in temperature during the 20th century is likely to have been the largest of any century during the last 1000 years (Fig. 1.1). Similar conditions may be expected for the Southern Hemisphere, but less is known because sufficient data are lacking. This unprecedented warming has taken place in a time span far shorter than the spans that paleoclimatic studies have shown for geological periods with similar changes. Further, temperatures have risen during the past four decades in the lowest 8 kilometres of the atmosphere. The global average sea level has risen, the heat content of the oceans has increased and the extent of snow cover and ice has decreased. Changes have also occurred in other important features of climate, such as the warm episodes of the El Niño Southern Oscillation.

Science has found that the climate is changing in response to numerous human activities that transfer gases into the atmosphere that enhance the natural greenhouse effect. For millennia, the greenhouse effect has facilitated a balance between incoming solar radiation and outgoing terrestrial radiation; a change in either incoming or outgoing radiation modifies the surface temperature of the Earth. Intensification of the greenhouse effect results in the observed warming that, in turn, brings changes in other climatic and weather variables. Apart from an increase in the natural greenhouse effect, some of these gases also deplete the stratospheric ozone layer, producing a net increase in the ultraviolet (UV) radiation reaching the ground. Both geophysical processes influence human health.

Fig. 1.1. Past and future changes in global mean temperature
Global average near-surface temperatures, 1860–July 2003 from 1961 to 1990 average



Source: Hadley Centre for Climate Research, Exeter, United Kingdom based on data from Jones et al., (1999) and Parker et al., (1995).

Aims

Global climate change is one of several unprecedented, large-scale, environmental changes now occurring around the world. These momentous changes reflect the overloading of several of Earth's biophysical and ecological systems by the combined weight of human numbers and economic activity. Together with global climate change, loss of biodiversity, desertification, stratospheric ozone depletion and water resource depletion give rise to global environmental change. These environmental changes are disrupting Earth's life-supporting infrastructure, posing risks to human well-being and health.

Three independent factors determine the scale of the human effects on the environment: consumption per capita, the size of the human population and the technologies used to produce and consume resources. The fact that human activities generate greenhouse gases, in addition to other pollutants of the air, water and soil, brought governments to adopt the United Nations Framework Convention on Climate Change (UNFCCC). The ultimate objective of the UNFCCC is to achieve

> *... , in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner.*

To achieve this objective, the Parties to the UNFCCC approved the Kyoto Protocol to the UNFCCC aiming to mitigate greenhouse gas emissions. Environmental changes are disrupting Earth's life-support systems, which pose a number of risks to human health and well-being. Researchers are intensifying their studies of the relationship between climate and weather and of the rates and patterns of mortality and morbidity. Indeed, these are now a central focus of the IPCC, which since 1988 has been responsible for assessing the information on the science of climate change; the vulnerability to and effects of climate change; and the strategies to mitigate greenhouse gases and to adapt to global warming. Governments, international and regional programmes and projects have undertaken studies to analyse the vulnerability of human health to climate change and the effects of climate change on a range of health outcomes.

The UNFCCC's efforts devoted to mitigate greenhouse gas emissions will not immediately reverse the current warming. In fact, the long lifetime of some greenhouse gases and the inertia of the climate system mean that, even if all emissions are stopped, the physical composition of the present atmosphere will continue to influence the climate system for decades or even centuries. The consequences of mitigation may therefore not become apparent until after a considerable time interval. These physical constraints have brought decision-makers to recognize that anticipated precautionary measures, designed to cope with the expected effects of climate change, are required. Adaptation strategies and measures should be developed to lessen the potential adverse effects and to take advantage of their potential beneficial effects. These actions should take into account the following factors.

- Climate change does not cause novel environmental exposures but may exacerbate the burden of climate-sensitive diseases, depending on the implementation of timely and effective interventions.

- Climate change results from both natural and human processes. Emissions of greenhouse gases affect human health at different scales. At the local scale, particulate matter emitted by vehicles has harmful effects. At the regional scale, transport of sulfur and nitrogen oxides cause acid deposition. At the global scale, the links between climate change and local environmental factors produce a range of hazards to human health.

- Intergovernmental agencies, nongovernmental and regional institutions and some national organizations have begun to assess the vulnerability of people to the potential health hazards resulting from climate variability (the El Niño Southern Oscillation) and change and to develop methods of assessing risk and enhancing adaptation.

This publication will serve as a reference to many activities associated with the protection of the human environment, such as those stemming from the foci on water, energy, health, agriculture and biodiversity from the World Summit on Sustainable Development in Johannesburg in 2002 and Agenda 21 by describing a basic approach to assessing the vulnerability of human populations to changes in the climate system.

Box 1.1. Definitions

- Climate is the average state of the atmosphere and the underlying land or water in a particular region over a specific time period.
- Weather is the day-to-day manifestation of climate in a particular place at a particular time.
- Climate change is a statistically significant variation in either the mean state of the climate or in its variability, persisting over an extended period (typically decades or longer).
- Climate variability refers to variations around the mean state, including the occurrence of extreme weather events.

Why conduct a national assessment on human health vulnerability and public health adaptation to climate change?

Few industrialized and developing countries have conducted national assessments of the potential effects of climate change on human health to better understand current vulnerability and to evaluate the country's capacity to adapt to climate change by modifying the health infrastructure or by adopting specific measures (Kovats et al., 2003a).

National assessments should be carried out to evaluate the risk of climate change for current and future generations and to enable policy-makers to plan for measures, policies and strategies to cope with climate change. In addition, more national information and assessments are needed to feed into the international policy processes, such as that of the national communications to the UNFCCC and those from other climate change assessments.

The importance of timely decision-making is indicated by the need to adapt to climate change long before the stabilization of greenhouse gas concentrations leads to the stabilization of temperature and mean sea level. This includes considering such issues as the time required to replace infrastructure.

Potential users of this document

Parties to the United Nations Framework Convention on Climate Change

In acting to achieve the ultimate objective of the UNFCCC (outlined earlier), the Parties to the UNFCCC must periodically communicate information related to its implementation to the Conference of the Parties. This information takes the form of national communications, including a national inventory of anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol on Substances that Deplete the Ozone Layer and information that assesses the national vulnerability to the potential effects of climate change.

The UNFCCC (1999), with the scientific cooperation of the IPCC, has developed reporting guidelines on national communications. These guidelines are periodically revised for the preparation of ongoing sets of national communications. The current guidelines include only a few references to human health.

Under Section 6, "Vulnerability assessment, climate change impacts and adaptation measures", the guidelines specify the following:

> *A national communication shall include information on the expected impacts of climate change and an outline of the action taken to implement Article 4.1(b) and (e) with regard to adaptation. Parties are encouraged to use the Intergovernmental Panel on Climate Change (IPCC) Technical Guidelines for Assessing Climate Change Impacts and Adaptations and the United Nations Environment Programme (UNEP) Handbook on Methods for Climate Change Impacts Assessment and Adaptation Strategies. Parties may refer, inter alia, to integrated plans for coastal zone management, water resources and agriculture. Parties may also report on specific results of scientific research in the field of vulnerability assessment and adaptation.*

Article 4 of the UNFCCC defines a number of "enabling activities" to support non-Annex I Parties (developing countries) in their efforts to undertake these assessments. Information on these activities may be obtained from the UNFCCC web site (Annex 2).

National adaptation programmes of action for climate change

International policy mechanisms for climate change are currently being directed towards implementing adaptation strategies, policies and measures in developing countries, where the effects of climate change are likely to be greatest. The need for national adaptation programmes of action for climate change was agreed under the UNFCCC process in 2001.

Least developed countries have contributed least to the emission of greenhouse gases but are the most vulnerable countries to the effects of climate change and have the least capacity to adapt to these changes, especially the impact of the increased damage from natural disasters. The least developed countries lack the necessary institutional, economic and financial capacity to cope with the impact of climate change and to rebuild their infrastructure when it is damaged by natural disasters. Adaptation has yet to become a major issue in developing countries. Although progress has been made in describing vulnerability to climate change in such populations, much more remains to be done to mainstream adaptation within the national policy-making processes (Huq et al., 2003). Several key lessons have been identified.

- Information on the impact of climate change needs to be translated from scientific research into language and time scales appropriate for policy-makers.

- Research on potential effects needs to be supported within countries to enable information to be improved and passed on to policy-makers.

- Sectoral-level decision-makers are relatively more likely to mainstream adaptation to climate change with ongoing and planned work, provided that information is given in a usable form.

Significant funds for implementing adaptation strategies are being made available, mainly through the Global Environment Facility of the United Nations Development Programme (UNDP). The Parties to the UNFCCC have agreed to develop the Least Developed Countries Fund to support the work programme, including preparing and implementing national adaptation programmes of action.

Regional programmes have also been developed to support developing countries in implementing the UNFCCC, as part of the Climate Change Training Programme of the United Nations. The South Pacific Regional Environment Programme developed the Pacific Islands Climate Change Program to be more appropriate to the needs of Pacific countries (Annex 2). The Special Climate Change fund was established under the UNFCCC Marrakesh Accords in 2001. Adaptation is one type of activity that is intended to be supported by the Special Climate Change fund and/or the Adaptation Fund of the Kyoto Protocol.

Such activities include (Dessai, 2002):

- starting to implement adaptation activities promptly where sufficient information is available to warrant such activities, including water resources management; land management; agriculture; health; infrastructure development; fragile ecosystems, including mountainous ecosystems; and integrated coastal zone management;
- improving the monitoring of diseases and vectors affected by climate change and related forecasting and early-warning systems, and in this context improving disease control and prevention;
- supporting capacity-building, including institutional capacity, for preventive measures, planning, preparedness and management of disasters relating to climate change, including contingency planning, especially for droughts and floods in areas prone to extreme weather events; and
- strengthening existing and, where needed, establishing national and regional centres and information networks for rapid response to extreme weather events, using information technology as much as possible.

This publication might help to focus some of the health-related adaptation activities within these plans.

Member States of WHO and the Climate Agenda

As a response to Agenda 21 and the UNFCCC, several organizations carrying out significant climate-related activities jointly developed the Climate Agenda, a comprehensive and integrating framework on all aspects of international climate-related programmes, including collecting and applying data, research on climate systems and studies of the socioeconomic, health and ecosystem effects of climate variability. The Fifty-first World Health Assembly endorsed WHO participation (resolution WHA 51.29). An informal Inter-Agency Network on Climate and Human Health was established in 1998 with a secretariat at WHO, to coordinate the relevant activities of the Climate Agenda. The work of WHO on climate change focuses on capacity-building, exchanging information and promoting research.

A first step was taken in the WHO European Region, where the European Ministers for Environment and Health welcomed the recommendations on the early health effects of climate change and stratospheric ozone depletion at the Third Ministerial Conference on Environment and Health in London in 1999. These included:

- developing the capacity, as necessary, to undertake national health impact assessments with the aim of identifying the vulnerability of populations and subgroups to ensure the necessary transfer of expertise among countries; and
- reviewing the social, economic and technical prevention, mitigation and adaptation options available to reduce the potential adverse impact of climate change and stratospheric ozone depletion on human health.

This publication can help health ministries and institutions in giving priority to climate change–related activities at the national, regional and local levels.

International reviews

Several international reviews have been undertaken. The scientists of the IPCC comprehensively assess the scientific literature on this and related issues in its reports. The First Assessment Report (IPCC, 1990) introduced the health effects of climate change under a general chapter on human settlements and linked them with air quality and ultraviolet B (UVB) radiation. The subsequent IPCC assessment reports devoted specific chapters to climate change and human health: the Second Assessment Report

(McMichael et al., 1996) and the Third Assessment Report (McMichael & Githeko, 2001). Further, the special report on the regional impact of climate change (Watson et al., 1997) included the human health issue in a number of regional chapters. The Third Assessment Report also includes chapters on impact of climate change by region. These global reviews make general statements about the types of effects climate change may have on human health outcomes. In theory, national assessments should provide important information for the global assessments on regional and local vulnerability. In practice, this has proved difficult to achieve because few national assessments have been undertaken. Assessments should be country-driven and reflect local environmental and health priorities.

A task group convened by WHO, the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) (IPCC, 1996) comprehensively reviewed the literature on the potential health impact of climate change. In 2003, WHO collaborated with UNEP and WMO in publishing an updated volume (McMichael et al., 2003b) that describes the actual and likely impact of climate change on health and how human societies and their governments should respond, with particular focus on the health sector.

2. Vulnerability and adaptation to climate change: key concepts

Both vulnerability and adaptation need to be understood to ensure effective risk management of the current and potential effects of climate variability and change. This chapter defines vulnerability and adaptation within the context of global climate change and discusses possible steps in conducting vulnerability and adaptation assessments. The terms vulnerability and adaptation are used by the climate change community and are analogous to concepts used in public health. The following definitions are provided to facilitate the communication between the public health and climate change communities.

The public health sector frames the interventions needed to reduce the potential negative impact of climate variability and change in terms of prevention. Public health prevention is classified as primary, secondary or tertiary. Primary prevention aims to prevent the onset of disease in an otherwise unaffected population (such as by supplying bed nets to all members of a population at risk of exposure to malaria). Secondary prevention entails preventive action in response to early evidence of health effects (including strengthening disease surveillance and responding adequately to disease outbreaks, such as the West Nile virus outbreak in the United States). Tertiary prevention consists of measures to reduce long-term impairment and disability and to minimize the suffering caused by existing disease. In general, secondary and tertiary prevention are less effective and more expensive than primary prevention. In terms of global climate change, the mitigation of greenhouse gas emissions could be considered as primordial prevention. For any specific health outcome of interest, there are many possible types of primary, secondary or tertiary prevention, as discussed in Chapters 5–11.

Definitions of vulnerability and adaptation

The public health and climate change communities share the goal of increasing the ability of countries, communities and individuals to effectively and efficiently cope with the challenges and changes that are likely to arise because of climate variability and change. Realistically assessing the potential health impact of climate variability and change requires understanding both the vulnerability of a population and its capacity to respond to new conditions. The relationships between vulnerability, adaptive capacity and potential effects are discussed below and shown in Fig. 2.1.

The IPCC defines vulnerability as the degree to which individuals and systems are susceptible to or unable to cope with the adverse effects of climate change, including climate variability and extremes. The vulnerability of human health to climate change is a function of:

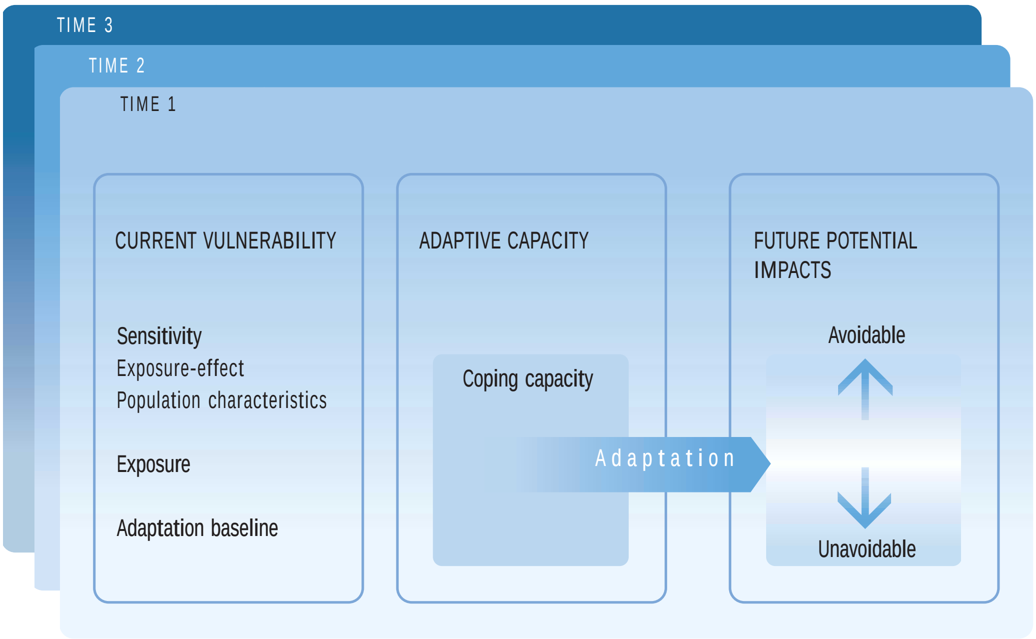
- sensitivity, which includes the extent to which health, or the natural or social systems on which health outcomes depend, are sensitive to changes in weather and climate (the exposure–response relationship) and the characteristics of the population, such as the level of development and its demographic structure;

- the exposure to the weather or climate-related hazard, including the character, magnitude and rate of climate variation; and

- the adaptation measures and actions in place to reduce the burden of a specific adverse health outcome (the adaptation baseline), the effectiveness of which determines in part the exposure–response relationship.

Populations, subgroups and systems that cannot or will not adapt are more vulnerable, as are those that are more susceptible to weather and climate changes. Understanding a population's capacity to adapt to new climate conditions is crucial to realistically assessing the potential health and other effects of climate change. In general, the vulnerability of a population to a health risk depends on the local environment, the level of material resources, the effectiveness of governance and civil institutions, the

Fig. 2.1. Schematic of relationships between vulnerability, adaptive capacity and potential health impact



Source: Ebi et al., (forthcoming).

quality of the public health infrastructure and the access to relevant local information on extreme weather threats (Woodward et al., 1998). These factors are not uniform across a region or country or across time and differ based on geography, demography and socioeconomic factors. Effectively targeting prevention or adaptation strategies requires understanding which demographic or geographical subpopulations may be most at risk and when that risk is likely to increase. Thus, individual, community and geographical factors determine vulnerability.

Adaptation includes the strategies, policies and measures undertaken now and in the future to reduce potential adverse health effects. Adaptive capacity describes the general ability of institutions, systems and individuals to adjust to potential damages, to take advantage of opportunities and to cope with the consequences. The primary goal of building adaptive capacity is to reduce future vulnerability to climate variability and change. Coping capacity describes what could be implemented now to minimize negative effects of climate variability and change. In other words, coping capacity encompasses the interventions that are feasible to implement today (in a specific population), and adaptive capacity encompasses the strategies, policies and measures that have the potential to expand future coping capacity. Increasing the adaptive capacity of a population shares similar goals with sustainable development – increasing the ability of countries, communities and individuals to effectively and efficiently cope with the changes and challenges of climate change.

Specific adaptation interventions arise from the coping capacity of a community, country or region. These interventions, similar to all interventions in public health, are designed to maximize the number of avoidable adverse health effects. Adaptation can be anticipatory (actions taken in advance of climate change effects) or responsive and can encompass both spontaneous responses to climate variability and change by affected individuals and planned responses by governments or other institutions. Examples of adaptation interventions include watershed protection policies and effective public warning systems for floods and storm surges such as advice on water use, beach closings and evacuation from lowlands and seashores. To explain the observed diversity in the ability of systems to adapt (primarily to natural hazards), the IPCC offered the hypothesis that adaptive capacity is a function of a series of determinants (Smit & Pilifosova, 2001):

- the range of available technological options for adaptation;
- the availability of resources and their distribution across the population;
- the structure of critical institutions, the derivative allocation of decision-making authority and the decision criteria that would be employed;
- the stock of human capital, including education and personal security;
- the stock of social capital, including the definition of property rights;
- the system's access to risk-spreading processes;
- the ability of decision-makers to manage information, the processes by which these decision-makers determine which information is credible and the credibility of the decision-makers themselves; and
- the public's perceived attribution of the source of stress and the significance of exposure.

A framework more familiar in public health is the prerequisites required for prevention (Last, 1998):

- awareness that a problem exists
- understanding of the causes
- a sense that the problem matters
- the capability to intervene or influence
- the political will to deal with the problem.

Table 2.1 compares the determinants of adaptive capacity with the prerequisites required for prevention (Yohe & Ebi, forthcoming). This comparison shows that the public health and climate change communities share similar perspectives but use somewhat different terms.

Human societies are currently adapted to some extent to weather and climate variability. It is therefore important to identify where populations are not able to cope with current climate variability and extremes, such as floods, droughts and heat-waves. This shows where additional interventions are needed now. Improving the capacity to cope with current climate variability will probably improve the capacity to cope with long-term climate change. An adaptation assessment describes specific strategies, policies and measures that can be implemented to reduce current and future vulnerability as well as the resources needed (financial, technological and human capital) to implement them. The information generated from an adaptation assessment can be combined with a cost–benefit or other economic analysis to inform priority-setting by policy-makers. The Adaptation Policy Framework developed under funding from the Global Environment Facility of UNDP further describes designing and conducting a project focused on identifying adaptation options for short- and long-term policy planning in developing countries (Annex 2).

Assessing vulnerability or health impact

Approaches to assessing the potential effects of climate variability and change on human health vary depending on the outcome of interest. Conventional environmental health impact assessment is based on the toxicological risk assessment model that addresses population exposure to environmental agents,

TABLE 2.1. DETERMINANTS OF ADAPTIVE CAPACITY AND THE PREREQUISITES FOR PREVENTION

Determinants of adaptive capacity	Prerequisites for prevention
Availability of options	Technically feasible; awareness; capability to influence
Resources	Capability to influence
Governance	Political will
Human and social capital	Understanding of causes; political will
Access to risk-spreading mechanism	Capability to influence
Managing information (including monitoring)	Understanding of causes; problem matters
Public perception	Awareness; problem matters

Source: adapted from Yohe & Ebi (in press).

such as chemicals in soil, water or air. Most diseases associated with environmental exposure have many causal factors, which may be interrelated. These multiple, interrelated causal factors, as well as relevant feedback mechanisms, need to be addressed in investigating complex associations between disease and exposure, because they may limit the predictability of the health outcome.

Historically, two important dynamics drive the design of public health interventions, including the management of environmental risks: 1) scientific and technical knowledge, including the level of confidence in that knowledge; and 2) public values and popular opinion. Environmental risk management is the process by which assessment results are integrated with other information to make decisions about the need for, approaches to and extent of reducing risk. Policy-makers decide what interventions to implement, if any, to address current vulnerability, including those resulting from climate variability and change, even as research continues to provide additional information. Policy-makers should consider the concerns and priorities of stakeholders, including the scientific community and the public. One important role of scientists in this regard is explaining the role of uncertainty in the scientific process and contrasting it to the role uncertainty may play in policy development (Moss & Schneider, 2000; Bernard & Ebi, 2001).

WHO has developed quantitative approaches to estimating the environmental burden of disease at both the global and the national levels (Ezzati et al., 2002). Climate change was included as one of the types of environmental exposure in relation to malnutrition, flood impact, vector-borne diseases and diarrhoeal disease. Quantitative risk assessment allows specific outcomes (diseases) to be estimated under a range of scenarios that describe alternative future climates and future socioeconomic growth. The environmental burden of disease project provided estimates using a standardized approach to facilitate comparison across multiple health outcomes. This method is applied in these guidelines, as appropriate.

Assessments of the potential health effects of climate variability and change have used a variety of methods (see Part II). Both qualitative and quantitative approaches may be appropriate depending on the level and type of knowledge; the outcome of an assessment need not be quantitative to be useful to stakeholders. An integrated approach is likely to be most informative, as the impact of climate is likely to transcend traditional sector and regional boundaries, with effects in one sector affecting the capacity of another sector or region to respond.

Climate impact assessment

The IPCC has developed methodological guidelines for assessing climate impact (Carter et al., 1994; Parry & Carter, 1998). The guidelines were developed primarily for the biophysical and economic sectors and were not intended to apply to the effects on health and social systems. However, it is desirable that health impact assessment follow IPCC practice to facilitate the inclusion and interpretation of health effects in the forthcoming Fourth Assessment Report. The Fourth Assessment Report is due to be completed in 2007, with research and assessments completed by mid-2005 considered in the assessment. The methods and tools in this publication are therefore consistent with IPCC guidance. In addition, this publication provides guidelines on the use of consistent scenarios of climate change and socioeconomic futures for comparison across assessments: across different countries and within a country or region over time (Chapter 4 discusses scenarios in more detail).

Another resource is the UNEP *Handbook on methods for climate change impact assessment and adaptation* (Feenstra,et al., 1998), which includes a chapter on health. The aim of the UNEP country studies programme was to improve the methods for assessing the effects of climate change in developing countries or countries with economies in transition.

Health impact assessment should aim:

- to evaluate the impact of climate variability and change in a range of areas and populations, especially among vulnerable populations and, when possible, to determine the attributable burden of weather and climate, including extreme events, to climate-sensitive diseases (Chapters 5–11 discuss methods of achieving this);
- to evaluate possible threshold effects;
- to evaluate the effects of multiple stresses, including changes in socioeconomic systems;
- to evaluate uncertainty and its implications for risk management;
- to evaluate the effects of reducing emissions, such as by comparing impact under scenarios with business-as-usual and stabilization of emissions; and
- to measure coping capacity, especially under different socioeconomic futures (such as Nakicenovic & Swart (2000) or health-related scenarios) and in the context of sustainable development.

Risk management

Applying appropriate risk management principles, tools, and measures can reduce current and future vulnerability to climate variability and change. Numerous risk management frameworks have been developed that can be modified to address national, regional and local assessment needs (Annex 2). The first steps in these frameworks are identifying risks and assessing exposure and response. Risk identification involves evaluating whether a specific exposure is a risk to human health and well-being. Once a type of exposure is determined to be a risk (such as heavy rain causing rivers to overflow), the exposure and response are assessed to determine the consequences of exposure for the health and well-being of the affected population. This involves describing: the magnitude and frequency of the risk; the likelihood of exposure; who is or will be at increased risk of adverse health effects by level of exposure; and what is or will be at risk that could adversely affect health, such as damage to built infrastructure and/or interference with health and social services.

The risk identification and assessment of exposure and response should be followed by assessing capacity to identify the strengths and weaknesses of the human and material resources available to reduce (or manage) the risks. This might include assessing the ability of public health units, fire departments, emergency services and even military units to provide emergency services during weather-related disasters. It should also assess the ability to cope with risks that increase gradually, such as progressive droughts shrinking water supplies and increasing crop failures. Policy-makers and the public need to know whether public health services and other health and social infrastructure might be weakened by a deteriorating economy and by shrinking government income and resources.

Next, information is needed on the awareness and tolerance of risk at the local, regional and national levels. Information should be gathered on the risks the affected economic or social sectors, various levels of government and interest groups, experts, citizens and other appropriate sources perceive to be the most important and why. Priorities need to be established for how, by whom, how quickly, to what extent and in which order the risks should and could be reduced. This means that comprehensive and efficient information-gathering and consensus-building is essential.

The process of risk mitigation (risk management) focuses on the issues of highest priority. The adaptation assessment will have identified a range of possible strategies, policies and measures that could be implemented to address the risks of concern. These interventions have varying degrees of effectiveness, ease of implementation, expected disadvantages and cost in reducing the risk of adverse effects. These interventions are often analysed for costs and benefits. Decision-makers and policy-makers combine this information with factors such as current policy priorities and social values in determining a strategic direction and in implementing specific intervention. Finally, a mechanism for monitoring and evaluation needs to be established to determine whether the intervention has the desired effect and whether mid-course corrections are needed. Corrections may arise because of changes in social, economic, environmental and technological conditions over time. Significant changes may require initiating a new cycle of assessment and risk management to take these changes into account. Risk management is a process; this progression in time and the cyclical nature of the tasks can be represented by a clock face (Fig. 2.2). The United Kingdom Climate Impacts Programme has developed a decision-making framework for risk-based decision-making with respect to climate change (Willows & Connell, 2003).

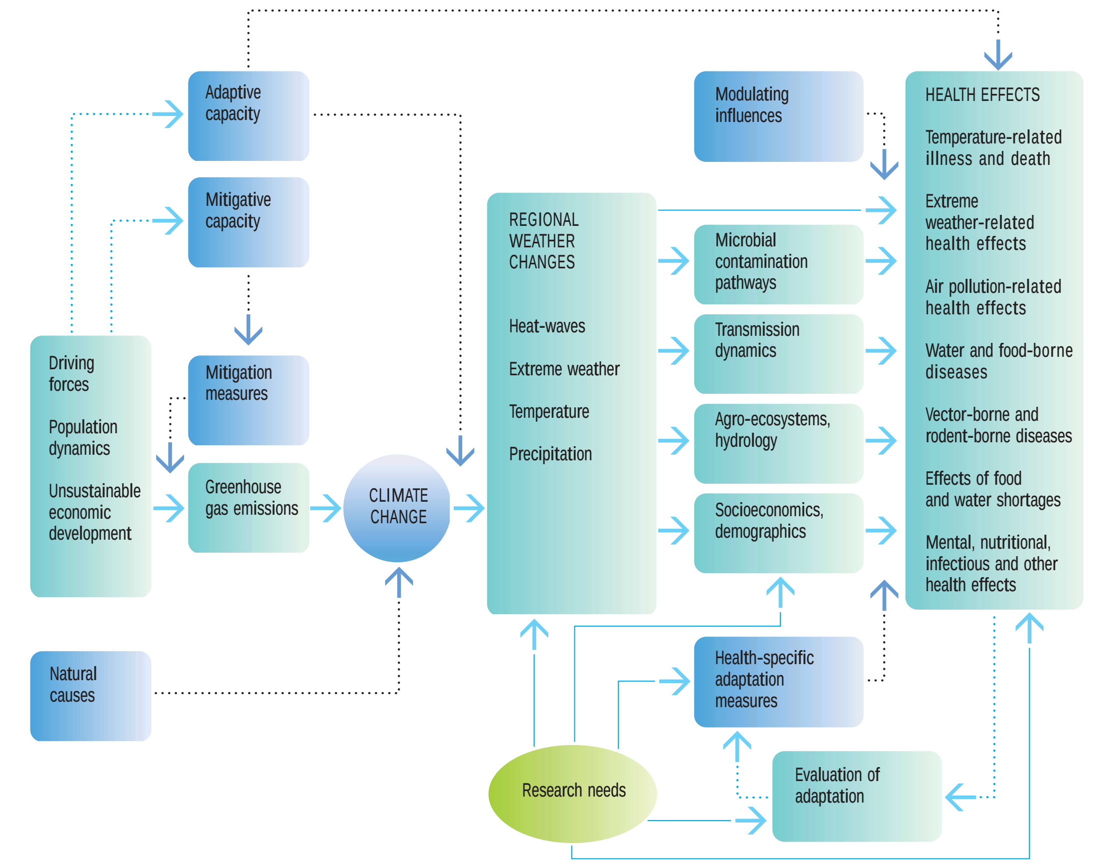
Fig. 2.2. The risk management cycle

Source: Treasury Board of Canada Secretariat (2001).

Steps in assessing vulnerability and adaptation

Assessment of vulnerability and adaptation uses similar concepts to those used in health impact assessment. Chapter 3 describes the process of conducting an assessment. Chapters 4 to 12 describe methods that can be used during the assessment process. Box 2.1 lists the recommended steps in conducting an assessment. The steps are consistent with the risk management framework; this report does not explicitly address the development of options, the selection of future strategies and the eventual implementation of the strategy as well as its monitoring, but they need to be considered in future policy development (Chapter 3). Not all steps may be possible or desirable, and the determination of which steps are included depends on the objectives and resources available for the assessment.

Fig. 2.3. Climate change and health: pathway from driving forces through exposure to potential health effects



Source: adapted from McMichael et al., (2003b).

1. Determine the scope of the assessment

The first step is to specify the scope of the assessment in relation to:

- the health and community security issues of concern today and of potential risk in the future;
- the geographical region to be covered by the assessment; and
- the time period.

Fig. 2.3 shows the many mechanisms by which changes in climate may affect human health. Table 2.2 describes the association between well assessed health outcomes and climate risks. Part II further addresses the evidence of an association between a specific health outcome and weather or climate.

Interactions between weather and climate and health are location-specific; using epidemiological evidence based on local data if they are available is therefore important. Evidence of an association between weather and health outcome may not imply an increased burden from climate change (see Chapter 4). Assessments should include current vulnerability to climate variability to inform understanding of what could occur with climate change. The extent to which an assessment addresses these issues depends on the goals of the assessment and the resources available.

The national boundaries may not be the most appropriate geographical framework for the assessment. Climate, diseases and vectors do not respect national boundaries, and other countries may therefore need to be considered to assess the national risk. Countries with similar health and climate problems may work together for a regional assessment. Many countries (such as the United Kingdom, the United States and Canada) have undertaken assessments at the subnational level. The geographical areas of interest are likely to vary by outcomes.

Box 2.1. Steps in assessing vulnerability and adaptation

1 Determine the scope of the assessment.

↓

2 Describe the current distribution and burden of climate-sensitive diseases.

↓

3 Identify and describe current strategies, policies and measures that reduce the burden of climate-sensitive diseases.

↓

4 Review the health implications of the potential impact of climate variability and change on other sectors.

↓

5 Estimate the future potential health impact using scenarios of future climate change, population growth and other factors and describe the uncertainty.

↓

6 Synthesize the results and draft a scientific assessment report.

↓

7 Identify additional adaptation policies and measures to reduce potential negative health effects, including procedures for evaluation after implementation.

TABLE 2.2. SUMMARY OF THE KNOWN EFFECTS OF WEATHER AND CLIMATE

Health outcome	Known effects of weather and climate
Cardiovascular and respiratory mortality and heat stroke mortality	• Short-term increases in mortality during heat-waves • V- and J-shaped relationship between temperature and mortality in populations in temperate climates • Deaths from heat stroke increase during heat waves
Allergic rhinitis	• Weather affects the distribution, seasonality and production of aeroallergens
Respiratory and cardiovascular diseases and mortality	• Weather affects concentrations of harmful air pollutants
Deaths and injuries	• Floods, landslides and windstorms cause death and injuries
Infectious diseases and mental disorders	• Flooding disrupts water supply and sanitation systems and may damage transport systems and health care infrastructure • Floods may provide breeding sites for mosquito vectors and lead to outbreaks of disease • Floods may increase post-traumatic stress disorders
Starvation, malnutrition and diarrhoeal and respiratory diseases	• Drought reduces water availability for hygiene • Drought increases the risk of forest fires • Drought reduces food availability in populations that are highly dependent on household agriculture productivity and/or economically weak
Mosquito, tick-borne diseases and rodent-borne diseases (such as malaria, dengue, tick-borne encephalitis and Lyme diseases)	• Higher temperatures shorten the development time of pathogens in vectors and increase the potential transmission to humans • Each vector species has specific climate conditions (temperature and humidity) necessary to be sufficiently abundant to maintain transmission
Micronutrient deficiences and undernutrition	• Climate change may decrease food supplies (crop yields and fish stocks) or access to food supplies
Waterborne and foodborne diseases	• Survival of disease-causing organisms is related to temperature • Climate conditions affect water availability and quality • Extreme rainfall can affect the transport of disease-causing organisms into the water supply

The responsible national or regional health authority can identify the health outcomes to be included in collaboration with, when appropriate, (1) the authorities responsible for the social security, environmental affairs and meteorological offices; (2) the research community; and (3) other stakeholders, such as nongovernmental organizations, business and the public. The assessment of some health outcomes may be postponed for future consideration if either climate or epidemiological information is currently insufficient to evaluate exposure and response. However, when the outcome is of high societal importance, qualitative estimates could be made.

2. Describe the associations between disease outcomes and climate variability and change

Once health outcomes (the climate-sensitive diseases) are identified for inclusion in the assessment, the current evidence (published literature) should be reviewed. A variety of statistical methods are available to analyse associations with exposure to weather or climate, taking into account modifying and/or interacting factors (described in detail in Part II). Adverse health outcomes associated with interannual climate variability, such as El Niño events, could also be considered. Meteorologists can provide input into how to define and describe the important types of weather exposure; for example, the severity and recurring periods of extreme weather events.

For each chosen outcome, determining the factors that could modify its association with weather and climate variables is important. Modifying factors will vary by disease outcome and could include socioeconomic and other variables. Consideration should be given to interacting effects. For example, morbidity and mortality may be increased during periods with both extreme heat and high levels of air pollutants. If epidemiological analyses cannot be conducted, such as if data are not of sufficient quality and quantity, the available literature can be reviewed to produce a qualitative assessment.

The current burden of the climate-sensitive diseases can be described using the following indicators and outcomes:

- the current incidence and prevalence of the disease and the trend (is the disease increasing or decreasing), which may be available from routine statistics from the appropriate national agency; and

- the attributable burden of a disease to climate and/or weather, such as what proportion of all cardiovascular deaths are attributable to high or low temperatures or the number of deaths caused by floods.

For vector-borne diseases, having a map showing the current geographical distribution of human cases and vectors may be useful. Finally, environmental and socioeconomic conditions also influence human vulnerability and need to be considered within the assessment.

3. Identify and describe current strategies, policies and measures that reduce the burden of climate-sensitive diseases

For each health outcome, activities and measures individuals, communities and institutions currently undertake to reduce the burden of disease should be identified and evaluated for effectiveness. Adaptation measures can be identified from: (1) review of the literature; (2) from information available from international and regional agencies (WHO, the Pan American Health Organization, UNEP and others) and from national health and social welfare authorities (ministries of health); and (3) from consultations with other agencies and experts that deal with the impact of the health outcome of concern (that is, agencies that deal with the effects of extreme weather events, such as river commissions). Identifying successful adaptations being undertaken to address the negative effects of climate variability and those implemented in anticipation of climate change is important. For example, is an early warning system for heat-waves in place? What activities are instituted during a heat-wave to reduce morbidity and mortality? Reviewing adaptation measures implemented in other regions with similar health concerns may be valuable.

Ideally, the effectiveness of adaptation measures should be evaluated. Information from the previously mentioned sources is needed to evaluate the effectiveness of measures, including the barriers to implementation for proposed interventions. An evaluation should consider approaches to monitor how the performance of a strategy, policy or measure may change over time compared with the baseline. For example, if an early warning system for heat-waves is in place, evaluation can determine whether morbidity and/or mortality is lower with the system based on comparable heat-wave.

The key questions to address for a specific health outcome include the following.

- What is being done now to reduce the burden of disease? How effective are these policies and measures?

- What could be done now to reduce current vulnerability? What are the main barriers to implementation (such as technology or political will)?

- What strategies, policies, and measures should begin to be implemented to increase the range of possible future interventions?

4. Review the health implications of the potential impact of climate variability an change on other sectors

Climate change is likely to affect natural and human systems. Assessments should therefore be integrated across the concerned scientific disciplines and non-health sectors included. International agencies (the IPCC) or regional or national authorities may have assessed the potential impact of climate change on the environment (habitat and land use) at the relevant spatial scale.These effects should be included in the assessments to better understand issues such as the health implications of the direct impact of climate change on the food supply and the risk of disasters (such as coastal or river flooding).The impact of implemented strategies, policies and measures in response to actual or projected climate change needs to be evaluated in terms of potential health effects. For example, in cases where domestic water storage is recommended, the implementation of this measure may have implications for vector breeding and the transmission of dengue. Water development projects should be subject to environmental and health impact assessment. Information at the regional, national or local scale about climate variability and change should be used whenever possible.

5. Estimate the future potential health impact

Climate variability and change are adversely affecting human health and well-being and will continue to do so. The inherent inertia in the climate system means that the impact of current greenhouse gas emissions will be delayed for decades to centuries.The IPCC projections for the increase in mean surface temperature for the 21st century range from 1.4°C to 5.8°C.As a consequence, anthropogenic warming is projected, on average, to range from 0.1°C to 0.5°C per decade during this century. Even larger changes may be expected beyond the 21st century. Greater climatic changes are expected in higher latitudes in both hemispheres, with increasing risks of heat-waves, flooding and drought events and the spread of infectious diseases.This emphasizes that health and civil defence authorities need to design and implement adaptation strategies, polices and measures to reduce potential health impact. The climate change community often chooses from the present until 2050 and until 2100 as the reference periods for projecting the impact of climate change.

This requires using climate scenarios. Climate scenarios are now available for a range of time scales (see Chapter 4). The time scale of the assessment depends on the scope and purpose of the assessment. However, addressing potential effects both in the near term (the next 20 years) and the long term (up to 2050 or 2080) is advisable.The focus on the near term provides relevant information within the usual planning horizon of health agencies. A further need is looking beyond the near term to develop comprehensive adaptation measures.

The potential future impact of climate variability and change on health may be estimated using a variety of methods, as described in Part II. These methods imply a top-down approach in which scenarios of climate change (and other changes) are used as inputs into a model on climate and health. Such models can be complex spatial models or be based on a simple relationship between exposure and response.

Models of climate change should include projections of how other relevant factors may change in the future, such as population growth, income, fuel consumption and other relevant factors. Projections may be incorporated from models developed for other sectors, such as flood risk, food supply and land-use changes (see step 4). An assessment needs to address uncertainty explicitly. Scientists, policy-makers and the public must recognize the existence of multiple sources of uncertainty, from climate projections to the potential future public health effects. This step should be realistic about the likelihood that the uncertainty can be resolved in a meaningful time frame. Carefully estimating uncertainty can further understanding of the level of confidence in what is known and can provide input into future research directions and to policy-making.

Future capacity to adapt to the effects of climate change depends on the future levels of economic and technological development, local environmental conditions and the quality and availability of health care and of public health infrastructure. Social, economic, political, environmental and technological factors strongly influence health. These determinants of health are complex enough that future projections about stresses on population health, including but not limited to projections of the potential effects of climate variability and change on health, become increasingly uncertain with expanding timelines. Future projections must make explicit their assumptions about adaptive capacity.

6. Synthesize the results and draft a scientific assessment report

This step synthesizes the quantitative and qualitative information collected in the previous steps to identify changes in risk patterns and opportunities and to identify links between sectors, vulnerable groups and stakeholder responses. Convening an interdisciplinary panel of experts with relevant expertise is one approach to developing a consensus assessment. Chapter 6 provides guidance for describing the level of evidence behind a consensus statement. Once synthesized, the information should be peer-reviewed and published.

Assumptions that underlie any quantitative estimates should be clearly described. Quantitative estimates should be clearly identified with a climate scenario. Vague statements about potential impact should be avoided. In particular, it should not be stated that climate change "may affect" a given disease, as this is virtually meaningless. The degree of certainty of a statement should be provided (see Chapter 4). The most vulnerable population groups should be identified (see Chapter 12).

Value judgements have to be made in summarizing the assessment. In particular, decisions should be taken about (Lehto & Ritsatakis, 1999):

- how to balance near-term and long-term effects;
- how to weight the different potential effects in different population groups;
- how to balance the more certain, quantifiable potential effects with those that are less certain and not quantifiable, as well as the qualitative effects; and
- how to balance the interests of the various stakeholder groups: experts, people potentially affected and decision-makers.

7. Identify additional adaptation policies and measures, including procedures for evaluation after implementation

Identify possible adaptation measures that could be undertaken over the short term to increase the capacity of individuals, communities and institutions to effectively cope with the weather or climate exposure of concern. These measures should be possible to institute within the population's access to material resources, technology and human and social capital. For example, if heat-related morbidity and mortality are health issues in an urban area and if an early warning system for heat-waves is not in place, then would implementing such a system be likely to benefit population health? Strengths and weaknesses as well as opportunities and threats to implementation should be evaluated and priorities set.

Every country needs to adapt to long-term climate change. The aim of this step is to identify possible measures that can be taken today and in the future to increase the ability of individuals, communities and institutions to effectively cope with future climate exposure, including extremes.

Consideration should be given to the lessons learned from past public health policies, including the effectiveness of various measures, such as vector control and early warning systems.

Many of the possible measures for adapting to climate change lie primarily outside the direct control of the health sector. They are rooted in areas such as sanitation and water supply, education, agriculture, trade, tourism, transport, development and housing. Intersectoral and cross-sectoral adaptation strategies are needed to reduce the potential health impact of climate change. A policy analysis will determine the feasibility of and priorities among these options. In general, many of the policies and measures identified also promote sustainable development.

Criteria should be established in advance for evaluating possible adaptation measures. Evaluation should be an ongoing process both to identify opportunities for improving the effectiveness of the measures but also to identify maladaptation and unintended consequences as quickly as possible. The traditional public health methods for evaluating the efficacy and effectiveness of a particular intervention should be applied, with appropriate consideration of the local circumstances. Table 2.3 summarizes again the terms used in this assessment and provides some examples. These concepts should be included as part of the synthesis of the assessment of vulnerability and adaptation.

TABLE 2.3. EXAMPLES OF CURRENT AND FUTURE VULNERABILITY AND ADAPTATION

Definition	Current	Future
Vulnerability: the degree to which individuals and systems are susceptible to or unable to cope with the adverse effects of climate change	Populations living in areas on the fringe of the current distribution of malaria are at risk for epidemics if the range of the *Anopheles* vector changes	Whether or not these populations might be vulnerable in the future depends, in part, on the implementation of timely and effective prevention activities
Adaptation baseline: the adaptation measures and actions in place in a region or community to reduce the burden of a particular health outcome	The exposure–response relationship is partly influenced by the current prevention measures aimed at reducing the burden of a disease. For example, the number of elderly people adversely affected by a heat-wave depends on the numbers who have access to and who use space cooling and rehydration	Increasing access to and use of space cooling will reduce the percentage of the elderly population who could be adversely affected by future heat-waves. For example, the 1995 heat-wave in the midwestern United States had greater effects than a similar heat-wave in 1999, in part because of programmes established in the interim
Coping capacity: the adaptation strategies, polices and measures that could be implemented now. Specific adaptation plans arise from a region or community's coping capacity	Several cities in middle-latitude countries have the level of material resources, effective institutions and quality of public health infrastructure to establish and maintain early warning systems for heat-waves. Until implemented, these systems are within a city's coping capacity	Over time, strategies, policies and measures can move from being possible to being implemented (that is, being part of the adaptation baseline). For example, universal access to adequate quantities of clean water is not yet possible, although significant progress has been made
Adaptive capacity: the general ability of institutions, systems and individuals to adjust to potential harm, to take advantage of opportunities or to cope with the consequences of climate variability and change	Adaptive capacity is the theoretical ability of a region or community to respond to the threats and opportunities presented by climate change. It is affected by a number of factors (see Table 2.1). It encompasses coping capacity and the strategies, policies and measures that have the potential to expand future coping capacity	Over time, it is hoped that regions and communities will increase their adaptive capacity: that they will increase their resilience to what the future climate will bring

3. The framework for the assessment

Assessments need to be informative and timely. Experiences from many developing and industrialized countries that have carried out assessments (WHO, 2001a) have shown that including various stakeholders in the assessment planning, implementation and evaluation from the beginning is very important.

Assessment requires an adequate management structure, to carefully plan the process, implement the assessment and to evaluate both the process and the outcome. Before, during and after the assessment, an adequate communication strategy needs to be planned, hand in hand with risk communication.

Assessments can have different levels of in-depth analysis. This often depends on the objectives, the interest of stakeholders and the funding available.

This chapter briefly describes the involvement of stakeholders, the management structure, the communication, the level of assessment, peer review and risk management.

Involvement of stakeholders

The stakeholders in a health assessment are people within governments, nongovernmental organizations, research institutions and private entities that focus on public health. If the ultimate goal of vulnerability assessment is to provide useful information to these stakeholders, then they must be engaged throughout the assessment process.

For an assessment to be informative, the assessors must know the issues and questions of greatest concern to the stakeholders. This does not imply that relevant issues – otherwise not identified or known as important to stakeholders – would be left out of the assessment. A comprehensive assessment could identify "surprises" not expected by stakeholders. Stakeholders should be engaged from the outset of the assessment process, including ongoing involvement in the analytical phase. Assessors and stakeholders are not necessarily distinct communities. In many cases, the stakeholder community can offer data, analytical capabilities, insights and understanding of relevant problems that can contribute to the assessment. Openness and inclusiveness enable different participants to bring a diversity of views and information that may benefit the assessment process. Involving all interested parties makes the assessment process more transparent and credible.

For an assessment to be timely, the assessors must understand how relevant stakeholders will use the information generated and understand the time frame within which the information is needed. Even with stakeholder involvement, researchers are often reluctant to make any statements policy-makers might use because scientific uncertainty still exists. Nevertheless, policy-makers make decisions under uncertainty, whether or not scientists are prepared to inform those decisions. Assessors strive to answer decision-makers' questions to the extent possible given uncertain science based on the assumption that informed decisions are better than uninformed decisions. They also characterize the uncertainty and explore what it implies for various policy or resource management decisions in the belief that improving the understanding of the quality and implications of scientific information leads to more informed decisions.

Finally, re-evaluating the level of stakeholder concern and identifying any new issues of concern to stakeholders as they are informed of assessment results are especially important. Once an assessment is completed and the stakeholders informed of the results, assessors should elicit from the stakeholders any new interests and concerns the assessment raises. Engaging stakeholders in the process and especially keeping stakeholders engaged throughout the assessment is not easy. The management structure should include the need to design strategies to achieve this.

Management structure

Before health impact assessment is begun, a management structure has to be established to supervise each stage of the assessment. Identifying one leading institution is useful to ensure that the assessment is supervised until completion. In countries, the national health ministry has primary responsibility for assessing and promoting the health of the population. It would therefore be advisable to identify a health institution to take the lead. However, other departments and organizations may have various responsibilities for protecting human health and may need to participate in the management structure as well (such as those within environment, transport and industry). The national health ministry should have the necessary expertise and capacity to manage an assessment of potential risks to public health resulting from climate change and to integrate climate change considerations into public health policy. The national health ministry or joint health ministries at the regional level, in conjunction with other environmental, social and security authorities, need to identify branches of responsibility within their organizations that will facilitate the development of the assessment. The health ministry has two primary tasks: to establish a management structure within the ministry with various responsibilities and to facilitate the development of the assessment.

As the project leader, the health ministry needs to identify branches of responsibility within its organization to undertake each of the tasks outlined below and to work together in an integrated fashion. Generally the tasks fall into three categories: developing partnership, generating knowledge and developing policy. Different offices within the organization should carry out these tasks through collaborative work. This forms the basis of the administrative operation.

Many of the aspects of the assessment process, such as synthesizing results, developing policy and engaging stakeholders, will have implications after the assessment is completed. Research gaps and information needs identified during the assessment will feed into the future development, selection and implementation of policy options and into further monitoring and surveillance work that typically constitute the risk management phase of an assessment. This publication focuses on the assessment of vulnerability and adaptation, although a strong management structure will plan ahead and identify the necessary resources and expertise required to make the transition to risk management activities.

Partnership development

The health ministry needs to work with international funding agencies, government and nongovernmental organizations and representatives of other sectors within and outside the country to secure access to the resources, expertise and training materials needed to conduct the assessment. The assessment process requires extensive and diverse human, financial and technical resources. For most industrialized countries, these resources are readily accessible or at least available within the country itself. For developing countries, these resources may need to be obtained from external sources (see Chapter 1 on national adaptation programmes of action and adaptation funds).

Relationships should be established and fostered with international organizations, such as WHO, the World Bank, UNEP, UNDP, the Food and Agriculture Organization of the United Nations (FAO) and international nongovernmental organizations.

The health ministry will also facilitate the identification and organization of key partners within the country or region being assessed to participate in various fora, including an overarching steering group, various working groups and peer review committees. Other important considerations are what and how information will be documented. The leading organization should keep records and make them available upon request, which requires resources. Proper documentation enhances transparency and accountability, aids in decision-making processes and provides a reference for future assessments.

The leading institution should set up a coordination and steering team. Core coordination can help to manage the process and to assist and advise the health, welfare and other relevant authorities.

The process design includes:

- the timing and scale of the assessment;
- the language: for example, indigenous or other minority languages might be needed;
- the information requirements;
- the peer review process;
- the terms of reference of the assessment; and
- the procedures for internal and external communication mechanisms, meetings and decision-making processes (if applicable).

Generating and exchanging knowledge

A primary task of the health ministry is to facilitate the successful building of a foundation of interdisciplinary evidence and action to identify and manage the potential risks to human health from climate change. Government and nongovernmental organizations, public health organizations, scientific researchers and policy-makers collaboratively identify possible human health impact from climate change and adaptation strategies, policies and measures to minimize potential adverse consequences. These feed into future monitoring and surveillance work to create an iterative cycle of assessment and policy development (see below).
The health ministry facilitates the organization of the assessment, so that the assessment conclusions and recommendations are useful for scientific studies, for giving priority to and implementing adaptation measures and for the needs of policy research.

The results of the assessment of vulnerability and adaptation need to be synthesized and communicated to decision-makers and policy-makers. The objectives include identifying changes in risk patterns and opportunities, identifying links between sectors, vulnerable groups and stakeholder responses and identifying adaptation measures and policies. Ideally, the individuals or groups conducting the assessment coordinate and collaborate throughout the assessment, so that the results can be easily integrated into a single product, such as a report.

Policy development and recommendations

The health ministry, together with experts and stakeholders, collectively develops the country's assessment of health vulnerability and adaptation. Based on this process, the health ministry collaboratively develops integrated health and well-being strategies, policies and measures for climate change at the national, regional and community levels that effectively manage the risks to health identified in the assessment. This collaborative process encourages all other partners in promoting health and well-being to develop and incorporate integrated collaborative adaptation policies and measures for climate change into their policies. Although this is fundamentally a risk management activity, policy implications should be considered throughout the assessment process. Risk managers and policy-makers should therefore be identified as relevant stakeholders and involved throughout the assessment.

Steps 1 to 7 described in Chapter 2 lead to the identification of current and future vulnerability to climate variability and change and to the identification of desirable adaptation options. For risk management and policy development, risks need to be ranked, policy options identified and a strategy selected and implemented. Assessment should proactively analyse the costs and benefits of the policy measures recommended for adaptation to climate change. The assessment should not only inform policy-makers but also enable them to make evidence-based decisions (Table 3.1). Decision-making is a social and political process that the assessment aims to inform. Assessment should help:

- to make the problem and the potential impact explicit and clear;
- to identify strategies, policies and measures that could reduce the potential adverse effects for a range of time frames;
- to establish programmes to evaluate specific strategies, policies and measures;
- to identify research gaps; and
- to assist decision-makers in choosing between competing alternatives.

Setting the research agenda

Assessments are iterative in nature. Key research gaps that are identified should guide the priority-setting of research to fill these gaps, and new research findings can advance future assessment. When different sectors are part of assessing vulnerability and adaptation, exchange of findings should be encouraged

TABLE 3.1. ASSESSING OF HEALTH VULNERABILITY AND ADAPTATION: PLANNED KEY MANAGEMENT DELIVERABLES

Policy development	Partnership development	Knowledge generation and exchange
Facilitate the organization of interdisciplinary fora of policy-makers and decision-makers to identify policy questions and research needs	Secure external funding, technical assistance and data sources to initiate and conduct interdisciplinary assessment of health vulnerability and adaptation	Assess the utility and efficiency of various methods and tools to conduct the assessment and identify capacity limitations, resource needs and information gaps
Facilitate the development of comprehensive, interdisciplinary assessment of health vulnerability and adaptation at the national level	Facilitate the organization of key national and international stakeholders for an overarching steering group and interdisciplinary fora of researchers, policy analysts and decision-makers for working groups	Facilitate the organization of interdisciplinary fora of researchers, policy analysts and decision-makers to identify research needs for generating knowledge and for promoting formal and informal dialogue
Organize interdisciplinary fora to set up a structured dialogue to bring research results forward to inform policy on health and well-being	Provide training resources and services for working group assessors and researchers	Develop effective ways of communicating research results to facilitate decision-making
Develop integrated health and well-being policies for climate change that effectively manage the risks to health	Facilitate electronic access to the knowledge generated, surveillance and monitoring data, information sources and opportunities for dialogue	Assess and synthesize research findings
Facilitate the development of monitoring and evaluation mechanisms to respond to changing climate conditions, evolving health impact concerns and opportunities for adaptation	Facilitate the organization of a multidisciplinary network of researchers to conduct peer review of assessment findings	Develop mechanisms for storing and retrieving information

across disciplines. Several health issues relate to impact in a variety of other sectors, such as coastal zones, water and agriculture.

Assessment teams

Because the issues involved are complex, insight is required from multiple and diverse disciplines. Assessment teams must therefore comprise researchers from a variety of disciplines working together to integrate their results, such as public health, climatology, economics, social sciences, environmental science and ecology. Each discipline alone is complex, and extra incentives should therefore be in place to encourage assessors to reach across established boundaries.

Assessment also entails considering how human behaviour might contribute to or ameliorate the risks. The extent to which climate change may harm human health depends on people's ability to successfully adapt to new climate conditions. This ability may depend on social, political, economic, environmental, technological and demographic factors that can affect human health. Hence, assessment must include expertise from the social, political, environmental and engineering sciences. Including stakeholders with information relevant to pertinent cultural and social practices may also be appropriate.

Levels of assessment

The material and human resources available result in vulnerability and adaptation being assessed at various levels.

A basic assessment could be conducted using readily available information and data, such as previous assessments, literature reviews by the IPCC and others and available region-specific health data. Limited analysis may be conducted of regional health data, such as plotting the data against weather variables over time (Part II further discusses methods). Consultation with stakeholders is relatively limited. The result may produce trends in disease rates, and the effects may be minimally quantified, if at all.

A more comprehensive assessment could include a literature search focused on the goals of the assessment, some quantitative assessment using available data (such as the incidence or prevalence of weather-sensitive diseases), more involvement by stakeholders, some quantification of effects and a formal peer review of results.

An even more comprehensive assessment could include a detailed literature review, collecting new data and/or generating new models to estimate impact, extensive analysis of quantification and sensitivity, extensive stakeholder involvement throughout the assessment process, formal uncertainty analysis and formal peer review.

Peer review process

Peer review is a critical step for ensuring the scientific credibility of assessment results. The peer review process must be rigorous and open, have broad-based participation and be transparent and well documented. For this to occur, a review process should include the following minimal elements.

Technical review. A technical review should be conducted to evaluate the accuracy and validity of statements of fact and interpretations of data. Technical reviews should focus on analyses from specific disciplines (presumably articulated in different sections of the final assessment report). The expert reviewers included in this step should include specialists active in relevant disciplines or fields of endeavour who did not participate in the assessment process.

Comprehensive review. Experts with broad scientific and technical expertise relevant to the particular region (or health effect) under study should comprehensively review the entire document. These reviewers should not have participated in the assessment process.

Public and stakeholder review. The assessment report should be circulated for comment to a range of interested parties, including the stakeholders engaged in the assessment. The report should also be available to the public upon request during the review period.

Documentation of reviews and responses. To ensure the transparency and credibility of the review process, a document should be prepared that compiles and summarizes all broad categories of comments and explains the responses of the assessment team.

Dissemination and risk communication

Risk communication is an "interactive process of exchange of information and opinion among individuals, groups, and institutions" (National Research Council, 1989). This process is defined by levels of involvement in strategies, policies and measures aimed at managing or controlling health or environmental risks. Traditional messages about health risk tend to flow one way to motivate individual behavioural change among stakeholders and policy-makers. Effective risk communications is a two-way process including all exchanges among interested parties (individuals, social groups, industry and governments). It is a key element of responsible management. Government agencies, industry and nongovernmental organizations are all expected to take part in this communication effort.

The risk communication process is deeply embedded in broader social issues, which means that there may be many barriers and problems. A key barrier is the differences in how interested parties measure, describe and perceive risk.

Planning for risk communication

Timeliness is essential to effective risk communication. Risk communication is, by definition, proactive and may involve many stakeholders and audiences, various levels of communication and phases or stages of communication to accommodate the needs inherent in each step of the assessment.

Key questions to be considered include:

- Who is responsible for initiating risk communication programmes?
- When should risk communication be started?
- What are the key messages to be delivered and what content supports them?
- Who are the key audiences and at what point should they be involved?
- What listening or response mechanisms will be in place to ensure two-way communication throughout the process?
- How is the effectiveness of communication going to be monitored?

Trust is a very important ingredient. National institutions are not always those that generate the most trust. An evaluation of both the reality and the perception of the health ministry's performance will provide important information in developing the strategic approach to communication. Continuous, two-way, open and responsive communication will help to establish trustworthiness.

One of the basic steps for success is early involvement of key stakeholders; knowing the stakeholders and audiences is essential. The potential for achieving successful risk communication increases with knowledge of the people with whom you are communicating – what their concerns are, how they perceive risk and whom they trust. Identifying this information early and incorporating it into the initial stages can reap benefits later in the process. For example, public health and environmental nongovernmental organizations, other scientific bodies, health care institutions and governments (which control funding for future activities) could be involved to varying degrees. Any or all of these initial stakeholders will eventually be in a position to contribute to the involvement of and communication with their own communities.

Implementing risk communication

When messages are established, clarity about the intentions is key to the communication (Box 3.1). All material should consistently relate to the key message. Messages need to be composed before packaging them for the different target audiences. This will ensure that the institutions responsible for risk communication maintain a consistent approach through core messaging. Messages should be simple, and care should be taken to never assume that the audience completely understands the technical or scientific knowledge on which the message is based. Communication should be tailored to the needs of the targeted audience and not to the needs of the people or institutions generating the information. It should also be adjusted and modified as required based on monitoring of the effectiveness of the communication.

Box 3.1. Principles for the practice of risk communication

- Accept and involve the public as a legitimate partner.
- Listen to the public's specific concerns.
- Be honest, frank and open.
- Coordinate and collaborate with other credible sources.
- Meet the needs of the mass media.
- Speak clearly and with compassion.
- Plan carefully and evaluate your efforts.

The social and cultural conditions under which the programme is launched should be considered in framing communication. Risk communication depends on knowledge, legal systems and social values. National culture, political traditions and social norms influence discussions and decisions on policy and adaptation measures. These guiding principles apply to stakeholder consultation at the scientific level as well as to the general population that may be at risk. Programme approaches must therefore be tailored to the political and cultural environments within which they are launched.

Finally, both human and financial resources contribute significantly to the success or failure of a risk communication exercise. Financial planning should include the costs of everything from the tools and tactics to ensuring that a solid framework and mechanism for evaluation is in place to monitor the effectiveness of a programme. Individuals working on the assessment are likely to require training in risk communication and in the key messages that have been established.

PART II. METHODS AND TOOLS

This part of the publication describes a range of methods and tools that can be applied within climate change and health assessment. Chapter 4 describes tools for quantitative risk assessment that can be applied across a limited range of health outcomes. Recommendations are made for the use of certain approaches or data sources to ensure some standardization in assessment between countries and over time. However, quantitative risk assessment is appropriate for few potential health outcomes, and many other methods are essential to comprehensively assess vulnerability, such as social science and qualitative methods. Many countries do not currently have sufficient resources, especially data on health outcomes, to undertake epidemiological studies or quantitative risk assessment.

Chapters 5 to 10 describe methods and tools in relation to specific health outcomes. Methods are relatively well established for some outcomes, such as vector-borne diseases.

Chapters 11 and 12 focus on effects that are of concern but are less amenable to quantitative risk assessment, either because data and models are not available or because the effects are very uncertain, such as population displacement. An assessment needs to include the effects of high-risk, low-probability events.

This publication cannot describe in detail the methods used for epidemiological research or risk assessment. Where possible, readers are referred to more detailed sources of information. For many outcomes, formal assessment methods have not yet been developed.

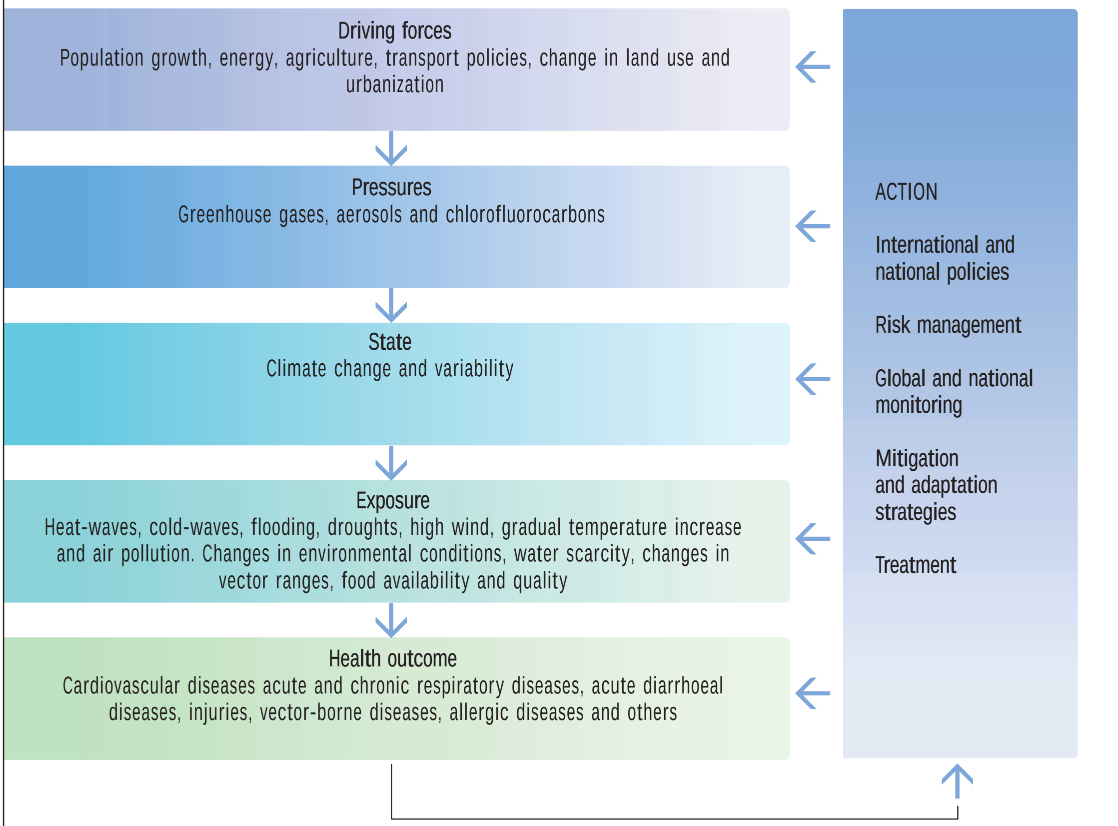
TABLE 4.1 SUMMARY OF THE COMPONENTS OF ASSESSMENT

Issues addressed in Part II for specific health outcomes	Corresponding step in Part I	Component
What is the evidence that climate change could affect health outcomes?	Step 2. Describe the associations between disease outcomes and climate variability and change Step 4. Review the implications of the potential impact of climate variability and change on other sectors – such as agriculture and food supply, water resources, disasters, coastal and river flooding – and the consequences for health	• The status of current scientific knowledge on the exposure and with reference to population of interest • The potential effects of climate change on other areas that have implications for health • Any available scenarios • Additional expertise
Methods for estimating the effect of climate and weather on health outcomes	Step 2. Describe the associations between disease outcomes and weather and climate	• The methods of epidemiological studies of weather and climate effects currently available
Methods for estimating future health impact attributable to climate change	Step 5. Estimate the future potential health impact using scenarios of future climate change, population growth and other factors and describe the uncertainty	• Identification and use of scenarios, developing models and assessing uncertainty in relation to the quantitative outcomes
Adaptation: strategies, policies and measures	Step 3. Identify and describe current strategies, policies and measures that reduce the burden of climate-sensitive diseases Step 7. Identify additional adaptation policies and measures to reduce potential negative health effects, including procedures for their evaluation after implementation	• Some examples of current adaptation measures and additional measures that could be implemented or should be implemented in the future

4. Quantitative health impact assessment

Environment and health: causal frameworks

Fig. 4.1. Driving forces–pressures–state–exposure–effect–action framework for describing linkages between health and climate change



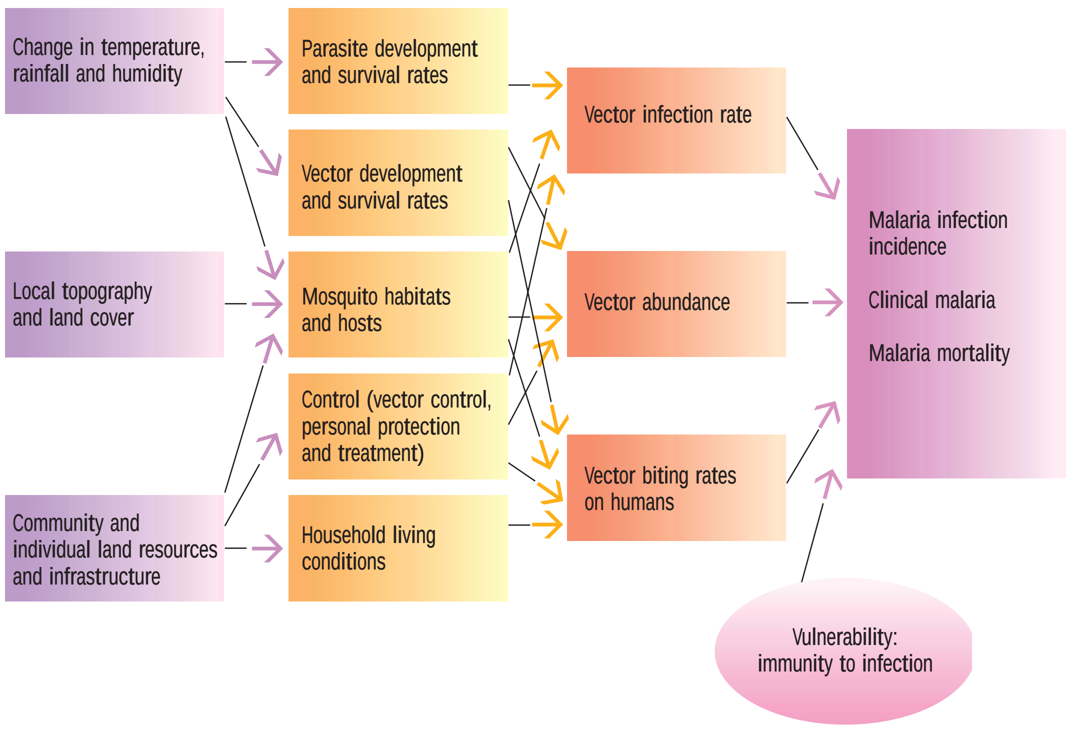
Source: adapted from WHO European Centre for Environment and Health (2001), and Corvalan et al., (2000).

Several different frameworks have been used in studying the environmental causes of disease. The driving forces–pressures–state–exposure–effect–action framework is widely used (Fig. 4.1). Driving forces are the factors that motivate and push the environmental processes involved. Pressures are normally expressed through human occupation or exploitation of the environment. State is the current status of the environment. Exposure refers to the intersection between people and the hazard inherent in the environment.

Fig. 4.1 illustrates how the driving forces–pressures–state–exposure–effect–action framework can be adapted to address the potential health effects of global climate change. The framework can be developed to identify the environmental causes of disease in a causal web. Proximal causes of disease are the more familiar types of exposure addressed within traditional environmental epidemiology, such as pollutants in the water, air or soil, or high temperatures. The distal causes of disease are often more difficult to investigate using epidemiological methods but are important from a policy perspective.

Fig. 4.2 illustrates the proximal and distal causes of a vector-borne disease such as malaria. Such diagrams are able to describe the role of climate (or climate change) in the context of other environmental risk factors. Climate change is largely a relatively distal risk factor for ill-health, often acting through complex causal pathways and influenced by multiple effect modifiers.

Fig. 4.2. Causal web for the associations between climate and one vector-borne disease (malaria)



Source: McMichael et al., in press.

The attributable burden of weather and climate exposure

Ecological studies are used to quantify the relationships between exposure and response for a range of climate-sensitive diseases. Ecological studies are epidemiological studies in which the exposure is defined at the population level rather than the individual level. Group-level relationships are investigated through spatial or temporal variation in exposure and outcome. These studies take advantage of large aggregated databases of health outcomes that are routinely reported, such as deaths or hospital visits. For more in-depth discussion of the advantages and limitations of ecological studies, see Corvalan et al., (2000), Chapter 6.

Similar to other epidemiological methods, potential confounders must be identified and, if possible, their effects removed from the analysis. Whatever method is used, it should be unbiased and appropriate to the data available.

Time–series methods have been developed to estimate the proportion of disease in a population that is attributable to weather: the day-to-day or week-to-week variation in exposure to weather (Schwartz et al., 1996). Temperature and daily mortality have been shown to be strongly associated (Chapter 5), as have temperature and cases of diarrhoea (Chapter 9). The advent of geographical information systems and the georeferencing of disease and exposure data have facilitated the investigation of the spatial distribution of many vector-borne diseases and/or their vectors (Chapter 8).

Epidemiological research can be used to identify and quantify relationships between exposure and response in the relevant population. This relationship can then be applied using risk assessment methods to estimate the population at risk or the population-attributable fraction (Bruzzi et al., 1985; Committee on the Medical Effects of Air Pollution, 1998). Risk assessment may be undertaken without first undertaking expensive epidemiological research if an appropriate exposure–response relationship is available in the published literature (Samet et al., 1998).

Any calculation of the attributable fraction or the absolute number of attributable cases should clearly state the underlying assumptions. In particular, the following should be addressed:

- justification for applying the exposure–response relationship beyond the bounds of the observed temperature range;
- justification for applying the exposure–response relationship derived from a different population; and
- the baseline disease incidence used to estimate attributable cases.

In traditional environmental epidemiology, only a proportion of the population is exposed to the exposure (a pollutant) of concern. Quantifying this exposure is therefore an important step in the assessment process. In climate change assessment, the whole population is assumed to be exposed to changes in climate, although the degree of change may vary spatially (Campbell-Lendrum et al., 2003). Groups within a population may differ in sensitivity (exposure–response relationships). For example, mortality among elderly people is much more sensitive to higher temperatures than is mortality in younger adults.

The attributable burden of climate change

Projecting mortality or morbidity into the future is difficult. An important task for public health is knowing the current and future burdens of disease to facilitate health policy decisions. In the short term, predictions of infectious diseases are modelled to estimate the course of an epidemic (such as HIV/AIDS or measles). Projections can be made based on current exposure (such as smoking) for diseases with a long latency (such as lung cancer).

Projecting the potential health impact of climate change requires different methods because the objective is to estimate the impact of different types of (future) climate exposure on different (future) disease patterns at specific times in the future. At the simplest level, the burden of disease attributable to climate change can be calculated as:

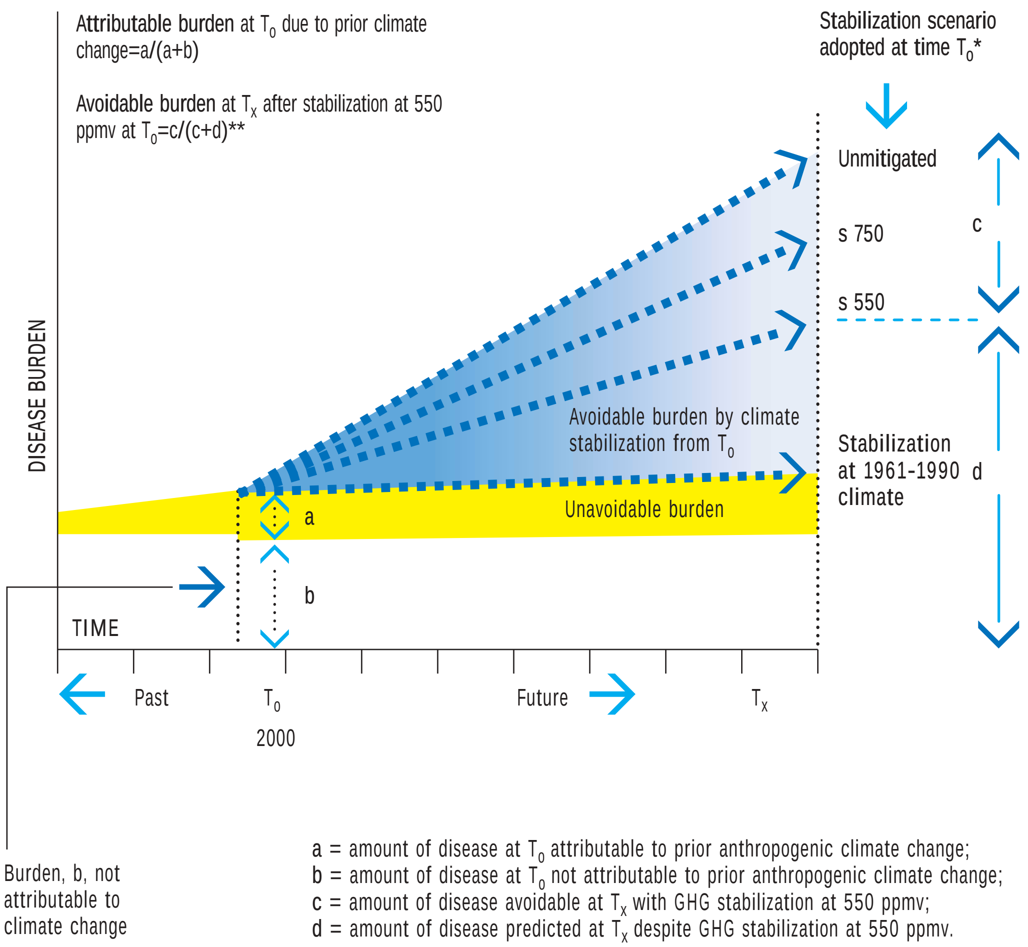
> Attributable burden = (estimated burden of disease under climate change scenario) – (estimated burden of disease under a baseline climate, such as that in 1961–1990).

Using this scenario-based approach, nothing changes in the future world except the climate. Although this is unlikely to be realistic, for many reasons, it is a useful approach as it separates out the contribution of climate from other factors that determine the burden of disease, such as population growth, ageing and socioeconomic development.

In 2002, climate change was one of the types of environmental exposure analysed in the WHO comparative risk assessment of the global burden of disease (WHO, 2002a; Campbell-Lendrum et al., 2003; McMichael et al., in press). WHO developed comparative risk assessment to quantify the burden of disease from specific risk factors and to estimate the benefit of realistic interventions that remove or reduce these risk factors. For climate change, the exposure cannot be completely removed, as some amount of climate change is inevitable in the future because of the inertia of the climate and ocean systems (Fig. 4.3). The burden of disease was therefore estimated based on one "business-as-usual" scenario (projected emissions with no policy on climate) and two scenarios in which greenhouse gas emissions are reduced and greenhouse gas concentrations have stabilized at some acceptable level. Fig. 4.3 illustrates the definitions used in comparative risk assessment in relation to climate change. As with other risk factors considered in the comparative risk assessment, the aim is to consider the potential benefits of reducing the risk factor rather than taking adaptive action to reduce the impact.

Avoidable burden of climate change = (estimated burden of disease under a business-as-usual climate scenario) – (estimated burden of disease under a stabilization climate scenario).

Fig. 4.3. Application of definitions in comparative risk assessment for climate change



a = amount of disease at T_0 attributable to prior anthropogenic climate change;
b = amount of disease at T_0 not attributable to prior anthropogenic climate change;
c = amount of disease avoidable at T_x with GHG stabilization at 550 ppmv;
d = amount of disease predicted at T_x despite GHG stabilization at 550 ppmv.

*Dashed arrows represent total of burden after a given shift in risk distributions at T_0.
**Avoidable burden by T_x would be given by ratio of different shaded areas.

Source: McMichael et al., in press.

Models of the impact of climate on health have been developed for a limited range of health outcomes. These are described in the following chapters. The choice of model depends on several factors, such as the purpose of the study and the type of data available. Integrated health risk assessment uses any or all of these methods to forecast the potential impact of global climate change and other major environmental changes (such as population growth or urbanization) and policy responses upon human health. However, quantitative modelling is only one approach for describing future vulnerability to the potential health effects of climate change (see Chapter 2), and other methods are more appropriate for some outcomes.

Systematic literature review

Thorough review of the relevant literature is required to provide a solid basis for health impact assessment. Such a review identifies existing knowledge and key gaps. One approach is to convene an expert panel to conduct the review. It is important that the most appropriate experts be identified and that they represent a range of skills and subject areas that are required for the assessment. With respect to climate change, having academic experts in the various diseases of concern as well as a climatologist would be important.
Clearly defining a search strategy is important (Box 4.1). This would include specifying the search terms (such as exposure and outcome) and the databases that will be searched (Annex 2).

The types of literature to be included should be decided at the beginning of the review. The assessment may include unpublished data from official sources (such as health statistics). An experienced literature searcher familiar with the relevant public health subject area should ideally be hired to perform these activities. Comprehensive literature review requires time and money.

Gaining access to literature in countries with less well developed library and Internet systems or few literature or journal subscriptions may be difficult. A current WHO initiative is promoting access to international journals for developing countries. The Health InterNetwork was created to bridge the

Box 4.1. Specific steps of a literature search

1. Determine the scope of the literature review

1.1. Scope
- Inclusion criteria
- Exclusion criteria

1.2. Types of literature
- Inclusion criteria
- Exclusion criteria (such as excluding newspaper articles or non-peer-reviewed material)

2. Determine the sources of relevant literature

2.1. Primary sources (such as original peer-reviewed articles)

2.2. Secondary and tertiary sources (also called grey literature) such as review articles, reports, citations in journal articles, books, literature directories, Internet databases, newspapers, personal communications and unpublished data

3. Locate literature

4. Review and evaluate literature

4.1 Develop evaluation criteria

4.2 Evaluate each paper in relation to
- Methods used
- Relevance to local area
- Validity of findings

5. Synthesize knowledge

6. Identify research gaps

digital divide in health, ensuring that relevant information – and the technologies to deliver it – are widely available and effectively used by health personnel: professionals, researchers and scientists and policy-makers (see Annex 2).

Using scenarios to estimate future effects

Scenarios provide an important tool for estimating the potential impact of climate change on specific health outcomes. Scenarios do not predict future worlds or future climates. There are many ways of applying scenarios, which have been variously defined as:

- plausible and often simplified descriptions of how the future may develop based on a coherent and internally consistent set of assumptions about driving forces and key relationships;
- hypothetical sequences of events constructed for the purpose of focusing attention on causal processes and decision points; and
- archetypal descriptions of alternative images of the future, created from mental maps or models that reflect different perspectives on past, present and future developments.

Participatory methods are increasingly used for designing scenarios. The latest scenarios also contain both a strong narrative and a quantitative component (Box 4.2) (Nakicenovic & Swart, 2000). These two trends can complement and reinforce each other: a group of stakeholders with diverse knowledge, experiences and perspectives provides greater richness to scenarios, and appealing narratives underpinned by numbers can engage key stakeholders.

Climate scenarios

Climate scenarios are plausible representations of future climate that have been constructed for use in investigating the potential impact of climate change. Many national climate scenarios have been specifically constructed for national impact assessment. For example, the UKCIP02 scenarios were constructed for the United Kingdom impact and adaptation assessments, and guidance was provided for their implementation (Hulme et al., 2002). National or regional scenarios are recommended to be used if they are available.

Box 4.2. The IPCC scenarios: special report on emission scenarios (SRES)

The IPCC special report on emission scenarios (Nakicenovic & Swart, 2000) documents a suite of global development scenarios, which the IPCC may use as foundation for its Fourth Assessment Report. This means that those undertaking impact and adaptation studies will be actively encouraged to use these scenarios. The scenarios couple future emissions pathways to explicitly defined future paradigms of the world that have their own unique trends in population growth and socioeconomic development.

These scenarios are non-interventionist scenarios and imply no explicit climate policies to reduce emissions. The aim of the scenarios was to provide consistent input to climate models and impact models. All scenarios are considered equally possible, and there is no best guess.

The scenarios are presented in four storylines that represent mutually consistent characterizations of future states of the world during the 21st century, including demographic and economic development, energy use and greenhouse gas emissions, together with associated changes in climate and sea level. Regional differences and interactions, especially between developing and industrialized countries, are also assessed.

A climate scenario is not a climate projection or prediction. Climate projections are the results of experiments using a climate model driven by scenarios of greenhouse gas emissions and alone rarely provide sufficient information to estimate the future impact of climate change. Model output commonly has to be manipulated and combined with observed climate data to be usable within the research communities studying vulnerability, impact and adaptation. For further information on climate scenarios, see Houghton et al., (2001). Table 4.2 summarizes the role of various types of climate scenarios.

Ensuring consistency in the methods used to study climate impact is important so that the results can be compared and evaluated. This includes the time periods used in the studies, both for the baseline (current climate) and future climates. The climate averaged over the 30-year period 1961–1990 is therefore recommended to be used as the baseline climate for climate impact studies, as the vast majority of research undertaken has used this period. Although WMO and climatologists have recently revised the climate normal, the 30-year period that best represents the current climate, to 1971–2000, it is not recommended that these data be used. Similarly, the research communities studying vulnerability, impact and adaptation within the IPCC have predominantly used three standard 30-year averaged periods for future assessment: 2010–2039 (30 years centred on the 2020s), 2040–2069 (30 years centred on the 2050s) and 2070–2099 (30 years centred on the 2080s).

Climate scenarios continue to need to improve temporal resolution (to examine variability and extremes) and spatial resolution. This need for information with higher resolution has to be balanced with the fact that the scale of information taken from the climate models for scenario development often exceeds the reasonable resolution of accuracy of the models themselves. Data for the construction of climate scenarios and further guidance information on the use of climate scenarios are available from the IPCC Data Distribution Centre (Annex 2). Obtaining expert advice from a climatologist is strongly recommended before using any climate information (scenarios or instrumental).

A climate scenario is constructed from climate model experiments using the following steps.

- Compute the difference (such as air temperature) or ratio (such as precipitation and solar radiation) between the climate model control run (unforced) and the climate model forced runs at the model grid boxes coinciding with the area of interest (see comments within Houghton et al., (2001), Chapter 10 on the use of output for a single relative to a cluster of grid boxes).

- Use change values to adjust the observed climate for the baseline period using the current climate as defined by the 1961–1990 period for the future period(s) of interest (2020s, 2050s and/or 2080s).

Methods for incorporating high-resolution information into climate scenarios include: regional climate modelling, statistical downscaling and high-resolution and variable-resolution time-slice techniques using an atmospheric-ocean general climate model. Once again, see Houghton et al., (2001) section 13.4 for more details on these methods.

The scenarios used in the assessment should incorporate both "high" emissions (leading to upper limits of the projections of changes in climate) and scenarios in which emissions are reduced by specific climate policies (mitigation). Stabilization scenarios refer to emissions scenarios in which the concentration of carbon dioxide (CO_2) is stabilized at a given time point (the current global mean concentration of CO_2 is around 370 ppm). For example, an emissions pathway that stabilizes CO_2 concentrations at 750 ppm by the 2030s delays by around 50 years the 2050 temperature increases under unmitigated emissions (Arnell et al., 2002). Using this approach would allow some assessment of the benefits of a climate mitigation policy. However, addressing the upper limits of the climate change projections may be most appropriate when planning adaptation measures. For example, a report on effects on small islands recommended planning for the worst-case scenario (Sear et al., 2001).

TABLE 4.2. CLIMATE SCENARIOS THAT CAN BE USED IN HEALTH IMPACT ASSESSMENT

Scenario type	Description or use
Incremental	Test system sensitivity Identify key climate threshold
Analogue	
Instrumental	Explore vulnerability and some types of adaptive capacity
Spatial	Extrapolate climate and population relationships Pedagogic
Climate model based	
Direct output of an atmosphere–ocean global climate model	Starting-point for most climate scenarios Large-scale response to anthropogenic forcing
High-resolution or stretched grid (atmosphere global climate model)	Provide high-resolution information at global or continental scales
Regional models	Provide high-spatial-resolution or high-temporal-resolution information
Statistical downscaling	Provide point or high-spatial-resolution information
Climate scenario generators	Integrated assessments Explore uncertainty Pedagogic
Weather generators	Generate baseline climate time–series Alter higher-order moments of climate Statistical downscaling
Expert judgement	Explore probability and risk Integrate current thinking on changes in climate

Note that a combination of methods may be used (such as regional modelling and a weather generator).

Source: adapted from Houghton et al., (2001).

Population scenarios

Population projections are available from a variety of national and international sources. National population projections are available from a central government agency in most countries. These are likely to include age-specific and other relevant demographic information. However, projections may not be available for time periods beyond 2020.

Global, regional, national and gridded population scenarios for the SRES illustrative emission scenarios (Box 4.2) will be available on the web site of the Center for International Earth Science Information Network (CIESIN) (Annex 2), based on the Gridded Population of the World version 2. The national and gridded projections are derived from United Nations projections. The population grid (0.5° by 0.5°) and country-level averages for individual years from 2000–2100 are available as well as for the three standard periods (2020s, 2050s and 2080s) to match the climate scenario information available on the IPCC Data Distribution Centre. Guidelines for use of these scenarios are being developed and will be made available on the CIESIN web site. This guidance and the data are also expected to be incorporated onto a CD-ROM together with climate change scenario information. A word of caution – CIESIN has downscaled using relatively simple methods that do not take into account different rates of growth of countries within the SRES regions. SRES scenarios are not intended to be used for assessment at the national level because better sources of population projections are likely to be available. National projections of population can be developed that are compatible with the scenarios of the emissions of greenhouse gas used to force the climate scenarios (Box 4.2).

Several alternative data sets are available that map the current population on a grid (see Annex 2). These can be used with geographical information systems to estimate changes in the size of the population at risk for a given climate scenario.

Socioeconomic scenarios

Adaptation to climate change will take place in a dynamic social, economic, technological, biophysical and political context that varies over time and location and across communities. It is essential that adaptation be included in estimates of future impact. Adaptive capacity is the ability of a system to adjust to climate change (including climate variability and extremes), to moderate potential damages, to take advantage of opportunities or to cope with the consequences. These features of communities and regions that appear to determine their adaptive capacity include economic resources, technology, information and skills, social infrastructure, social institutional development and equity in terms of the arrangements governing the allocation of power and access to resources (Smit & Pilifosova, 2001).

Scenarios can be developed regarding possible changes in the adaptive capacity of the community of interest. In general, several variables can be identified that determine adaptive capacity and as well as the plausible states of these variables in the future. One method is to consider two or three states for the future:

- reduced capacity as a result of deterioration in one or more of the determinants of adaptive capacity;
- similar capacity with little or no change in the determinants; and
- increased capacity as a result of an enhancement in one or more of the determinants.

As in all scenarios, the basis and assumptions for constructing these scenarios must be consistent and plausible in light of the chosen future view (Table 4.3, Box 4.2). The topic-specific Chapters 5 to 12 address some specific aspects of adaptive capacity.

Several initiatives are currently developing national-level indicators of adaptive capacity. Some global

TABLE 4.3. TYPES OF NON-CLIMATE SCENARIOS THAT CAN BE USED IN HEALTH IMPACT ASSESSMENT

Type	Quantitative	Scale	SRES link	Example
Gross domestic product per capita or related economic indicators	Yes	Global	Driven	Malaria (Tol & Dowlatabadi, 2001), disasters (Yohe & Tol, 2002) and diarrhoeal disease (Campbell-Lendrum et al., 2003)
Target-based scenario, reflecting an achievable level of disease prevalence and incidence	Yes	Global or local	Can be linked	Millennium Development Goals Millennium Ecosystem Assessment National targets
Business as usual, based on current levels of disease or current trends	Yes	Global or local	Can be linked	High incidence of HIV infection, high incidence of malaria, etc.
Ecological, such as presence of vector	Yes	Local	Can be linked	Portuguese national assessment (Casimiro & Calheiros, 2002)
Environmental change scenarios	No	Local	Can be linked	Syndromes of environmental degradation promoted by the Potsdam Institute for Climate Impact Research (Petschel-Held et al., 1999; German Advisory Council on Global Change, 1997)

assessments use gross domestic product (GDP) per capita as a national indicator of adaptive capacity because the SRES scenarios include a range of GDP projections (Yohe & Tol, 2002). Although SRES scenarios have been downscaled to national projections, they are not appropriate for use at the national level but must be re-aggregated for regional or global assessments. However, the adaptive capacity scenarios should be evaluated in relation to the SRES storylines if the SRES climate scenarios are used. For a national assessment, GDP or income scenarios need only be compatible with the SRES scenarios.

The economic projections used in SRES are mostly based on national accounts, which measure income using an internationally tradable currency, such as US dollars. Data sets using this measure are comprehensive, widely accessible and available for several decades. Alternative economic scenarios using income measured in purchasing power parity (PPP) account in part for different national price structures that particularly charge the costs of non-traded goods and services. However, PPP data sets are more limited than market exchange rate data sets (such as GDP per capita in US dollars) and this reduces their utility. The choice of method depends on the objectives and methods of the risk assessment.

Assessors using scenarios should be aware of the advantages and disadvantages, as outlined in Box 4.3.

Box 4.3. Advantages and disadvantages of scenarios

Scenarios are useful because they:

- *articulate key considerations and assumptions:* scenarios can help to imagine a range of possible futures if a key set of assumptions and considerations is followed;
- *blend quantitative and qualitative knowledge:* scenarios are powerful frameworks for using both data and model-produced output in combination with qualitative knowledge elements;
- *identify constraints and dilemmas:* exploring the future often yields indications for constraints in future developments and dilemmas for strategic choices to be made;
- *expand thinking beyond the conventional paradigm:* exploring future possibilities that go beyond conventional thinking may result in surprising and innovative insights.

There are many disadvantages in using scenarios:

- *lack of diversity:* scenarios are often developed from a narrow, disciplinary-based perspective, resulting in a limited set of standard economic, technological and environmental assumptions;
- *extrapolations of current trends:* many scenarios have a "business-as-usual character, assuming that current conditions will continue for decades;
- *inconsistency:* the sets of assumptions made for different sectors, regions or issues are often not consistent with each other;
- *lack of transparency:* key assumptions and underlying implicit judgements and preferences are not made explicit. For example, it may not be clear which factors or processes are exogenous or endogenous and to what extent societal processes are autonomous or influenced by concrete policies.

Summary measures of health

Comparing effects across a wide range of health outcomes and across mortality and morbidity outcomes is difficult. For these reasons, several aggregate measures have been developed, but these require information on future morbidity and premature mortality. Although generating such outcomes in risk assessment is desirable, this may not be possible because of limitations in data availability and model development.

- Potential years of life lost measures the years of life lost due to premature death. It measures the relative impact of various diseases and lethal forces on society. The potential years of life lost highlights the loss to society as a result of youthful or early deaths.
- Disability-adjusted life–years (DALYs) measures both the burden of disease and the effectiveness of health interventions, as indicated by reductions in the burden of disease. It is calculated as the present value of the future years of disability-free life that are lost as the result of the premature deaths or cases of disability occurring in a particular year. It reflects functional limitation and premature mortality and is adjusted for age, gender and duration of illness.
- Quality-adjusted life–years (QALYs) measures combine mortality and the quality of life gained: the outcome of treatment measured as the years of life saved, adjusted for quality. This is calculated by estimating the total years of life lost to disease or gained by treatment and weighing each year with a quality-of-life score (from 0, representing the worst health possible to either 1 or 100, representing the best health possible) to reflect the quality of life in that year.

WHO has a database of DALYs and the cost of selected interventions to gain DALYs. Information on how to calculate DALYs can also be obtained from the WHO web site (see Annex 2).

Describing and quantifying uncertainty

Studies of climate impact span a wide range of approaches, from simple correlation of variables to increasingly complex integrated assessment of multiple stresses. Many of these studies attempt to integrate data of varying quality from multiple disciplines. There is always a danger that assessments can undermine their own public credibility because of simplifying assumptions. Managing uncertainty is just as important as reducing uncertainty.

Assessing health outcomes in relation to climate change is a complex task that must accommodate the multiple types of uncertainty that compound across the antecedent environmental and social changes. Many different types of uncertainty relate to the health effects of climate change (Table 4.4). A major source of uncertainty relates to the degree to which future emissions of greenhouse gases will change radiative forcing over the coming century. Greenhouse-gas emissions are driven by complex factors such as population growth, economic growth and energy policy. Addressing this level of uncertainty is limited to the emissions scenarios that are available (Box 4.2). This section addresses uncertainty in relation to health impact assessment.

TABLE 4.4. EXAMPLES OF SOURCES OF UNCERTAINTY

Source of uncertainty	Examples
Problems with data	• Missing components or errors in data • "Noise" in data associated with bias or incomplete observations • Random sampling error and biases (nonrepresentativeness) in a sample
Problems with models (relationships between climate and health)	• Known processes but unknown functional relationships or errors in structure of model • Known structure but unknown or erroneous values of some important parameters • Known historical data and model structure but reasons to believe that the parameters or model or the relationship between climate and health will change over time • Uncertainty regarding the predictability of the system or effect • Uncertainty introduced by approximating or simplifying relationships within the model
Other sources of uncertainty	• Ambiguously defined concepts or terms • Inappropriate spatial or temporal units (such as in data on exposure to climate or weather) • Inappropriateness of or lack of confidence in the underlying assumptions • Uncertainty resulting from projections of human behaviour (such as future disease patterns or technological change) in contrast to uncertainty resulting from "natural" sources (such as climate sensitivity)

Source: adapted from McCarthy et al., (2001), p. 127.

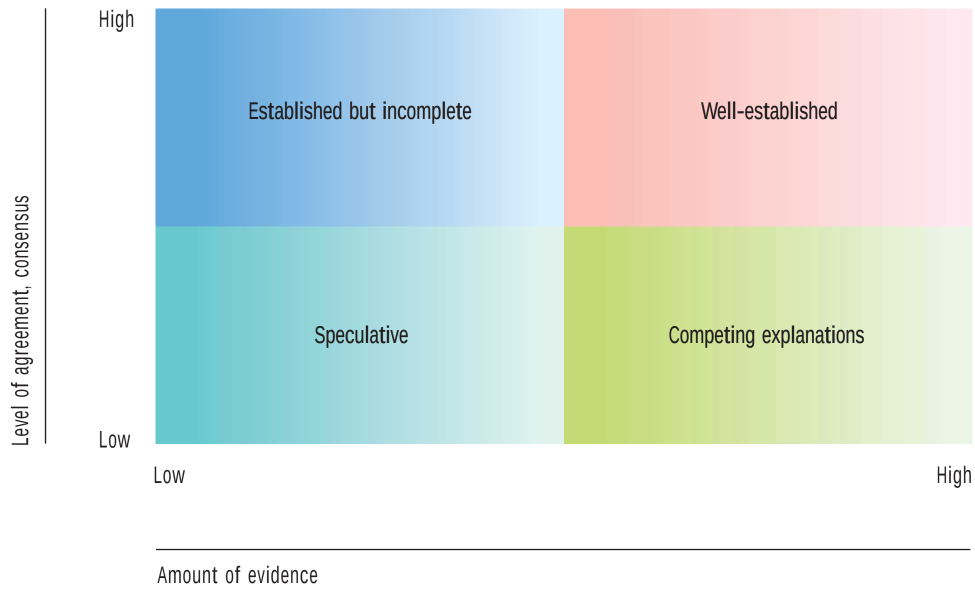
Options for consistency and clarity

The IPCC developed guidance for describing uncertainty to improve communication across disciplines and between decision-makers, the public and scientists (Moss & Schneider, 2000). We recommend the IPCC approach for assessing, characterizing and reporting uncertainty within national health impact assessment.

The following qualitative descriptions should be used to assess and report the quality or level of scientific understanding that supports a given conclusion (Fig. 4.4) (McCarthy et al., 2001).

- Well established. Models incorporate known processes; observations are consistent with models; or multiple lines of evidence support the finding.
- Established but incomplete. Models incorporate most known processes, although some parameters used may not be well tested; observations are somewhat consistent but incomplete; current epidemiological estimates are well founded but the possibility of changes over time in governing processes is considerable; or only one or a few lines of evidence support the finding.
- Competing explanations. Different model representations account for different aspects of observations or evidence or incorporate different aspects of key processes, leading to competing explanations.
- Speculative. Conceptually plausible ideas that have not received much attention in the literature or that are laced with difficulty in reducing uncertainty.

Fig. 4.4. Qualitative types of uncertainty



Source: Moss & Schneider (2000).

More formal methods have also been developed to quantify uncertainty. Authors should explicitly state what approach is being used for a specific estimate. The Bayesian approach is based on the theory that the probability of an event is the degree of belief that exists among the leading authors and reviewers that the event will occur, given the observations and modelling results and theory currently available. Scientists conducting health impact assessment are therefore encouraged to provide probability distributions for specific estimates, as this is preferable to having users less expert in the topic make their own determinations. The conclusions in the Third Assessment Report of the IPCC were assigned confidence levels according to a 5-point scale derived from the Bayesian approach (Fig. 4.5). A quantitative scale was agreed to ensure that the probabilities were consistently reported. For example, "high" confidence referred to probabilities of 67–95%, and "very high" confidence referred to probabilities greater than 95%.

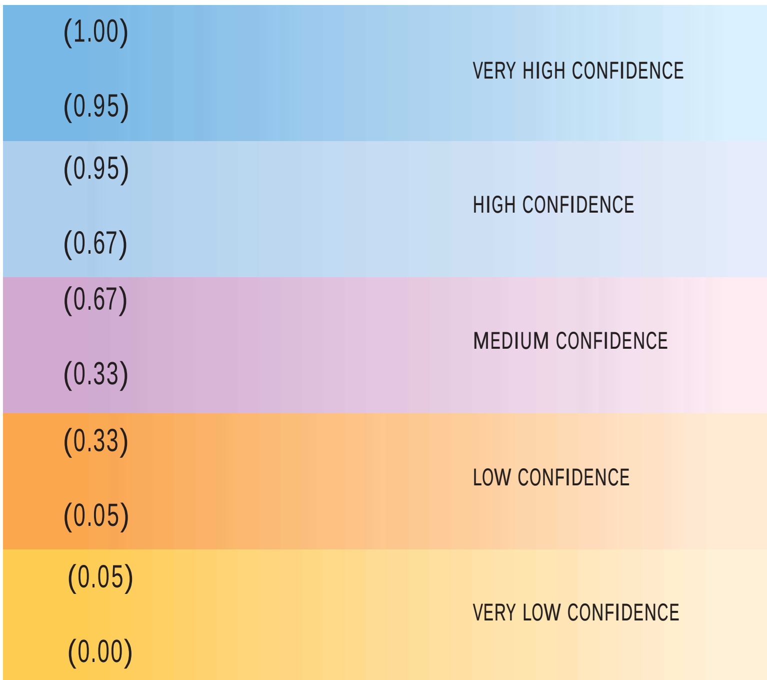
Epidemiological approaches to evaluating, interpreting and presenting uncertainty in health risk assessment have also been developed (Annex 2). The specific content of the uncertainty of analysis of climate and health depends on the objectives of the assessment. However, the following should be addressed in addition to the standard measures of statistical precision (P-values and confidence intervals):

- qualitative estimates of uncertainty in the effect (exposure–response) estimates, which may be due to random error, bias and confounding (quantitative methods have not yet been developed);

- uncertainty around the key assumptions, which should be investigated using sensitivity analysis, including the choice of statistical or biological model; and

- uncertainty in the baseline estimates of burdens of disease or population at risk.

Fig. 4.5. Confidence levels assigned by the IPCC



Source: Moss & Schneider (2000).

5. Direct effects of heat and heat-waves

What is the evidence that climate change could affect temperature-related mortality and morbidity?

The health effects of exposure to heat and cold have been studied in several populations (Curriero et al., 2002; McMichael et al., 2003a). Physiological and biometeorological studies have shown that high and low temperatures affect health and well-being. High temperatures cause well described clinical syndromes such as heat stroke, heat exhaustion, heat syncope and heat cramps. Many causes of death increase during periods of higher temperatures (heat-waves), especially those from cardiovascular and respiratory disease in temperate countries.

Epidemiological studies have described seasonal fluctuation in mortality and morbidity. Most temperate countries have a strong seasonal pattern, with mortality peaking in winter. Populations with tropical climates have considerably less seasonality in mortality patterns.

Methods for estimating the effect of the thermal environment on mortality and morbidity

The preferred epidemiological method for estimating the impact of temperature on mortality is time–series studies of daily mortality, following methods developed for air pollution studies (Schwartz et al., 1996). These methods are considered sufficiently rigorous to assess short-term (day-to-day or week-to-week) associations between the environmental exposure and mortality if adjustment is made for longer-term patterns in the data series. The relationship between temperature and mortality can be derived using a regression model that quantifies the extent to which day-to-day variability in deaths is explained by variation in temperature. An important step is to remove the seasonal component of the data series so that only the short-term (day-to-day) associations are left. This is done because non-temperature seasonal effects are thought to strongly contribute to the seasonal pattern of mortality. Several approaches can be used to adjust for season:

- indicators for month;
- Fourier methods that fit sine and cosine patterns to model seasonal cycles in the series; and
- smooth or moving averages, such as the LOESS (a weighted moving average) or smoothing splines.

The relationship between temperature and mortality is often nonlinear across the whole temperature range. Most studies report a linear relationship above and below a minimum mortality temperature (or range of temperatures). Thus, the temperature–mortality relationship in temperate countries is described as nonlinear (V-shaped or U-shaped) where a minimum mortality point (or threshold) is identified (Fig. 5.1). The threshold value and the slope of the temperature–mortality relationship can be quantified (Curriero et al., 2002; McMichael et al., 2003a; Pattenden et al., 2003). Populations in tropical or subtropical climates are likely to show a different temperature–mortality relationship.

Quantifying temperature-related mortality requires daily counts of deaths, ideally grouped by underlying cause of death, and temperature measured at a similar temporal and geographical resolution. Mortality data are available from national or regional registries in some places. However, the data may not be available in digital format. Coding of cause of death also varies between countries and may be incomplete. Attention should be paid to the accuracy with which the date of death is recorded.
The impact of individual heat-wave events can be estimated using episode analysis. This method cannot be applied to estimate future populations at risk from climate change. Studies of heat-wave events can be used to inform the adaptation assessment.

Box 5.1. Use of meteorological data

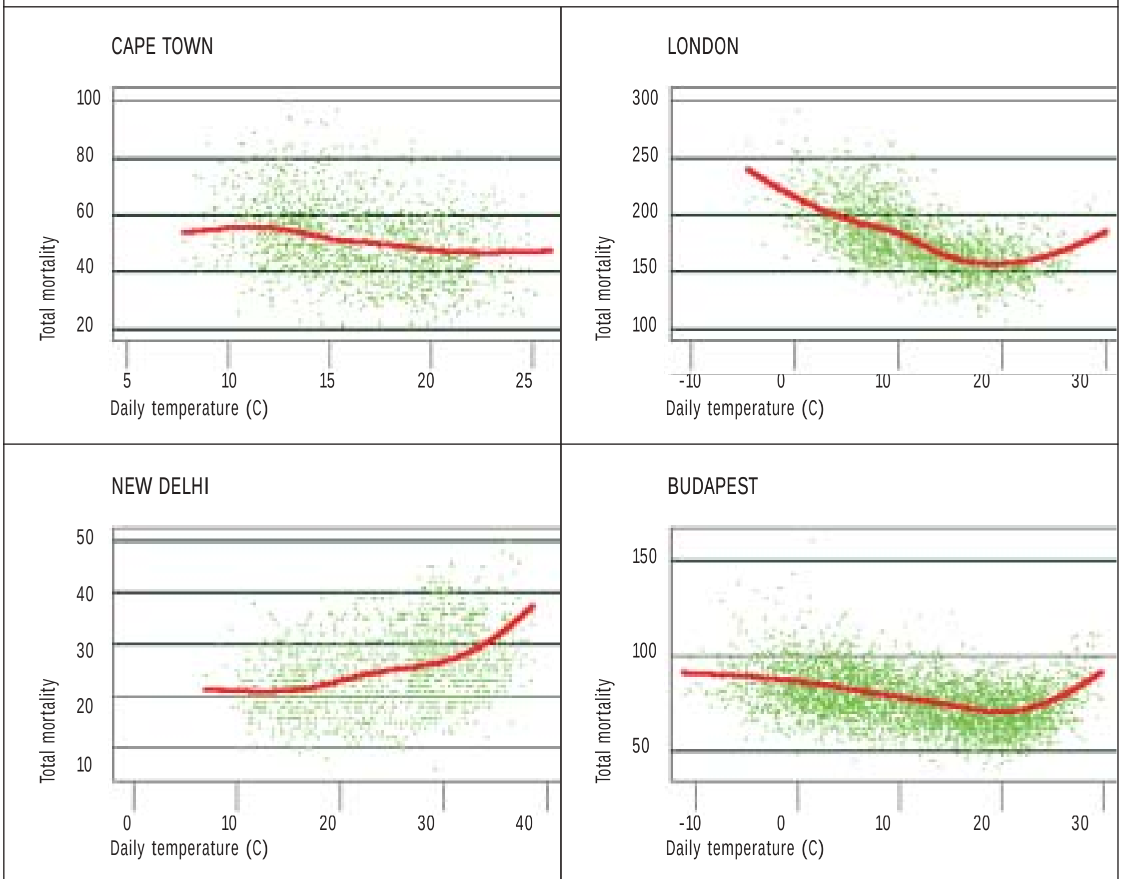
Daily meteorological variables can be obtained for stations near the population under study. In cities, this is not usually a problem. In rural areas, however, finding a station nearby may be difficult.

As a general rule, if daily data are used, temperatures are homogeneous within about a 300-km radius if no local landscape features affect climate, such as mountains, watercourses or coastal regions. For monthly data, temperatures are similar up to 1200 km in radius. Precipitation is more localized in time and space. Such data should therefore not be used beyond a 50-km radius (daily values) or 400-km radius (monthly). For these reasons, care should be taken when aggregating variables such as precipitation and humidity over large areas.

Other historical climate data sets are available when data from stations that are missing have been interpolated or supplemented with modelled data (also called re-analysis data). Although these sources are readily available online, using local observed data is preferable if possible. Using reanalysis data may give spurious results for studies of local effects.

Fig. 5.1. Relationship between temperature and mortality in Cape Town, London, New Delhi and Budapest

The red lines are the fitted values of the predictive model (unadjusted).
The green dots represent the crude mortality counts.



Sources: data from Health Department, Cape Town Metropolitan Council, South Africa; Office for National Statistics, London, United Kingdom; World Bank; and National Institute of Environmental Health, Budapest, Hungary.

Methods for estimating future health impact

Research papers or assessments may have investigated the potential impact of climate change on the frequency of temperature extremes in a particular region or city.The impact of climate change on the urban heat island has been estimated. Modelling studies (Fig.5.2) have estimated the impact of climate scenarios on a range of biometeorological indices, such as the heat index or perceived temperature (Table 5.1).

TABLE 5.1. HEAT-WAVES AND CLIMATE CHANGE: MAPPING HEAT STRESS INDICATORS IN SPACE OR TIME

Study	Model	Model output	Region
Barrow & Hulme (1996)	SPECTRE	Probabilities of daily maximum and minimum temperate extremes (such as maximum temperature > 20 °C in July)	Nine sites in the United Kingdom
Karacostas & Downing (1996)	Extreme Values model EXAM	Number of days that exceed the temperature humidity index threshold	Oxford, United Kingdom and Thessaloniki, Greece
Gawith et al., (1999)	Extreme Values model EXAM	Number of days that exceed the temperature humidity index threshold	Oxford, United Kingdom and Thessaloniki, Greece
Hulme et al., (2002)	Uses daily global climate model output	Number of days with temperature > 23 °C in summer (temperature greater than 90th centile of distribution)	Southern United Kingdom
Wagner (1999)	Global climate model output	Large increase in the frequency of continuous days with extreme high temperature	Berlin, Germany

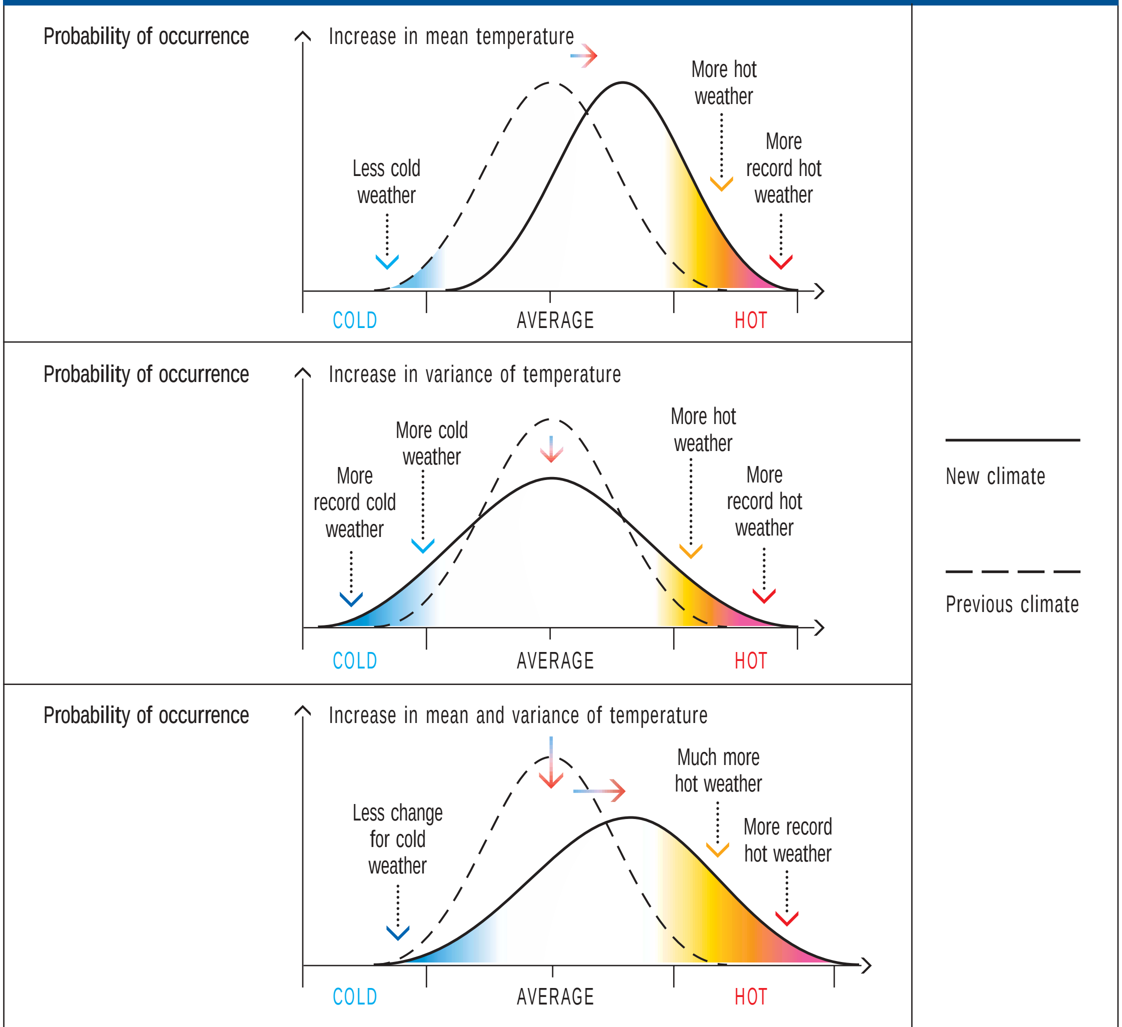
Several assessments have estimated the future burdens of heat and cold stress on mortality.An important source of uncertainty is how climate change could affect the daily thermal environment in a given locality, such as a city or town. Methods are available that downscale climate scenarios to the local level, and these should be explored in consultation with a meteorological expert (see Table 5.1).

A proportion of the "acute" effect of heat episodes on mortality may be the hastening of death in already ill people by a few days or weeks.This mortality displacement effect can sometimes be seen in the lower than expected mortality immediately following a heat-wave. The key question is what proportion of deaths was brought forward by more than a matter of days or weeks? Assumptions on short-term mortality displacement should be clearly stated if the risk assessment quantifies mortality outcomes.

The population-attributable fraction can be estimated from the slope of the temperature–mortality relationship and the proportion of degree–days that occur above the threshold temperature for each climate scenario. Simply directly applying the change in mean temperature to the temperature–mortality relationship is not recommended.

A key assumption in estimating future impact is whether the population acclimatizes to changes in

Fig. 5.2. Climate change and changes in the distribution of daily temperatures



Source: Watson et al., (2001).

climate. Changes in population vulnerability and adaptive processes are predicted to substantially influence the burden of mortality and morbidity attributable to the direct effects of thermal extremes. For example, the WHO assessment of the global burden of disease incorporated an assumption regarding acclimatization of the populations to the changing climate that reduces the impact of climate change (Campbell-Lendrum et al., 2003).

This study assumed that the threshold temperature (minimum mortality point) is increased as populations adapt to a new climate regimen, reflecting the physiological and behavioural acclimatization that can take place over the time scale of decades. Changes in the threshold temperature (minimum mortality point) were region- and scenario-specific and reflected the rate of warming experienced. Changes were assumed to be proportional to the projected change in average summer temperature (mean in June, July and August).

This assessment further assumed that the shape (slope) of the temperature–mortality relationship did not change over time. However, this is unlikely to be true, as the relationship reflects the adaptive capacity of the population, which is likely to change over time.

Milder winters may reduce cold-related mortality. The assessment should therefore address the potential benefits of climate change on temperature-attributable mortality.

Adaptation: strategies, policies and measures

Assessment of adaptation generates a range of strategies, policies and measures to address the potential health impact of heat and heat-waves. Ideally, this list will range from interventions that are theoretically possible at some future date to those that can be implemented practically in the short term. Policy-makers and decision-makers should be aware of possible interventions that could be available in the future to address heat and heat-waves so that appropriate action can be taken. This includes establishing research programmes to encourage the development of interventions that are not yet technically feasible or are too costly, instituting trials of the effectiveness of promising but undemonstrated interventions or changing policies or public attitudes for desirable interventions that are currently not socially acceptable.

The interventions that policy-makers choose to implement need to satisfy a number of requirements, including being effective in reducing the burden of disease, technically and economically feasible, socially acceptable and compatible with current policies. Typically, cost–benefit analysis will be conducted to demonstrate the value of the intervention. In addition, having coordination and collaboration across regions or countries on a specific issue may be desirable. Establishing a process of cross-boundary coordination in advance of a heat-wave will help to ensure a more effective response.

The following section briefly discusses some of the interventions that aim to reduce heat-related morbidity and mortality; this is intended only to illustrate some approaches. The appropriateness of a specific intervention depends on local circumstances, including the projected severity of heat-waves, the degree to which the population is affected by heat episodes, the age distribution of the population, the level and distribution of economic resources in the population, the proportion of the population that lives in urban centres, the type of housing and the systems in place (if any) to protect vulnerable groups during a heat-wave.

A common way of reducing heat-related mortality is implementing a weather-based heat-wave warning system. Each city needs to develop a different system based on that city's specific weather, the population's response to temperature extremes and the social infrastructure. Specific weather and health thresholds are determined and used to issue health warnings or advisories, with the warnings tailored to each population. These systems have been shown to be effective in a number of cities in the United States and are being pilot-tested in other countries (Koppe et al., in press).

New buildings are designed to have a long lifetime. Changing lifestyles and new technologies all have implications for building design. In addition, climate change is likely to result in an increasing number of extreme hot days; designing comfortable, energy-efficient and safe buildings is therefore a priority. The design should aim to limit both the frequency of high-temperature episodes inside the building and their indoor intensity and duration. Traditional building designs have evolved in harmony with the environment and usually provide adequate protection against heat. In recent decades, rapid urbanization seems to have led to an increase in poor building design in many cities. Thus, populations in these dwellings are less adapted and perhaps more vulnerable to heat episodes. People who live in informal dwellings in large cities also may be very vulnerable to weather extremes.

The urban heat island is defined as the difference in temperature between a city and the temperature of the surrounding rural area. This effect is greatest at night and during winter. The impact of heat-waves in cities is exacerbated by the heat island effect, which can help maintain high nighttime temperatures. Urban planners and decision-makers have a range of interventions from which to choose that are designed to reduce urban heat islands and thereby reduce the temperature exposure during heat-waves.

6. Air pollution

What is the evidence that climate change could affect air quality and thereby health?

Weather conditions influence air quality via the transport and/or formation of pollutants (or pollutant precursors). Weather conditions can also influence air pollutant emissions, both biogenic emissions (such as pollen production) and anthropogenic emissions (such as those caused by increased energy demand). Exposure to air pollutants can have many serious health effects. Long-term exposure to elevated levels of air pollution may have greater health effects than acute exposure. Current air pollution problems are greatest in cities in developing countries.

Epidemiological studies conducted in the 1980s and 1990s, combined with analysis of the health effects recorded during individual episodes of severely elevated air pollution levels, provide strong evidence for significant associations between exposure to air pollutants and various types of health effects (Table 6.1). Six standard air pollutants have been extensively studied in urban populations: sulfur dioxide,

TABLE 6.1. SELECTED AIR POLLUTANTS, SOURCES AND HEALTH EFFECTS

Pollutant	Sources	Health effects
Carbon monoxide	Biomass and fossil fuel combustion, cigarette smoke, vehicular emissions	Headache, nausea, dizziness, breathlessness, fatigue, low birth weight, visual disturbances, mental confusion, angina, coma, death
Ozone	Vehicular emissions, hydrocarbon release, fossil fuel combustion (primary pollutant)	Eye irritation, respiratory tract irritation, reduced exercise capacity, exacerbation of respiratory disease
Particulate matter	Biomass and fossil fuel combustion, cigarette smoke, vehicular emissions	Eye irritation, respiratory tract infections, allergies, morbidity and mortality from respiratory cardiovascular disease and cancer
Nitrogen oxides	Biomass and fossil fuel combustion, construction materials, industry, cigarette smoke, vehicular emissions	Eye irritation, respiratory tract infections (children are especially vulnerable), exacerbation of asthma, irritation of bronchi
Sulfur oxides	Biomass and fossil fuel combustion, industrial emissions	Respiratory tract irritation, impaired pulmonary function, exacerbation of cardiopulmonary disease
Pollen	Flowering plants	Exacerbation of allergic rhinitis, asthma and other atopic diseases

Source: adapted from Yassi et al., (2001).

ozone, nitrogen dioxide, carbon monoxide, lead and particulate matter. Other important air pollutants include toxic chemicals (such as benzene and mercury) and biological particles (such as some pollen and mould spores).

Biological particles such as pollen and mould also affect health. There is some evidence from Europe that the average length of the growing season in Europe has increased by 10–11 days over the last 30 years (Huynen et al., 2003). The pollen season is starting and peaking earlier, and this is more pronounced in species that start flowering earlier in the year. The duration of the pollen season has been extended in some summer and late-flowering species.

Evidence is growing that climate change might facilitate the geographical spread of specific plant species to new areas as they become climatically suitable. Warming is likely to further cause an earlier onset and may extend the duration of the flowering and pollen season for some species (such as grasses and weeds). Some species, such as ragweed and mugwort, present particular risks for health and require land-use measures, maintenance of public areas or eradication. The impact of climate change on the incidence, prevalence, distribution and severity of allergic disorders is still uncertain. However, there is no current evidence that climate change will affect the prevalence or incidence of asthma (Huynen et al., 2003).

Methods for estimating the health effects of exposure to air pollutants

Many studies have been undertaken that quantify the relationship between air pollutants and health outcomes, mortality and morbidity, in a variety of populations. Such studies are not recommended to be undertaken within the remit of a climate change assessment. There is now an established method for quantifying the health effects of exposure to air pollutants (WHO Regional Office for Europe, 2000). A WHO working group concluded (WHO Regional Office for Europe, 2000) that the most complete estimates of both attributable numbers of deaths and average reductions in life span associated with exposure to air pollution are based on cohort studies. Risk assessment should carefully evaluate whether applying the exposure–response relationship from one population to another is appropriate. There are problems with applying relationships from cities with low pollutant levels to cities with high pollutant levels, such as those in many developing countries.

Time–series methods can be used to estimate the impact of airborne dust (windblown soil) on health outcomes. Larger particles have fewer health effects than do fine particles. However, little epidemiological research has been performed on this exposure.

Methods for estimating future health impact

Studies relevant to climate change and air pollution can be divided into two general categories:

- those that estimate future levels of air pollution; and
- those that estimate the combined impact of weather and air pollutants on health outcomes.

Future changes in air quality depend on many factors, especially emissions and the availability of precursor pollutants. In urban areas, the main source of primary air pollutants is motor vehicles. The concentrations of air pollutants are seasonal. During winter in temperate countries, air pollution episodes are often caused by stagnant weather conditions. Ozone levels are highest in hot sunny weather, when ultraviolet light interacts with nitrogen dioxide and volatile organic compounds from motor vehicles and other industrial sources. Summer ozone episodes often affect a larger region.

The background levels of ozone vary seasonally and from region to region. The background ozone concentration has steadily increased in most regions of the world. If other factors are unchanged, an increase in summer temperatures may increase the concentration of ground-level ozone and increase the frequency of episodes of high pollutant concentration. However, the magnitude of the effect is uncertain. For other pollutants, the effects of climate change and/or weather have been less well studied.

Modelling current and future pollutant concentrations is complex. Future emissions are estimated using linked models of energy use and economic activity. Atmospheric chemistry models need to be linked to emissions projections to estimate future air quality at the appropriate geographical and temporal resolution. Research is needed on the potential effects of climate change on air quality, including the effects on daily levels, seasonal patterns and changes in geographical distribution. At the time of writing, a few such research projects were being undertaken. Emission scenarios that are associated with a large increase in the emissions of greenhouse gases (see Box 4.2 on the SRES scenarios: the A1FI and A2 scenarios are associated with high background levels of tropospheric ozone) also project a significant increase in the background levels of tropospheric ozone, especially in Europe (northern middle latitudes) (Houghton et al., 2001).

The United Kingdom assessment addressed future air pollutant exposure under climate change (Table 6.2) (United Kingdom Department of Health, 2002). Projections of winter pollution episodes were developed based on information on minimum temperature and minimum wind speed from a global climate model. The number of days per decade with poor dispersion conditions was calculated for each emission scenario and time period (Table 6.2). Projections of summer pollutant episodes were derived from information on days with high temperatures (> 25 °C) and low wind speed.

TABLE 6.2. CHANGES IN LEVELS OF AIR POLLUTION LIKELY TO BE ASSOCIATED WITH CLIMATE CHANGE IN THE UNITED KINGDOM

Pollutant	2020s	2050s	2080s
Particles	Large decrease	Large decrease	Large decrease
Ozone (assuming no threshold)[a]	Large increase (by about 10%)	Large increase (by about 20%)	Large increase (by about 40%)
Ozone (assuming a threshold)[a]	Small increase	Small increase	Small increase
Nitrogen dioxide	Small decrease	Small decrease	Small decrease
Sulfur dioxide	Large decrease	Large decrease	Large decrease

[a] *There is some debate about whether or not there is a threshold for the health effects of ozone, so estimates were calculated for both assumptions.*

Source: United Kingdom Department of Health (2002).

Quantitative estimates of excess hospital admissions and premature deaths attributable to climate change were derived from published exposure–response relationships for England and Wales, consistent with the approach developed by the Committee on the Medical Effects of Air Pollution (1998) of the Department of Health.

Adaptation: measures, strategies or policies

Air pollution is usually controlled by air quality standards: acceptable concentrations of air pollutants. Reducing the emissions that lead to outdoor air pollution is considered the most effective intervention. The WHO Guidelines Air Quality (WHO, 2000) provides a framework for countries to improve their air quality by long-term intersectoral preventive activities (environmental health management).

Action taken to reduce greenhouse gas emissions is very likely to benefit population health (Barker & Srivastava, 2001; Davies et al., 2000). Fossil fuel combustion releases both local hazardous air pollutants (especially particulate matter, ozone precursors, nitrogen oxides and sulfur dioxide) and greenhouse gases. Hence, policies to reduce greenhouse gas emissions by reducing vehicle emissions or other transport policy measures could benefit health (see also Metz et al., (2001), section 9.2.8.4). Controlling road traffic could also benefit health through reductions in road traffic accidents and a possibly a decrease in sedentary lifestyles.

7. Disasters: floods and windstorms

What is the evidence that climate change could affect the health impact of weather disasters?

Climate change is likely to have major effects on human health via changes in the magnitude and frequency of extreme events: floods, windstorms and droughts. Climate change projections are based on the anticipation of increasing means or norms. Global or regional climate models are not easily able to forecast future climate variability, whether daily, interannual or decadal. Changes in extreme events can be forecast by estimating changes in probability distributions (Downing et al., 1996; Palmer & Raisenen, 2002; Campbell-Lendrum et al., 2003; Maheepala & Perera, 2003).

This chapter primarily addresses the impact of floods and windstorms (including tropical cyclones), but the methods described can be applied to other types of disasters. The effects of drought are primarily associated with food security (Chapter 11) and increasing waterborne disease (Chapter 9). The melting of permafrost in mountain regions is likely to increase the risk of avalanches of stones and mud.

Weather disasters affect human health by causing considerable loss of life. Extreme weather events cause death and injury directly. Following disasters, deaths and injuries can occur as residents return to clean up damage and debris. The nonfatal effects of natural disasters include:

- physical injury;
- reduced nutritional status, especially among children;
- increases in respiratory and diarrhoeal diseases because of crowding of survivors, often with limited shelter and access to potable water;
- effects on mental health that may be long lasting in some cases;
- increased risk of water-related diseases from disruption of water supply or sewerage systems; and
- exposure to dangerous chemicals or pathogens released from storage sites and waste disposal sites into floodwaters.

Bereavement, property loss and social disruption may increase the risk of depression and mental health problems. Substantial indirect health impact can also occur because of damage to the local infrastructure (such as damage to clinics and roads) and population displacement.

Methods for estimating the health effects of disasters

Information on the impact of disasters may be available from the national meteorological agency or the national agency for disasters or emergency services. Global and regional agencies (such as EM-DAT, the Emergency Events Database of the Centre for Research on the Epidemiology of Disasters, or WMO) and reinsurance companies also collect information on disasters, but this is usually limited to the total number of deaths attributed to an event. The total health impact of a disaster is difficult to quantify, because injuries and secondary effects are poorly reported and communicated.

Current vulnerability to weather disasters needs to be described in terms of total and age-specific mortality and morbidity. Determining whether this vulnerability is increasing or decreasing is then important. Projecting the future impact of disasters on health outcomes is not advisable because the projections and future vulnerability are highly uncertain under climate change.

Floods

In vulnerable regions, the concentration of risks with both food and water insecurity can make the impact of even minor weather extremes (floods and droughts) severe for the households affected (Table 7.1). The only way to reduce vulnerability is to build infrastructure to remove solid waste and wastewater and to supply potable water. No sanitation technology is "safe" when covered by floodwaters, as faecal matter mixes with floodwaters and is spread wherever the floodwaters run.

Epidemiological studies of flood events can be undertaken in relation to the following outcomes to compare incidence in the pre- and post-flooding situations:

- injuries
- infectious diseases, especially skin, gastrointestinal and respiratory infections; and
- mental disorders: increases in common anxiety and depression disorders.

Routine surveillance may provide data on episodes of infectious disease both before and after a flood. Obtaining accurate information on disease incidence or prevalence before the flood may not be possible. Detection may increase after the flood and bias the estimate because surveillance activity is enhanced. Injuries are not routinely recorded in relation to flood events. Because the methods of attributing health impact to a flood event are difficult, the type of study used to quantify the impact should be clearly stated (Glass & Noji, 1992). Qualitative methods can also be used to estimate the impact of a flood on health and quality of life (Ohl & Tapsell, 2000; WHO Regional Office for Europe, 2002; Few, 2003).

Drought

A potential increase in drought could substantially affect water resources and sanitation in situations where water supply is effectively reduced. This could lead to an increased concentration of pathogenic organisms in raw water supplies. Additionally, water scarcity may require using poorer-quality sources of fresh water, such as rivers, which are often contaminated. All these factors could increase the incidence of diseases. Epidemiological assessment should be used to quantify this risk.

The health consequences of drought include diseases resulting from lack of water. In times of shortage, water is used for cooking rather than hygiene. In particular, this increases the risk of faecal-oral (primarily diarrhoeal) diseases and water-washed diseases (such as trachoma and scabies). Malnutrition also increases susceptibility to infection (see Chapter 11 for discussion on food security).

Mapping effects in time and space

Mapping flood deaths or the other effects of a given event may be useful in identifying current and future populations at risk. Mapping can be done at the local scale, with linkage to census-derived small area indicators, or at a larger scale to show which geographical areas within a country are most at risk of flooding. Some countries have prepared maps of flood risk zones.

TABLE 7.1. PATHWAYS BY WHICH ABOVE-AVERAGE RAINFALL CAN AFFECT HEALT

Event	Type	Description	Potential health impact
Heavy precipitation event	Weather	Extreme event	•Increased or decreased mosquito abundance (decreased if breeding sites are washed away)
Flood	Hydrological	River or stream overflows its banks	• Changes in mosquito abundance • Contamination of surface water
Flood	Socioeconomic	Property or crops damaged	• Changes in mosquito abundance • Contamination of water with faecal matter and rat urine (leptospirosis)
Flood	Catastrophic flood disaster	People killed or injured More than 10 people killed and/or 200 affected and/or government call for external assistance	• Changes in mosquito abundance • Contamination of water with faecal matter and rat urine, and increased risk of respiratory and diarrhoeal disease • Deaths (drowning) • Injuries • Health effects associated with population displacement • Loss of food supply • Psychosocial effects

Source: adapted from Kovats et al., (1999).

Methods for estimating the future health impact of weather disasters

Estimating the impact of climate change on climate extremes is very difficult (Table 7.2). Climate scenarios do not typically incorporate information on extreme events. However, information may be available from other sources.The following may have been assessed for the population of interest:

- the risk of coastal flooding from rising sea level and changes in the frequency of storm surges;
- the risk of riverine flooding in relation to specific catchment areas and floodplains;

- changes in the frequency of windstorms;
- the effect of climate change on the frequency and/or intensity of El Niño events; and
- the risk of drought.

TABLE 7.2. ESTIMATES OF CONFIDENCE IN OBSERVED AND PROJECTED CHANGES IN EXTREME WEATHER AND CLIMATE EVENTS

Changes in phenomenon	Confidence in observed changes (latter half of 20th century)	Confidence in projected changes (during the 21st century)
Higher maximum temperatures and more hot days over nearly all land areas	Likely[c]	Very likely[c]
Higher minimum temperatures, fewer cold days and frost days over nearly all land areas	Very likely[c]	Very likely[c]
Reduced diurnal temperature range over most land areas	Very likely[c]	Very likely[c]
Increase in heat index[d] over land areas	Likely[c] over many areas	Very likely[c] over most areas
More intense precipitation events[a]	Likely[c] over many Northern Hemisphere middle- to high latitude land areas	Very likely[c] over many areas
Increased summer continental drying and associated risk of drought	Likely[c] in a few areas	Likely[c] over most middle-latitude continental interiors (lack of consistent projections in other areas)
Increase in tropical cyclone peak wind intensities[b]	Not observed in the few analyses available	Likely[c] over some areas
Increase in tropical cyclone mean and peak precipitation intensities[b]	Insufficient data for assessment	Likely[c] over some areas

[a] *For other areas, either data are insufficient data or results conflict.*
[b] *Past and future changes in tropical cyclone location and frequency are uncertain.*
[c] *Judgement estimates for confidence: virtually certain (greater than 99% probability that the result is true); very likely (90–99% probability); likely (66–90% probability); medium likelihood (33–66% probability); unlikely (10–33% probability); very unlikely (1–10% probability); and exceptionally unlikely (less than 1% probability).*
[d] *Based on warm season temperature and humidity.*

Source: McCarthy et al., (2001).

Adaptation: strategies, policies and measures

There are four classical phases of disaster reduction:

- mitigation: long-term activities undertaken prior to impact aimed at reducing the risk or occurrence and/or effect of a disaster;
- preparedness: pre-disaster activities intended to increase the effectiveness of emergency response during a disaster;
- response: activities undertaken immediately prior to and during an event to protect lives and properties; and
- recovery: post-disaster activities undertaken to return affected communities to a more normal condition.

Numerous policies have been identified to reduce the health impact of extreme events (Pan American Health Organization, 1981):

- undertaking vulnerability studies of existing water supply and sanitation systems and ensuring that new systems are built to reduce vulnerability;
- developing improved training programmes and information systems for both national programmes and international cooperation on emergency management; and
- developing and testing early warning systems; these should be coordinated by a single national agency and involve vulnerable communities, providing and evaluating mental health care, especially for people who may be particularly vulnerable to the adverse psychosocial effects of disasters, such as children, elderly people and bereaved people.

Institutional and cultural barriers remain to using seasonal forecast information. Decision-makers should be educated or encouraged to use scientific information that may reduce losses from natural disasters. Glantz (2002) studied 12 countries to evaluate responses to disasters associated with the 1997/1998 El Niño event.

8. Vector-borne diseases

What is the evidence that climate change could affect the burden of vector-borne diseases

Vector organisms that do not regulate their internal temperatures and are therefore sensitive to external temperature and humidity transmit many important infectious diseases. Climate change may alter the distribution of vector species (increasing or decreasing) depending on whether conditions are favourable or unfavourable for their breeding places (such as vegetation, host or water availability) and their reproductive cycle (Box 8.1).Temperature can also influence the reproduction and maturation rate of the infective agent within the vector organism and the survival rate of the vector organism, thereby further influencing disease transmission.

Changes in climate that can affect the potential transmission of vector-borne infectious diseases include temperature, humidity, altered rainfall, soil moisture and rising sea level. Determining how these factors may affect the risk of vector-borne diseases is complex. The factors responsible for determining the incidence and geographical distribution of vector-borne diseases are complex and involve many demographic and societal as well as climatic factors. Transmission requires that the reservoir host, a competent vector and the pathogen be present in an area at the same time and in adequate numbers to maintain transmission.

Box 8.1. Climate effects on vectorial capacity, vector abundance and distribution

Climate affects a variety of biological processes in vectors, influencing their presence or absence at a particular time and place, their abundance and their ability to transmit disease. For anthroponotic diseases such as malaria, the overall ability of a vector population to transmit disease can be summarized as the vectorial capacity. Vectorial capacity has various formulations (Garrett-Jones, 1964, Dye, 1992), but is a function of the following parameters:

- human-biting rate: the daily biting rate of a female mosquito;
- human susceptibility: the efficiency with which an infective mosquito infects a human;
- mosquito susceptibility: the chance that an uninfected mosquito acquires infection from biting an infectious person;
- the probability of daily survival of the mosquito; and
- the incubation period for the parasite inside the mosquito.

Vectorial capacity is most sensitive to changes in the parameters that are present as squared terms (biting rate) or as exponential terms (mosquito mortality and parasite intrinsic incubation period). These are among the parameters that are most sensitive to climate, especially temperature. This is the property that makes vector-borne diseases so sensitive to even small changes in climatic conditions.

Global climate change may be expected to cause the following changes in vector-borne disease transmission.

- The overall incidence and the duration of the transmission season in particular sites may increase or decrease. Small changes in seasonality may be very important, as transmission rates tend to increase exponentially rather than linearly during the transmission season.

- The geographical distribution of disease transmission may increase or decrease, as climate-driven changes in vectorial capacity cause transmission to become unsustainable in previously endemic areas or sustainable in previously nonendemic areas. Even small increases in disease distribution may mean that new populations are exposed. New populations often lack acquired immunity, which can result in more serious clinical disease.

Climate effects on vector-borne disease should be analysed as a whole, combining climate data with concurrent measurements of the vectorial capacity and infection rate of vectors, abundance and infection rate of reservoir hosts (if any) and the infection rate and eventual health effects on humans (Table 8.1). The relationships between climate and disease distribution and transmission have been investigated for many vector-borne diseases, including the development of predictive models (Table 8.1). Predictive models can be broadly classified as biological (based on aggregating the effect of climate on the individual components of the disease transmission cycle) or statistical (derived from direct correlations between geographical or temporal variations in climate and associated variation in disease incidence or distribution, either in the present or recent past).

Multiplying the vectorial capacity by the number of days a case remains infectious gives the basic reproduction number R_0, the average number of secondary infections arising from each new infection in a susceptible population. Only if vectorial capacity is sufficient to maintain R_0 above one (each case gives rise to at least one secondary case) will disease transmission persist. This climate-influenced property therefore describes the distribution limits of sustainable disease transmission.

Climate also acts on vector reproduction and mortality rates to influence the overall abundance of disease vectors, itself a component of vectorial capacity. Although the effects of other factors mean that climate and abundance are rarely simply related, vector species usually reproduce and survive best within a defined range of climatic conditions. Abundance therefore tends to be highest where these conditions are most closely matched and decreases where and when climate is suboptimal. The point at which conditions are unsuitable for any population to be sustained marks the distribution limit of the particular vector species.

Vectorial capacity is difficult to measure in the field. Small errors in measurement in vector survival rates have exponential effects on estimates of vector capacity. The entomological inoculation rate is a product of vector abundance, the biting rate per vector and the vector infection rates (Dye, 1986, 1992). The entomological inoculation rate is closely related to vectorial capacity and is also affected by weather and climate. However, it is an easier variable to measure in the field, especially in areas at the edge of the vector's distribution (such as highland areas), where vector abundance is often low. It can be directly estimated by carrying out human-biting captures. The vector infection rates can be determined by dissection.

TABLE 8.1. VECTOR-BORNE DISEASES CONSIDERED TO BE SENSITIVE TO CLIMATE CHANGE

Vector	Diseases
Mosquitoes	Malaria, filariasis, dengue fever, yellow fever, West Nile fever
Sandflies	Leishmaniasis
Triatomines	Chagas' disease
Ixodes ticks	Lyme disease, tick-borne encephalitis
Tsetse flies	African trypanosomiasis
Blackflies	Onchocerciasis

Mapping disease in time and space

Demonstrated climate effects on the abundance and distributions of vectors either now or in the recent past constitute indirect evidence that they have been, or could be, affected by climate change. The recent increase in affordable computing power and the advent of geographical information system software has facilitated the mapping of available data on vector abundance and distributions. New ground and satellite-based sensors have allowed these data to be matched against increasingly accurate climate measurements.

Many vectors are collected using a variety of different trapping methods, applied with varying effort over time and space, so that obtaining standardized measurements of abundance is often difficult. With some notable exceptions, most studies therefore centre on analysing patterns of presence versus absence (that is, distributions), which are relatively more robust and less data-intensive. The correlation between climatic variables and the distribution of vectors may be analysed using either explicitly statistical techniques (Rogers & Randolph, 1991) or semiquantitative climate-matching methods such as the CLIMEX model (Sutherst, 1998). Factors other than climate may significantly influence distribution patterns (such as variation in natural vegetation, land use or natural or artificial barriers to species dispersal) and, as far as possible, their effects should be tested and included in multivariate models exploring climate effects.

In general, the mapping studies that have so far been carried out confirm the importance of climate as a limiting factor in the distribution of many vectors. Such confirmations suggest that their distributions are likely to change as climate change progresses. These studies have been reviewed elsewhere (Kovats et al., 2000; McMichael et al., 2003b).

Geographical information systems

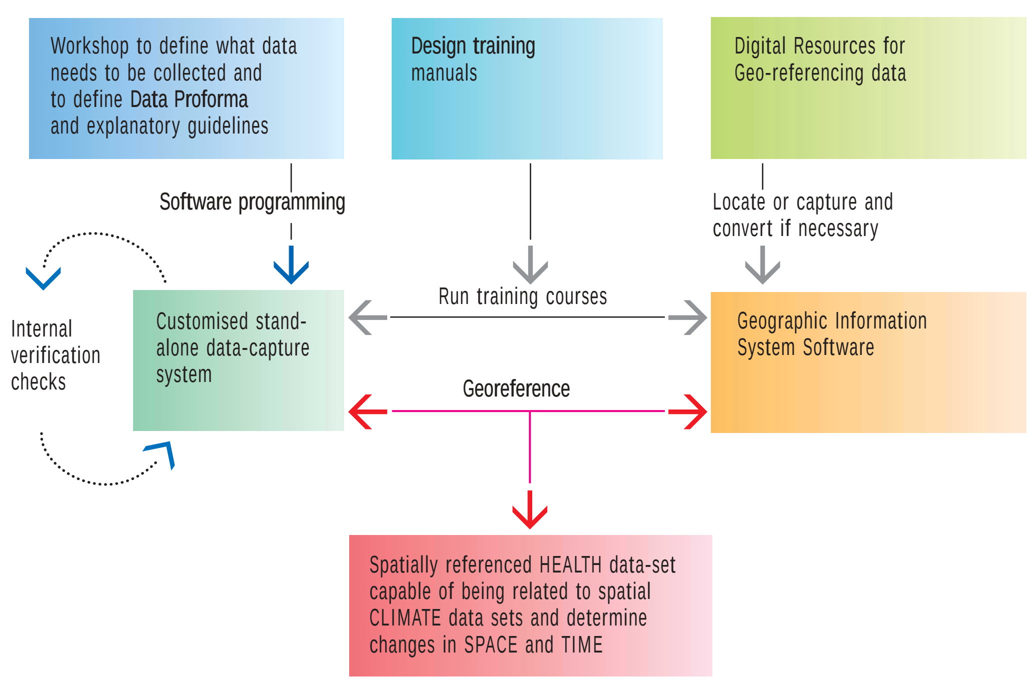
Geographical information systems are extremely important tools in assessing the impact of climate change. A geographical information system is essentially a system for linking together geographical information (such as the geographical coordinates of a specific point or the outline of a defined administrative region) to some information about that location (such as the number of people killed in floods in that region in a given year). For investigating climate effects, any geographical information system should contain:

- geographical information defining the study points or areas, such as the latitude and longitude of the study points or digitized georeferenced outlines of administrative regions;
- information about the distribution of the exposure (climate) in space and time, such as the mean and standard deviation of precipitation for specific points or administrative regions;
- information about the health effects of this exposure, such as the incidence or prevalence of climate-sensitive outcomes in the corresponding time and place; and
- information about possible determinants of vulnerability to climate change, such as average income or housing quality.

Such a system allows:

- the different kinds of information for each time and place to be linked;
- trends in exposure, modifying factors and outcomes in space and time to be mapped; and
- the linked data to be exported in a format that allows appropriate statistical analysis, ensuring that any correlations drawn between the exposure data and the outcome data are based on data drawn from the same place at the same time.

Fig. 8.1. The Mapping Malaria Risk in Africa (MARA) process



Source: David Le Sueur.

The process outlined in this section is based on how the Mapping Malaria Risk in Africa (MARA) collaboration was operationalized. Fig. 8.1 illustrates the process undertaken to establish a robust database capable of supporting studies of climate change and/or variability. Such a database also has broader application in epidemiological research and disease control programmes. Implementation requires selecting strategically placed data collection centres that can take responsibility for data collection for a defined geographical area. This is most easily achieved by linking to existing research institutions at which key individuals are identified as partners and then trained.

An important characteristic of the system described is that a large part of it is generic in terms of its application to multiple diseases. Thus, although MARA was designed for malaria, a large part of the effort is in the capture of digital information that is used to position (latitude and longitude) the disease data and in training individuals in geographical information system skills. Thus, the system makes capturing data for other climate-related diseases much easier. Such systems may initially seem potentially costly. However, when their broader application is considered, especially in terms of reduced morbidity or mortality, then they are easily justifiable.

Box 8.2. MARA LITe

One of the challenges for the MARA collaboration was to disseminate the database in a format that made it easy to use for service personnel involved in district health management and control. MARA LITe (Low-end Information Tool) was developed as a stand-alone query system of the MARA database. Dissemination was in CD format. MARA LITe has numerous capabilities in terms of extracting country data for a defined geographical region. Data may be extracted and summarized at either country, province or district level.

MARA LITe has modules that display MARA maps, calculates populations at risk and helps with statistical design in terms of surveys to assess the impact of control measures. In terms of climate-related studies, its value lies in the ability to easily extract retrospective data and to calculate a long-term mean of expected prevalence for a given region. Selecting "calculate" will provide a summary of the mean, range, standard deviation, sample size, confidence interval etc. It thus facilitates the creation of a baseline against which future increases or decreases in disease from climate change can be quantified.

Interannual climate variability, El Niño and epidemic disease

The El Niño Southern Oscillation cycle is irregular and varies in length from 2 to 7 years. Several studies have identified associations between disease risk and El Niño or La Niña events. Extreme weather can trigger disease outbreaks. Such outbreaks are often attributed to the El Niño Southern Oscillation when the weather pattern is consistent with its known effects. However, only a consistent association observed across several El Niño events using time–series methods can be considered strong evidence of a true association between the El Niño Southern Oscillation and disease in a given population (Kovats et al., 2003a).

Statistical analysis is needed to assess how disease incidence or epidemics vary over time with the El Niño Southern Oscillation cycle. This requires a long data series (at least 20 years) because El Niño Southern Oscillation events are infrequent. Such analyses should demonstrate that disease incidence or epidemics vary over time with the local weather pattern (such as rainfall) that is associated with the El Niño Southern Oscillation. The analyses should take into account potential confounding factors over the time period that may account for the observed association, such as changes in land use that may affect vector abundance. Confounding factors are unlikely to vary coincidentally with the El Niño Southern Oscillation cycle over long periods, and the likelihood of confounders explaining the observed relationship is therefore greater for short time–series or single-event case studies. Population vulnerability to climate variability may also change. For example, changes in public health infrastructure, including changes in vector control, may change vulnerability and therefore enhance or reduce the magnitude of the relationship.

Parameters of El Niño Southern Oscillation that are used in time–series studies include: identification of an El Niño "year"; the Southern Oscillation Index; and sea surface temperatures in specific regions in the Pacific. Additional considerations for the quantitative analyses include the following (Kovats et al., 2003b).

- Variability in the climate series (such as year-to-year) should correspond to variability in the health time–series.

- Both time–series and spatial analyses of correlations between climate and health outcomes should adjust for temporal autocorrelation. Failure to do so will tend to overestimate the effect of climate variables.

- Quoted statistical significance values for the association between temporal variation in climate and health outcomes should clearly distinguish between the effects of (in increasing order of relevance) seasonal variation, interannual variation and long-term trends in climate.

- Analyses should take into account, as far as possible, other changes that have occurred over the same time period that could plausibly account for any observed association with climate.

The use of monthly data to lengthen the time–series should be avoided as it begins to merge with seasonal phenomena that can impede the interpretation of results.
As with all climate health studies, the climate drivers of any association with the El Niño Southern Oscillation should be identified and the biological plausibility of the observed relationship considered.

If a relationship between the El Niño Southern Oscillation and disease is established, then it provides good evidence that the disease system is sensitive to climate factors. However, this observed relationship is not recommended to be used directly to infer the potential impact of climate change. It is important to understand whether the relationship between the El Niño Southern Oscillation and disease is driven primarily by changes in rainfall or temperature. For example, if the effect is driven by drought, then it should be assessed whether climate change is projected to increase the risk of drought in this area.

Methods for estimating future health impact if the disease is already present

Changes in the spatial distribution of diseases are clearly important as new populations are exposed to risk. Such populations lack immunity, and morbidity and mortality can therefore be significantly higher than in populations in which the disease is endemic. Populations may also lack health expertise and mechanisms with which to respond to the disease. For example, the spread of malaria from areas of constant endemic transmission (and therefore high levels of immunity) to regions where the disease had not been experienced before is likely to lead to epidemic transmission with great effects on public health.

Distributional fringe areas such as highlands and deserts are the areas most likely to show the influence of climate factors on malaria transmission. Highland areas are of interest because the climate (mainly temperature) varies significantly over a small geographical area. Temperature decreases as altitude increases. Temperature thresholds in highland regions are dynamic and highly variable over short distances, so that altitude on its own is not a reliable predictor of environmental temperature. Both large-scale factors, such as latitude and proximity to the ocean, and local factors, such as aspect and proximity to large water bodies, have important influences on local climate. The transmission factors that are directly or indirectly affected by altitude are of epidemiological significance, rather than altitude itself.

Most modelling of the effects of climate change has focused on malaria and to a lesser extent on dengue fever and some tick-borne diseases (see below). Assessments should address areas in which climate change might decrease, as well as increase, the risk of transmission of a specific disease.

The following outcomes can be addressed when assessing the potential impact of climate change:

- evidence of the current distribution of disease cases and the main vector species;
- climate-driven changes in the potential distribution of disease and vector species for a specified climate scenario;
- the additional population at risk due to climate change under specified population and climate scenarios;
- the additional person–months at risk due to climate change under specified population and climate scenarios; and
- the additional cases of disease or deaths due to climate change under specified scenarios for population, climate and adaptive capacity.

Strategies, policies and measures implemented in other sectors can affect health status. For example, water resource developments should be evaluated for the implications for vector-borne disease transmission. Water storage practices can affect the prevalence of the dengue vectors, as studies have previously shown that increased water storage during droughts can increase dengue transmission.

The health effects of wetlands regeneration should be assessed. Wetlands provide breeding sites for many mosquito vectors. Natural or planned changes in wetland areas may have implications for local transmission of disease.

The impact of climate change on livestock and herd animals may be important if they are an important reservoir or host. Modelling of pest species of plants and livestock may provide useful information for potential effects on insect and tick vectors.

Biological models of vector-borne disease transmission

Biological models of malaria are based on the relationships between temperature and the extrinsic incubation period of the parasite, and therefore the probability of completing the transmission cycle. These relationships are derived from laboratory data and are assumed to apply to all areas. Although valid for their original purpose as sensitivity analyses for relative changes in risk, these models are not ideal for defining the most probable changes either in geographical distribution or in disease burden within endemic areas. Both outputs require the calculation of absolute rather than relative values of R_0 (see Box 8.1), so as to identify areas in which $R_0 > 1$, allowing disease transmission to persist. In these models, such calculations depend in part on parameter values that are arbitrarily defined in the absence of empirical data (Rogers & Randolph, 2000). Factors such as vector abundance are difficult to measure at the national scale.

The biological models are based on temperature relationships derived from studies on vectors in the laboratory. The relationships may therefore not be appropriate to conditions in the wild. The models also assume that climate input data accurately represent the climatic conditions that mosquitoes and parasites experience in the field, disregarding the possibility that vectors might exploit microhabitats that are very different from those in meteorological stations. The outputs from biological models should therefore be validated against current disease distributions to provide useful information for a national assessment.

Box 8.3. Modelling seasonal patterns of malaria transmission in Africa

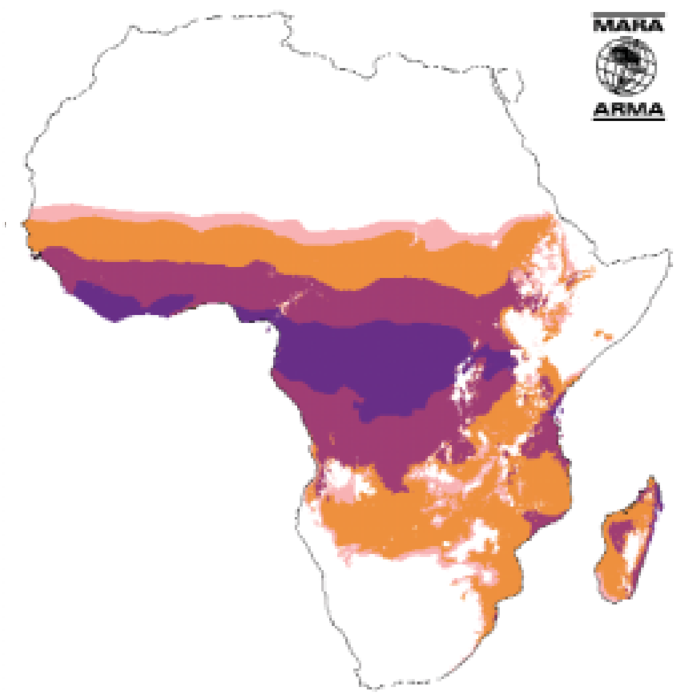
A model has been developed to define the limits of climate suitability for *P. falciparum* malaria in Africa (Fig. 8.2) (Tanser et al., in press). Temperature and precipitation thresholds were identified from field data and were within the published biological ranges affecting both vector and parasite development. The thresholds were further refined using area-specific expert opinion knowledge of the distribution and seasonality of the disease in Africa and historical published and unpublished maps. The model was spatiotemporally validated using independent data from field parasite surveys conducted throughout Africa and has been used to estimate person–months of exposure in Africa (Tanser et al., in press).

The climate scenarios used in the model represent a 30-year average of monthly temperature and precipitation data and are used in the model to represent an average or typical year. The model estimates the climate transmission potential for an average year and the suitability for a given seasonal pattern of transmission. Weather extremes may trigger epidemics in particular areas, but such models cannot address the impact of climate variability on malaria risk.

Statistical models

Models have been developed that use statistical relationships to define only the distributional limits of disease. Although this approach does not allow the specific mechanisms driving the climate sensitivity of vector-borne diseases to be dissected, it is generally considered more objective than using incomplete biological models, since model outputs do not depend on arbitrarily defined parameter values. This method requires complete and up-to-date information on the geographical distribution of the disease and/or the vector.

Fig. 8.2. Map of the transmission season length for *P. falciparum* malaria in Africa under current climate



- No transmission
- 1-3 months
- 4-6 months
- 7-9 months
- 10-12 months

Source: Tanser et al., (in press).

Malaria

Malaria is transmitted by mosquitoes of the genus *Anopheles*. About 70 species are vectors of malaria under natural conditions. These species vary considerably in their ability to transmit malaria. Although *Anopheles* mosquitoes are most abundant in tropical or subtropical regions, they are also found in temperate climates.

Malaria is caused by four species of protozoa that invade human red blood cells. Only the two main species (accounting for 90–95% of all cases) are considered: *Plasmodium vivax* and *P. falciparum*. Parasites differ in the minimum temperature for parasite development and in current health impact and distribution. The assessment of the impact of climate change on malaria should therefore be presented separately for *P. vivax* and *P. falciparum*.

P. falciparum malaria is unusual in that several research groups have independently modelled the relationships between climate and disease distribution at the global, regional and local level (Martens et al., 1999; Rogers & Randolph, 2000). Malaria models can be used to estimate the populations at risk or person–months at risk for a range of climate and population scenarios.

The MARA collaboration developed a climate-driven model for Africa (Craig et al., 1999). The model represents uncertainty around the edges of the distribution of endemic malaria. The model was validated by comparison with current and historical distribution maps that were apparently independent of the model-building process. The main limitations of this model are (1) the reliance on laboratory data and a small number of field studies to define climate cutoffs, (2) apparent subjectivity in at least one parameter estimate: the proportion of mosquitoes that need to survive the sporogonic cycle to maintain transmission, which defines the precise value of the lower temperature cutoff, (3) the need to make an assumption about the shape of the "fuzzy membership curve" and (4) validation by visual comparison rather than calculating diagnostic statistics.

A model that has already been developed and validated for the relevant geographical area is recommended to be used in the national assessment. If this is not possible, then the development of a new model may be limited by the data that are available. Any model must be formally validated against the current geographical and, if possible, seasonal distribution of the disease.

Dengue

Dengue is transmitted by two species of mosquitoes, *Aedes aegypti* and *Aedes albopictus*. The dengue virus (a flavivirus) has four distinct serotypes (designated DEN-1, -2, -3, and -4). Climate affects the seasonal abundance and distribution of Aedes mosquitoes and seasonal patterns of dengue transmission. Several studies have explored the relationship between climate and the intensity of dengue transmission. Most were derived from a series of biological models that relate climate variables to determinants of the population biology of *Aedes* vectors and dengue transmission (Focks et al., 1995). Global dengue models have been developed that use biological (Jetten & Focks, 1997) or statistical methods (Hales et al., 2002).

Biological dengue models have been used to estimate the future change in transmission potential associated with climate scenarios. Mosquito survival, human biting habits and the duration of human infectiousness were set as temperature-independent constants, with parameter values defined using field data from a number of sites. As stated above, applying a biological model requires validation with local data. An increase in seasonal temperature (as in all climate scenarios) will indicate an increase in transmission potential. However, interpreting this indicator in relation to actual cases of disease is difficult.

An alternative method of estimating the impact of climate change on dengue is to use current data to map its distribution within a statistical model. Several indicators have been developed to measure infestation of the *A. aegypti* mosquito: ecological index, house (premises) index and Breteau index

(WHO Regional Office for South-East Asia, 2003). Describing the current seasonal pattern of transmission and, if possible, quantifying the effects of temperature and precipitation are important. Dengue is primarily an epidemic disease, and the risk of epidemics is linked to complex patterns such as host immunity. A temperature rise may be expected to increase transmission intensity and lead to lowering of the average ages of primary and secondary infections and thereby significantly increase the proportion of secondary infections occurring among infants and adolescents, the ages thought to be especially susceptible to dengue haemorrhagic fever and shock syndrome.

Box 8.4. Tools for modelling dengue: CIMSiM and DENSiM

CIMSiM is a weather- and habitat-driven entomological dynamic simulation model that produces mean-value estimates of various parameters for all cohorts of a single species of *Aedes* mosquito within a representative 1-hectare area (Focks et al., 1995). CIMSiM maintains information on abundance, age, development with respect to temperature and size, weight, fecundity and gonotrophic status. Development times of eggs, larvae, pupae and the gonotrophic cycle are based on temperature using an enzyme kinetics approach. Daily weather data are used in CIMSiM.

Microclimate is a key determinant of survival and development for all stages. Adult microclimate is assumed to be the same as the daily local weather. For mosquito immatures, however, CIMSiM calculates daily water temperatures and water gains and losses for each of the representative containers based on local weather and container characteristics and location. The model can be validated for a specific population if local information is obtained through a pupal and demographic survey. The DENSiM model is the corresponding simulation model of human population dynamics driven by country and age-specific birth and death rates. The outcome of CIMSiM provides input to DENSiM, and an infection model accounts for the development of virus within individuals and its passage between both populations (see Annex 2 for web site with more details).

Schistosomiasis

Schistosomiasis, caused by five species of the trematode (flat worm) *Schistosoma*, requires water snails as an intermediate host. The worldwide prevalence has risen since the 1950s largely because of the expansion of irrigation systems in hot climates where viable snail populations can survive and the parasite can find human carriers (Brown, 1994).

The distribution of the snail hosts is focal and has been mapped in relation to climate and environmental factors. All three genera of intermediate hosts (*Bulinus, Biomphalaria and Oncomelania*) can tolerate a wide temperature range. Life-table experiments indicate that the optimum temperature is 25 ± 2 °C. At low temperatures, snails are effectively dormant, fecundity is virtually zero but survival is good; at high temperatures, egg production increases but so, too, does mortality. Snails are mobile and can move to avoid extreme temperatures within their habitats: water can act as an efficient insulator.

Mechanisms to be considered include the following.

- In highland areas, global climate change might allow schistosomiasis transmission to extend its range to higher altitudes.
- Increasing temperatures at sea level could be lethal unless the snails can move to cooler refuges. The precise conditions within water bodies that should be taken into account depend on numerous factors related to the local geology and topography, the general hydrology of the region, the presence or absence of aquatic vegetation and local agricultural usage.

- An increase in heavy, local or widespread thunderstorms, could flush snails out of many of their habitats.

- Prolonged or persistent flooding might increase the number of potential snail habitats downstream.

- Reduced rainfall could reduce snail populations, and prolonged drought may eliminate the snail population altogether.

The potential impact of climate change on the distribution of schistosomiasis has been modelled in an endemic country (Moodley et al., in press). Schistosomiasis is currently endemic in KwaZulu-Natal province and is present in several other provinces in South Africa. The distribution of the disease is associated with climate factors (mainly temperature), geomorphology and habitat stability. Two models were developed to map the current and future distributions. The models projected that *Schistosoma haematobium* could extend its distribution inland and estimated the additional population at risk (restricted to those aged 5–14 years) under a medium-range climate scenario.

Although snails reproduce relatively rapidly, they do not disperse rapidly, either actively or passively. However, *Schistosoma* parasites themselves may be rapidly and widely transmitted within human hosts and may infect new snail species in previously risk-free areas. Schistosomiasis may therefore expand into newly climatically suitable areas. However, given the relative immobility of the snail hosts, climate change may be expected to have greater short- and medium-term effects on the local distribution and abundance than on the global distribution of suitable vectors.

Tick-borne diseases

Ticks may live for 3 years. Their year-round survival, egg-hatching and development from larvae into nymphs and finally adults depend on the presence of certain ecological as well as climatic conditions. The environment and climate determine (1) the limits of the spatial distribution for the distribution of ticks according to latitude and altitude, (2) the daily variability in the risk of infective tick bites; (3) the seasonal patterns in the risk of infective tick bites, (4) interannual variability in the risk of infective tick bites and (5) long-term trends (WHO Regional Office for Europe, in press). Tick activity patterns vary between years and between locations depending on both climate variability and habitat vegetation. In central Europe, the developmental cycle is 2–3 years and is considerably affected by the microclimate of the habitat and long-term changes in weather. The number of days per season with temperature and humidity favourable for tick activity, development and year-round survival directly affect tick abundance. Tick density, and subsequent disease risk, during a specific year has been linked to seasonal daily climatic conditions during two successive years previous to the one studied (Lindgren, 1998; Lindgren et al., 2000; Lindgren & Gustafson, 2001).

The possible effects of future climate risks can be assessed by models based on current spatial associations between the incidence of tick-borne encephalitis and climate or by quantifying temporal patterns in tick-borne encephalitis with climate, including interannual variability and long-term trends. The key question for Europe, for example, is whether the apparent increase in cases reported per year since the 1980s in the Baltic countries (Estonia, Finland, Latvia, Lithuania, Poland and Sweden) and in central Europe (the Czech Republic, Germany, Slovakia and Switzerland) can be attributed to the climate change during that time. Some of this upward trend could result from changes in reporting procedures or in changes in human activity patterns leading to greater exposure. However, no such increasing trend has been observed in the most southerly countries of the tick-borne encephalitis range, where climate change is more likely to lead to a reduction in incidence: Croatia, Hungary and Slovenia (Randolph, 2000).

The possible impact of future climate change on the distribution of Lyme disease (borreliosis) in Europe, for example, can be investigated by quantifying the role of climate on the observed spatial and temporal patterns described above. Much research has been undertaken on *Ixodes ricinus* of the activity and thresholds for metamorphosis as well as the effect of climate variables on tick survival. Such knowledge can be used to develop a biological process–based model of *I. ricinus* abundance, seasonality and distribution (Randolph et al., 2002). However, attempts to predict the distribution of *I. ricinus* or Lyme disease have largely been limited to statistical pattern-matching models (Daniel & Kolár, 1991; Daniel et al., 1999; Zeman et al., 1999; Estrada-Peña, 1997, 1999, 2002; Rizzoli et al., 2002).

Methods for estimating future health impact if the disease is not currently present

Climate change may affect the risk of the introduction of a disease into an area where it has been present previously (re-emergence) or where it has never been present (emergence).

Malaria

Malaria is currently confined to tropical areas, but at the peak of its distribution it was present in many middle-latitude countries. Although malaria has been successfully eradicated from western Europe and North America, the vectors are still present. A large region in the Pacific Ocean (Polynesia and Micronesia) has always been free from *Anopheles* and therefore malaria.

The basic reproduction number R_0 can be used as an indicator of the vulnerability of a country or region to the reintroduction of malaria. R_0 can be calculated from information on indigenous cases (the cases acquired within the country and not imported) and the capacity of the most important vectors (Kuhn, 2003). For a European country, R_0 can be measured as the ratio of indigenous to imported cases, making the reasonable assumption that the whole population is susceptible to malaria (Kuhn, 2003). Table 8.2 shows estimates for R_0 calculated for selected countries. Such calculations rely on the accurate reporting of cases of indigenous transmission; the accuracy of reports varies between countries.

TABLE 8.2. ESTIMATES OF R_0 (BASIC REPRODUCTION NUMBER, APPROXIMATED AS THE RATIO OF INDIGENOUS TO IMPORTED CASES OF MALARIA) FOR SELECTED EUROPEAN COUNTRIES

Country	Total indigenous cases	Total imported P. *vivax* cases	R_0
Bulgaria	18	117	0.1534
Belarus	5	48	0.1463
Greece	4	182	0.0220
Italy	5	3064	0.0024
Germany	2	4189	0.0005

Source: Kuhn (2003).

Vectorial capacity expresses the potential for a vector population to sustain malaria transmission following the introduction of one infectious case (Box 8.1). R_0 is therefore a function of the vectorial capacity (which is affected by climate) and other factors, such as the duration of infection, that are mainly affected by social conditions, such as insecticide spraying. However, vectorial capacity can be estimated by calculating R_0 using the method described above. A study in Europe has shown that estimated R_0 correlated well with GDP and life expectancy (Kuhn, 2003). This observed relationship can be used to estimate this socioeconomic component in the country of interest. This component can be multiplied by the relative vectorial capacity to measure the "true" R_0.

A qualitative approach can be applied using expert judgement. The risk of changes in abundance of the most important vectors should be addressed. The most important vectors can be identified using the following criteria (Kuhn, 2003):

- widespread present distribution and historical distribution in areas that were known to be malarious;
- the finding in nature of the species infected with malaria parasites;
- a tendency to feed on humans;
- the ability to become infected with tropical strains of malaria parasites; and
- existing evidence that the species is currently involved in malaria transmission.

Australia's national assessment used the CLIMEX model (Sutherst et al., 1998) to project the future areas at risk of malaria under a range of climate scenarios (McMichael et al., 2003c). The CLIMEX model maps the translocation of particular vector species between different areas as they respond to climate change. CLIMEX analyses indicate that the indigenous vector of malaria in Australia (*Anopheles farauti*) would be able expand its range south under current scenarios of climate change. These studies clearly cannot include all factors that affect species distribution. For example, local geographical barriers and interaction and competition between species are important factors that determine whether species colonize the full extent of suitable habitat.

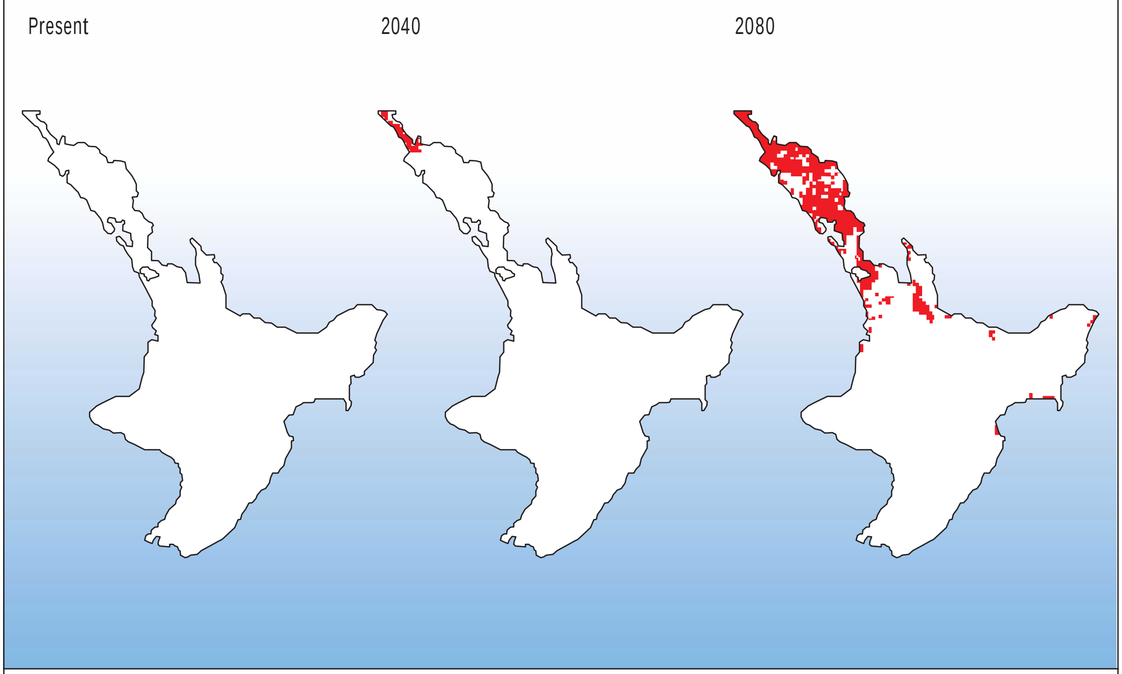
Dengue

Assessing the risk of introduction of dengue if it is not currently present may be important. *Aedes albopictus* is highly invasive and has spread from Japan throughout the world, although climate is not thought to be a contributory factor. The (re)introduction of dengue is a major concern for many countries. In the New Zealand assessment, the HOTSPOTS model was developed to map the potential distribution (the climatic envelope) of the important dengue vector, *Aedes aegypti*, in the North Island (Fig. 8.3) (de Wet et al., 2001). New Zealand does not currently have either the vector or the disease. Under present climate conditions, the introduction of the vector is considered unlikely.

Case study: climate change and the risk of vector-borne diseases in Portugal

The health chapter of Portugal's national assessment of vulnerability and adaptation to climate change (Casimiro & Calheiros, 2002) addressed a range of mosquito-borne diseases using a new qualitative approach. Four scenarios were developed that incorporate changes in climate and changes in the vector population in Portugal (Table 8.3). These scenarios were then considered for each disease using expert judgement (Table 8.4).

Fig. 8.3. Potential distribution of *Aedes aegypti* in the North Island of New Zealand predicted by a model



Source: HOTSPOTS model of dengue fever risk developed by the International Global Change Institute, University of Waikato, with funding from the Health Research Council

TABLE 8.3. SCENARIOS USED IN ASSESSING VECTOR-BORNE DISEASE

	Assuming current knowledge of vector and parasite prevalence in Portugal	Assuming the introduction of a small population of parasite-infected vectors into Portugal
Current climate	Scenario 1	Scenario 2
Climate change (doubling of CO_2 concentration)	Scenario 3	Scenario 4

TABLE 8.4. POTENTIAL RISK OF MOSQUITO-BORNE DISEASES IN PORTUGA

Disease	Scenario	Suitable vector	Parasite	Risk level
P. vivax malaria	1	Widespread distribution	Imported cases only	Very low
	2	Focal distribution (new vector)	Changes from low to high prevalence	Low
	3	Widespread distribution	Imported cases only	Very low
	4	Changes from focal to potentially regional distribution (new vector)	Changes from high focal prevalence to high prevalence regional distribution	Low to medium
P. falciparum malaria	1	None present	Imported cases only	None
	2	Focal distribution	Changes from low to high prevalence	Low
	3	None present	Imported cases only	None
	4	Changes from focal to potentially regional distribution	Changes from high focal prevalence to high prevalence regional distribution	Low to medium
Dengue	1	None present	Imported cases only	None
	2	Focal distribution	Changes from low to high prevalence	Low
	3	None present	Imported cases only	None
	4	Changes from focal to potentially regional distribution	Changes from high focal prevalence to high prevalence regional distribution	Low to medium
Yellow fever	1	Widespread distribution	Imported cases only	Very low to none
	2	Focal distribution (new vector)	Changes from low to high prevalence, focally distributed	Low
	3	Widespread distribution	Imported cases only	Very low
	4	Changes from focal to potentially regional distribution (new vector)	Low prevalence, widespread distribution	Low to medium
West Nile fever	1	Widespread distribution	Low prevalence, focally distributed	Low
	2	Focal distribution (new vector)	Changes from low to high prevalence, focally distributed	Low
	3	Widespread distribution	Changes from low to high prevalence, regionally distributed	Low to medium
	4	Focal distribution (new vector)	Changes from low to high prevalence, focally distributed	Low

Detecting early evidence of climate change effects

Assessment should also address whether climate change has had a role in the emergence or re-emergence of disease within the country (see the example of tick-borne encephalitis above). Early detection of climate change effects could be facilitated by careful selection of indicators, following the criteria already developed for non-health outcomes (Parmesan, 1996; Ahmad & Warrick, 2001). Suitable indicators may measure either risks to health or the health states themselves.The indicators should show high climate sensitivity and vulnerability (little intentional or unintentional adaptation to climate change effects) and have few plausible alternative explanations. Kovats et al., (2000) have suggested a preliminary stratification of possible indicators for climate change effects on vector-borne disease. Of the candidate variables, almost all are highly climate-sensitive: however, they vary significantly in vulnerability and the plausibility of alternative explanations. Among the most suitable are the length of activity seasons and the altitude distribution of vectors in pristine environments. Among the least suitable are changes in the incidence of controllable diseases, transmitted in and around houses. Results from non-health studies suggest that monitoring the most suitable indicators could be expected to demonstrate clear effects of climate change within the next decade or two, assuming similar rates of change to those observed in recent years.

Adaptation: strategies, policies and measures

Assessment of adaptation generates a range of strategies, policies and measures to address the potential health impact of vector-borne diseases. Ideally, this list will range from interventions that are theoretically possible at some future date to those that can be implemented practically in the short term. Policy-makers and decision-makers should be aware of possible interventions that could be available in the future to address vector-borne diseases so that appropriate action can be taken. This includes establishing research programmes to encourage the development of interventions that are not yet technically feasible or are too costly, instituting trials of the effectiveness of promising but undemonstrated interventions or changing policies or public attitudes for desirable interventions that are currently not socially acceptable.

The interventions policy-makers choose to implement need to satisfy a number of requirements, including being effective in reducing the burden of disease, technically and economically feasible, socially acceptable and compatible with current policies.Typically, cost–benefit analysis is conducted to demonstrate the value of the intervention. In addition, having coordination and collaboration across regions or countries on interventions such as vector-control activities when the vector and pathogen are problems across boundaries may be desirable.

The following section briefly discusses some of the interventions that aim to reduce morbidity and mortality from vector-borne diseases; this is intended only to illustrate some approaches.The appropriateness of a particular intervention depends on local circumstances, including the age distribution of the population, the degree of immunity to the disease, the level and distribution of economic resources in the population, the proportion of the population that lives in areas at risk and the effectiveness of current vector control measures.

The presence of vector-borne diseases depends on vector control measures. Malaria epidemics are focal in nature and may often be controlled by limited application of safe and effective residual insecticides. Parasite resistance to antimalarial agents is a threat to malaria control programmes and drug sensitivity must therefore be reviewed regularly.At the personal level, insecticide-protected fabrics such as bednets have been shown to be effective against infective mosquito bites.

Dengue vector control

The vector mosquito in Asia and the Americas breeds primarily in human-made containers such as barrels and other water storage containers. Elements of a global strategy to control dengue include:

- conducting surveillance of vector density and disease transmission;
- developing selective and sustainable vector control, including preparedness for emergency control;
- strengthening local capacity for assessing the social, cultural, economic and environmental factors that lead to increased vector density and increased transmission of disease;
- ensuring early diagnosis and prompt treatment of dengue haemorrhagic fever in disease management;
- conducting research in vector control; and
- mobilizing other sectors to incorporate dengue control into their goals and activities.

Epidemic preparedness

Malaria prevention illustrates approaches to adaptation that apply to other vector-borne disease threats. Human populations must take adaptive measures to reduce the increased risks of malaria. Although changes in weather or socioeconomic conditions may trigger malaria epidemics, many health services fail to monitor these variables because the indicators of risk for epidemic-prone areas have not been determined.

Malaria surveillance and epidemic preparedness may benefit from recently developed tools that predict the seasonality and risk of epidemics using satellite or ground-based meteorological data (Githeko & Ndegwa, 2001; WHO, 2001a). New approaches to mapping the distribution of malaria vectors over large areas may facilitate species-specific vector control activities. In western Kenya, the risk of malaria transmission in the highlands can be predicted using a simple predictive model dependent on rainfall and temperature.

Integrated environmental management

The incidence of certain waterborne and vector-borne infections can be reduced by several environmental measures. Experience with the WHO/FAO/UNEP/UNCHS (United Nations Centre for Human Settlements) Panel of Experts on Environmental Management for Vector Control has shown that early consultations between the health and agricultural sectors can greatly reduce the burden of vector-borne diseases such as malaria and schistosomiasis in large-scale irrigation projects (Birley, 1991). Climate change is likely to amplify the challenge of pest control because new ecological niches will appear that may sustain exotic pathogens and disease vectors.

The recent establishment of the Environmental Risk Management Authority in New Zealand is an example of a strategy of collaboration between the health, forestry, environment and conservation sectors (Woodward et al., 2001). New Zealand is especially vulnerable to invading species. The Authority provides an integrated approach with a wide-ranging brief that includes regulation of importation, investigation of incidents and emergencies and review of existing hazards. The Authority has formal links with many sectors, must consider public input from diverse interest groups and reports directly to a senior minister who holds both the environment and biosecurity portfolios.

9. Waterborne and foodborne diarrhoeal disease

What is the evidence that climate change could affect the burden of diarrhoeal disease?

Many infectious diseases are sensitive to either temperature or rainfall, showing strong seasonal variation in numerous sites. Many diarrhoeal diseases (infectious intestinal disease) peak in cases during the hottest months of the year. This is true for *Salmonella* infections in Europe and for *Shigella* infections in South Asia. Temperature and relative humidity directly influence the rate of replication of bacterial and protozoan pathogens and the survival of enteroviruses in the environment. Rainfall, and especially heavy rainfall events, may affect the frequency and level of contamination of drinking-water.

Diarrhoeal disease have multiple modes of transmission, such as via water, food, insects or contact between humans. The relative importance of the various pathogens that cause diarrhoea varies between locations and is greatly influenced by the level of sanitation. Several studies have described climate effects on specific diarrhoea pathogens (Campbell-Lendrum et al., 2003). Pathogens vary in the severity of clinical symptoms and the likelihood that they will be reported to health services. The numbers of cases reported either through clinics or laboratory-based surveillance therefore only represent a small proportion of the total disease burden, especially for diseases that are not severe. Further, relationships between climate and disease derived from passive reporting may differ from those based on other methods of surveillance.

Climate change could greatly influence water resources and sanitation in situations where water supply is effectively reduced. Drought events can lead to an increased concentration of pathogenic organisms in raw water supplies. In addition, water scarcity may necessitate using sources of fresh water of poorer quality, such as rivers, which are often contaminated. Increases in rainfall may cause flooding and overwhelm sewerage systems. All these factors could result in an increased incidence of disease.

Methods for estimating the health impact of weather

Time–series methods can be used to quantify an association between variation (daily, weekly or monthly) in diarrhoea outcomes and environmental temperature. The seasonal cycle and other long-term patterns should be removed from the data series to address non-temperature-related seasonal factors (see Chapter 5). Other confounders should be taken into account in the modelling process. The effect of high temperatures may be only apparent after 1–2 weeks, as delay is inherent between the time of infection, the onset of symptoms and when disease is recorded through routine surveillance. The following factors should be considered:

- Health data may be available from routine surveillance (laboratory-confirmed cases by pathogen) or the records of infectious intestinal illness at primary care clinics or hospitals.
- The date of onset of illness (or admission) should be reasonably accurately recorded, and data should be available at the weekly or daily resolution. Analysis of aggregate monthly data may lead to overestimation of a temperature effect because the potential to control for the effects of non-climate factors (such as seasonal confounding) is limited.
- If the model is based on a relationship derived from a different population, then justifying this extrapolation is important, especially if the other population differs in climate and the burden of diarrhoeal disease.
- A climate relationship with a specific diarrhoea pathogen can be used to estimate the effects on the total burden of diarrhoeal disease if information is also obtained on (1) their relative contribution to

overall disease incidence and (2) equivalent data on climate-sensitivity and relative prevalence for all other diarrhoea pathogens.

Methods for estimating future health impact

Modelling the effects of changes in temperature

Very few studies have estimated the potential impact of climate change on diarrhoeal disease. The WHO assessment of the global burden of disease restricted their estimates to the effect of increasing temperatures on the incidence of all-cause diarrhoea and made no prediction of the effect of changing rainfall patterns (Campbell-Lendrum, 2003). The relationship between temperature and diarrhoeal disease was derived from two published studies.

- Time–series analysis was used to correlate measurements of temperature and relative humidity with daily hospital admissions at a single paediatric clinic for diarrhoeal disease in Lima, Peru (Checkley et al., 2000). Admissions increased by 4% (95% confidence interval 2–5%) for each 1 °C increase in temperature during the hotter months and 12% per 1 °C (95% confidence interval 10–14%) increase in the cooler months, averaging an 8% increase per 1 °C (95% confidence interval 7–9%) over the course of the study.

- Time–series analysis was used to correlate the monthly reported incidence of diarrhoea throughout Fiji with variation in temperature, after allowing for the effects of seasonal variation and long-term trend (Singh, 2001). The reported incidence increased by about 3% (95% confidence interval 1.2–5.0%) for each 1 °C increase in temperature.

Studies have also been undertaken in industrialized countries that quantify the relationship between temperature and reported cases of salmonellosis.

- Time–series analyses was used to estimate the relationship between weekly reports of cases of salmonellosis and weekly mean temperature in several European countries (Kovats et al., 2003c), after allowing for the effects of seasonal variation, trend and the effect of public holidays on the disease reporting.

- Poisson regression was used to estimate the association between monthly variation in *Salmonella* infection and temperature in five cities in Australia (D'Souza et al., in press).

The potential impact of an increase in temperatures depends on the burden of disease at that time. The estimated relative increase (relative risk) can be applied to appropriate projections of diarrhoeal disease for the population that is the focus of the assessment. These baseline levels independent of climate change are likely to change over time with development, tending to decrease with economic development and improved sanitation in developing countries (see the discussion of socioeconomic scenarios in Chapter 4).

Modelling the effects of changes in rainfall

The potential impact of changes in rainfall on waterborne disease is clearly very important. However, little epidemiological research has addressed the role of rainfall in either triggering individual outbreaks or in the overall burden of waterborne disease. Potential mechanisms include the following.

- Heavy precipitation causes sewers to overflow and people come into contact with pathogens and faecal matter.

- Heavy rainfall causes contamination of surface or coastal water if the sewers are used as storm drains.

- Heavy rainfall leads to agricultural runoff contaminated with livestock faeces into surface water, which reaches the public water supply or direct contact with humans.
- Heavy rainfall leads to failure in a wastewater-treatment plant.
- Drought reduces the amount of surface water and groundwater, leading to increasing concentrations of pathogens and the use of alternative sources of water that are less potable.

Methods are much less well developed to undertake risk assessment of the impact of changes in rainfall associated with climate change. There are several reasons for this. It may only be possible to identify reported disease outbreaks and assess the role of weather or extreme rainfall. Most industrialized countries have few outbreaks of waterborne disease.

Adaptation: strategies, policies and measures

Assessment of adaptation generates a range of strategies, policies and measures to address the potential health impact of water- and foodborne diseases. Ideally, this list will range from interventions that are theoretically possible at some future date to those that can be implemented practically in the short term. Policy-makers and decision-makers should be aware of possible interventions that could be available in the future to address water- and foodborne diseases so that appropriate action can be taken. This includes establishing research programmes to encourage the development of interventions that are not yet technically feasible or are too costly, instituting trials of the effectiveness of promising but undemonstrated interventions or changing policies or public attitudes for desirable interventions that are currently not socially acceptable.

The interventions that policy-makers choose to implement need to satisfy a number of requirements, including being effective in reducing the burden of disease, technically and economically feasible, socially acceptable and compatible with current policies. Typically, cost–benefit analysis will be conducted to demonstrate the value of the intervention.

The appropriateness of a particular intervention depends on local circumstances, including the age distribution of the population, the level and distribution of economic resources in the population and the degree of access to clean drinking-water and sanitation.

The most important adaptive measure is to ensure universal access to clean potable water and sanitation. Further, the sanitation infrastructure should be evaluated to determine its vulnerability to extreme precipitation events (including droughts and floods).

Other adaptation measures include improving structures for water control and processing; water resource planning at sub-watershed levels; education campaigns to encourage the use of soap and water for handwashing; and temporary measures to reduce the pathogen concentration in drinking-water, such as chlorine tablets, boil-water alerts and using sari cloth as a filter.

10. Stratospheric ozone depletion

Stratospheric ozone depletion is a quite distinct process from the accumulation of greenhouse gases in the lower atmosphere (troposphere). Stratospheric ozone has been depleted in both hemispheres, from the polar regions to middle latitudes. The ozone layer is expected to recover and will be back to pre-industrial levels by 2050 if compliance is achieved on the banned ozone-depleting substances.

The problem is often considered alongside climate change for the following three reasons.

- Several of the greenhouse gases (especially chlorofluorocarbons) also damage stratospheric ozone.
- Cooling in the upper stratosphere associated with global warming can potentially increase the seasonal rate of ozone depletion.
- Absorption of solar radiation by stratospheric ozone influences the heat budget in the lower atmosphere.

Stratospheric ozone depletion is included here as it is a concern for some countries and often included in national assessment of the impact of climate on human health.

The UNEP/WMO scientific assessment of ozone depletion 2002 (UNEP, 2002) concluded as follows.

- Observations in the stratosphere indicate that total chlorine abundance is at or near its peak, whereas bromine abundance is probably still increasing.
- Springtime Antarctic ozone depletion (the ozone hole) has increased in area throughout the last decade, but not as rapidly as it did in the 1980s.
- A future Arctic ozone hole similar to that observed in the Antarctic appears unlikely.
- Springtime Antarctic ozone levels will begin recovering by 2010 because of projected decreases of ozone-depleting substances in the stratosphere.

What is the evidence that stratospheric ozone depletion could affect human health?

Stratospheric ozone absorbs part of the sun's incoming UV radiation, including much of the UVB radiation and all of the highest-energy UVC radiation. Sustained exposure to UVB radiation harms humans and many other organisms (UNEP, 2002). It can damage the genetic (DNA) material of living cells and can induce skin cancer in experimental animals. UVB is implicated in causing human skin cancer and lesions of the conjunctiva, cornea and lens; it may also impair the body's immune system (WHO, 1994; Goettsch et al., 1998; Longstreth et al., 1998).

Solar radiation has been consistently implicated in causing nonmelanocytic skin cancer in fair-skinned humans. Malignant melanoma arises from the pigment-producing cells of the skin. Although solar radiation is substantially involved in melanoma causation, the relationship is less straightforward than for nonmelanocytic skin cancer; exposure in early life appears to be a major source of increased risk. The marked increases in the incidence of melanoma in industrialized countries over the past two decades reflect increases in personal exposure to solar radiation caused by changes in patterns of recreation, clothing and occupation and not necessarily increases in background UV radiation.

Methods for estimating the health impact of ground-level UV radiation

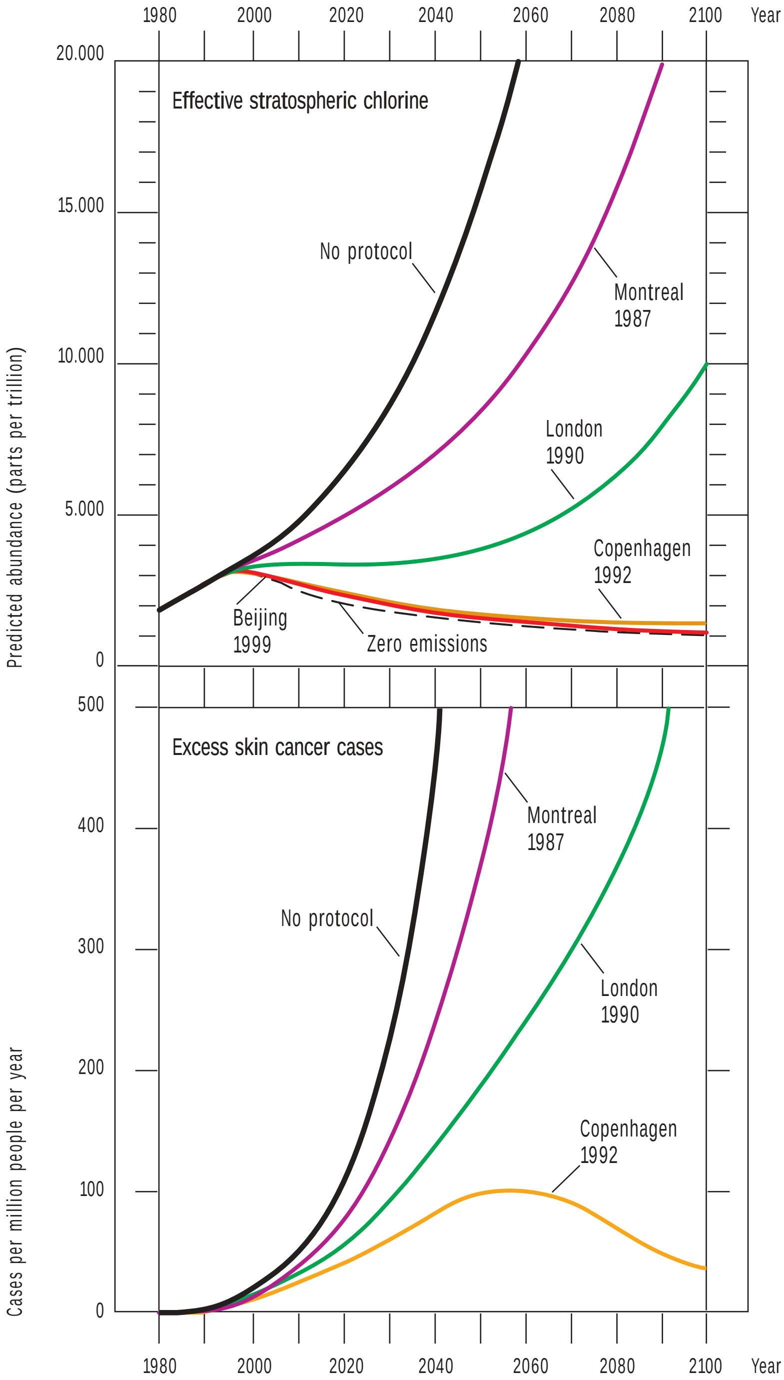
The effects of ozone depletion on health have been assessed quantitatively for skin cancer and cataract where adequate data exist (Feenstra et al., 1998; Longstreth et al., 1998).

Information on the general relationship between solar exposure and skin cancer is available from a large body of epidemiological research. It provides estimates of risk increments associated with different amounts of time, by stage of life, spent exposed to solar radiation. Measuring an individual's actual radiation exposure has not generally been possible (especially retrospectively); the exposure has been expressed in terms of such indices as person–time outdoors, frequency of severe exposure episodes or category of occupation. The risk gradients associated with observed levels of exposure to UV radiation must be estimated to estimate the impact of changes in UV irradiation on skin cancer incidence. These may be derived from broad population-level epidemiological studies that describe the relationship between average ambient local exposure levels and local skin cancer rates.

Scenarios of ozone depletion have been developed based on future projections of the emissions of ozone-depleting substances assuming compliance with the various amendments to the Montreal Protocol on Substances that Deplete the Ozone Layer – the international agreement that restricts the emissions of ozone-depleting substances (Fig. 10.1). Full compliance with the latest amendment is projected to lead to a peak in stratospheric chlorine concentration and ozone depletion in the first decade of the 21st century.

Fig. 10.1. Scenarios for stratospheric ozone depletion and associated projections of excess cases of skin cancer

Effect of the Montreal Protocol



Source: Fahey et al., (2003).

Montreal 1987: the Montreal Protocol on Substances that Deplete the Ozone Layer. London 1990: amendments agreed in 1990. Copenhagen 1992: amendments agreed in 1992. Beijing 1999: amendments agreed in 1999.

One assessment has estimated that the full-compliance scenario would lead to a peak in excess skin cancer of about 5–10% by about 2050 (Slaper et al., 1996). The model incorporates a delay (lag) because the incidence of skin cancer depends on the cumulative UVB exposure and the time it takes for cancer to develop (cancer latency). The United States Environmental Protection Agency (1988) has developed a risk assessment model and estimated excess cases of cataracts under a range of ozone depletion scenarios (UNEP, 1998). However, the epidemiological evidence underlying the exposure–response relationships for cataracts and UV radiation is less certain than for skin cancer outcomes.

The models are limited by uncertainty in the validity of the dose–response relationship, and especially the role of personal exposure. As the outcomes occur primarily in certain age groups, age-specific scenarios of population growth should be included in any modelling exercise. Such models could be adapted for a specific population using published epidemiological studies. Estimates have been published for selected latitudes and selected countries.

Adaptation: strategies, policies and measures

In response to Agenda 21, WHO in collaboration with UNEP, WMO, the International Agency on Cancer Research and the International Commission on Non-Ionizing Radiation Protection set up INTERSUN, WHO's Global UV Project "to reduce the burden of disease resulting from exposure to UV radiation". INTERSUN encourages and evaluates research and develops an appropriate response through guidelines, recommendations and disseminating information. Specifically, INTERSUN aims:

- to collaborate with specialist agencies in implementing key research needs;
- to develop reliable predictions of the health and environmental consequences of changes in exposure to UV radiation with stratospheric ozone depletion;
- to develop practical ways of monitoring change in UV-induced health effects over time in relation to environmental and behavioural change; and
- to provide practical advice and information to national authorities on the health and environmental effects of exposure to UV radiation, means of efficiently disseminating this information and measures to protect the general public, workers and the environment against the adverse effects of increasing levels of UV radiation.

Campaigns to reduce personal exposure to sunlight have been implemented in many industrialized countries. These have been successful and rely on health promotion and education campaigns. A global UV index has also been developed to enhance education about sun protection (WHO, 2002b).

11. Food security

Food security remains one of the main political concerns of climate change. High seasonal and year-to-year variability in food supplies, often the result of unreliable rainfall and insufficient water for crop and livestock production, is a major contributor to chronic undernutrition and food insecurity. Drought affects health through several pathways. In the most extreme case, famine, the number of deaths associated with insufficient food consumption, increases substantially. Famine often occurs when a pre-existing situation of malnutrition worsens. Although food yields and agriculture has been a main focus of research on the impact of climate change, surprisingly little work has been done on how climate change may affect health through changes in the food supply.

What is the evidence that climate change will affect the food supply and thereby health?

Climate change could affect food production in several ways:

- geographical shifts and yield changes in agriculture;
- reduction in the quantity of water available for irrigation;
- loss of land through rising sea level and the associated salinization; and
- effects on fisheries productivity through rising sea level and changes in water temperatures, currents, freshwater flows and nutrient circulation.

The IPCC Third Assessment Report (McCarthy et al., 2001) was reasonably optimistic that, at the global level, the agricultural system could adapt to climate change in the near term. However, the distribution of vulnerability among regions and populations will be uneven. For example, in some tropical areas, crops are already near their maximum temperature tolerance. In dryland areas, non-irrigated agricultural production is likely to be sensitive to even small changes in precipitation. Poor people, and especially those living in marginal environments, are most vulnerable to climate-induced food insecurity (Downing & Parry, 1994). The following groups may be most at risk (McCarthy et al., 2001):

- rural smallholder producers
- pastoralists
- rural wage labourers
- urban poor people
- refugees and displaced people.

Hunger and malnutrition are already among the most devastating problems facing countries. FAO (2002) estimated that 840 million people were undernourished in 1998–2000. This figure includes 11 million in industrialized countries, 30 million in countries in transition and 799 million in developing countries. This latest figure of 799 million represents a decrease of only 20 million since 1990–1992, the benchmark period used at the World Food Summit. Nearly half the people in countries in central, southern and eastern Africa are undernourished. Environmental factors, both natural and those resulting from human activities, can limit agricultural potential. These include extremely dry or cold climate, poor soil, erratic rainfall, steep slopes and severe land degradation. FAO (2002) further states that undernutrition and malnutrition prevail in regions where environmental economic and other factors expose the population to a high risk of impoverishment and food insecurity.

FAO (2002) estimates of food insecurity are based on calculations of the amount of food available in each country (national dietary energy supply) and a measure of inequality in distribution derived from household income and expenditure surveys. Alternative methods of estimating food insecurity rely on data from a range of sources: household expenditure surveys; individual food intake surveys; anthropometric surveys on children and adults; and qualitative and indicative self-assessment surveys (such as the measure of food insecurity in the United States). The strengths and weaknesses of each method have been actively debated and assessed in the production of global assessments of undernutrition. Stunting and wasting are indicators commonly used in epidemiological studies to measure undernutrition. The stunting rate is defined as the proportion of children younger than 5 years who have a low height for age when measured or compared with the normal height for the age group. The wasting rate is defined as the proportion of children younger than 5 years who have a low weight for height when measured or compared with the normal weight for height for the age group.

Countries that currently have problems with food security would be especially vulnerable to the potential impact of climate change on food supplies. However, very few national assessments have addressed the potential impact of climate change on malnutrition. Zambia was concerned about this potential outcome of climate change (Phiri & Msiska, 1998).

Methods for estimating future health impact

National assessments have used models that simulate the effects of climate scenarios (and other scenarios) on crop yields and food-related outcomes. Predicting the impact of climate change on crop and livestock yields is complex. Agricultural production is sensitive to the direct effects of climate, especially extreme weather events. It is also sensitive to the indirect effects of climate on soil quality, the incidence of plant diseases and weed and insect (including pest) populations. In particular, irrigated agriculture would be affected by changes in water resources.

Few studies have mapped climate, environment and nutritional outcomes at the national or local level. Temporal studies can also reveal vulnerability to interannual climate variability or the effect of the El Niño Southern Oscillation. A study in Papua New Guinea has shown that women living in poorer-quality environments produce less food, suffered chronic malnutrition and had children with lower birth weight (Allen, 2002). The sporadic occurrence of El Niño was associated with sharp and severe shortages of food in both the favoured and poorer environments.

At the global and regional scale, integrated assessment of the impact of climate change of populations at risk of hunger has been attempted (Parry et al., 1998). The population at risk of hunger is defined as the population with an income insufficient to either produce or procure their food requirements, based on methods developed by FAO. Regionally based crop yield models are first used to simulate the effects of climate change (a scenario based on the global climate model) and increased CO_2 (which has a fertilization effect) on the yield of the major cereal crops. An established world food trade model (the Basic Linked System) is then used to simulate the economic consequences of yield changes, including changes in world food output and in world food prices. Projections assume a 50% liberalization of trade by 2020 and an annual increase in cereal yields of just under 1%. Some consider these assumptions to be optimistic, but they are consensus best estimates.

National and regional assessments of the impact of climate change on agricultural productivity may be available at the national or subnational level, as agriculture is an important economic sector in many countries. Studies focus on model simulations for changes in crop yield and agricultural risk but provide limited information on future vulnerability to undernutrition. The application of a scenario-driven approach requires a sophisticated approach to the development of non-climate scenarios (see Chapter 4).

Non-scenario-driven approaches have been developed that address vulnerability and coping capacity at the local level. Current methods are being developed within the UNDP Adaptation Policy Framework that will be available in 2004. See the UNDP web site (http://www.undp.org/cc) for further information.

Adaptation: strategies, policies and measures

Assessment of adaptation generates a range of strategies, policies and measures to address the potential health impact of food security. Ideally, this list will range from interventions that are theoretically possible at some future date to those that can be implemented practically in the short term.

Governments incorporate most of the nutrition activities on which WHO focuses – whether concerning micronutrient deficiencies, protein and energy malnutrition or the development of food-based dietary guidelines – in national nutrition policies or plans of action for nutrition. The World Declaration and Plan of Action for Nutrition obligates countries to develop and implement coherent national plans and policies to tackle nutritional problems comprehensively. Countries should consider the impact of future global environmental changes that affect nutrition, especially global climate change, within a comprehensive national food policy.

A crop failure can lead to a disaster in many communities in developing countries, requiring emergency food relief. In such a case, timely and sufficient access to international aid agencies and distributional networks will determine the magnitude of the event.

12. Vulnerable populations

Many effects are not disease specific but address more broad questions for human health (Woodward et al., 1998). In addition to the "direct" health effects, losses are anticipated from forced migration caused by rising sea level, impact on production activities and food insecurity. As land areas suitable for cultivation of key staple crops or productive fishing grounds undergo geographical shifts in response to climate change, they may become the subject of political conflict. Competing demands for water may also cause conflict in semi-arid areas – although such claims are often considered controversial (McCarthy et al., eds., 2001).

Depending on the scope and purpose of the assessment, other groups that may be specifically addressed include:

- indigenous populations and native peoples
- nomadic populations
- elderly people
- children
- chronically ill people
- people with a low income
- homeless people.

An assessment report should state clearly why specific groups are considered more vulnerable to the potential health impact associated with climate change.

Population displacement

The IPCC (1990) noted that "the greatest effect of climate change may be on human migration as millions of people will be displaced due to shoreline erosion, coastal flooding and agricultural disruption". Refugees represent a very vulnerable population with significant health problems. Large-scale migration is likely in response to flooding, drought and other natural disasters associated with climate change. Both the local ecological disturbance caused by extreme events and the circumstances of population displacement and resettlement would affect the risk of outbreaks of infectious disease. An increase in the magnitude and frequency of extreme events would also disrupt political stability. Displacement caused by longer-term cumulative environmental deterioration (such as land degradation and water scarcity) is also associated with many health effects.

Tuvualu is a small island that is predicted to lose much of its land area in the coming decades. The Government of Tuvalu has accepted the inevitable and has appealed to the neighbouring governments to help in the managed relocation of Tuvalu's population. An agreement was reached with New Zealand, and the managed relocation of inhabitants is now in progress. Programmes must be developed to support the settlement and cultural adaptation of the displaced people.

There is concern not only about the source of displaced people but also about countries that may receive the displaced people. The New Zealand national health impact assessment addressed the potential impact of climate change on regional stability (Woodward et al., 2001). The impact of climate change and rising sea level on Pacific Island countries would have implications for the planning and provision of health services in New Zealand. This assessment was based on expert assessment, and more formal methods were not developed.

Indigenous populations

Indigenous populations (Box 12.1) have been identified as especially vulnerable to climate change because such populations:

- are more likely to rely on subsistence farming or hunter–gathering and are therefore more vulnerable to climate-related changes in food supplies;
- are more likely to inhabit land that may be affected by climate change or sea level rise;
- often have lower socioeconomic status and poorer health status;
- have less infrastructure to cope; and
- are often socially marginalized from access to services, including reduced access to health care.

The United States national assessment included a chapter on the potential consequence of climate variability and change for native peoples and homelands in the United States (National Assessment Synthesis Team, 2001:351–377). A key concern was the health and welfare implications of an increase in the frequency of extreme events, mainly heat-waves, given the type of housing and reduced access to health care facilities for these populations.

Box 12.1. Climate change and health in Nunavik and Labrador

Climate change is projected to significantly affect the distribution of sea ice and ecosystems in the Arctic region, and there is some evidence that this is already occurring. A project was undertaken to develop better understanding of climate change processes and potential health impact in two Inuit populations in Canada (Furgal et al., 2002). The methods used were a review of the health sciences, including environmental, medical and traditional knowledge literature, consultation with experts and focus groups with experienced hunters, elders and women in Nunavik and Labrador. The participants reported significant changes in the environment in the past 20–30 years and described the impact of these changes, including:

- ability and safety to travel at certain times of the year;
- ability to find and hunt certain types of food; and
- ability to gain access to potable water while practising traditional pursuits.

In all cases, changes were not reported to be taking place in isolation but simultaneously with other environmental changes. Adaptive strategies that were being developed to cope with these changes were also identified.

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Annex 1. Key terms used in this report

Adaptation is the strategies, policies and measures undertaken now and in the future to reduce potential adverse health impacts for climate variability and change.

Adaptive capacity describes the general ability of institutions, systems and individuals to adjust to potential harm, to take advantage of opportunities or to cope with the consequences of climate variability and change in the future.

Attributable burden is the reduction in current burden that would have been observed if past levels of exposure to a risk factor had been reduced to zero.The attributable burden is the attributable risk multiplied by the disease burden.

Attributable risk is the proportion of disease burden in an exposed population that can be attributed to a specific risk factor.

Climate change is defined as a statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (typically decades or longer).

Climate is the average state of the atmosphere and the underlying land or water in a specific region over a specific time scale.

Climate-sensitive disease is a disease that is sensitive to weather or climate factors, with the current spatial distribution and seasonal transmission being affected.

Climate variability refers to variations around the mean state, including the occurence of extreme weather events.

Comparative risk assessment is defined by WHO as the systematic evaluation of the changes in population health that result from modifying the population’s exposure to a risk factor or a group of risk factors.

Coping capacity describes adaptive strategies, policies and measures that could be implemented now to minimize potential harm from climate variability and change.

Environmental burden of disease is the burden of disease caused by environmental factors estimated using methods described by WHO.

Relative risk describes the ratios of incidence in the exposed population compared with the unexposed population.

Stabilization scenario is one in which greenhouse gas emissions have been reduced such that the concentration of carbon dioxide in the atmosphere is stabilized at a given point in time and at a level that avoids some level of effects from climate change.

Vulnerability is defined as the degree to which individuals and systems are susceptible to or unable to cope with the adverse effects of climate change, including climate variability and extremes.

Weather describes the day-to-day changes in atmospheric conditions in a specific place at a specific time. More simply, climate is what you expect and weather is what you get.

Annex 2. Sources of data and information

Adaptation to climate change in developing countries

- UNDP Adaptation Policy Framework: www.undp.org
- United Nations Framework Convention on Climate Change and national adaptation programmes of action (NAPA): www.unfccc.int
- Pacific Islands Climate Change Program (PICCAP): http://unfccc.int/resource/ccsites/marshall/activity/piccap.htm
- AIACC Program (Assessments of Impacts and Adaptations to Climate Change in Multiple Regions and Sectors). This web site facilitates access to extensive data, software and bibliographical resources related to climate impact, adaptation and vulnerability across multiple sectors. http://sedac.ciesin.columbia.edu/aiacc/index.html

Calculating the environmental burden of disease

- World Health Organization: method of assessing the environmental burden of disease: http://www.who.int/peh/burden/methods.htm

Risk management frameworks

- Focardi S, Jonas C. Risk management: framework, methods, and practice. New York, John Wiley & Sons, 1998.
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Literature sources

- PubMed: http://www.pubmedcentral.nih.gov

- WHO initiative on access to journals: http://www.healthinternetwork.net

Climate change and scenario data

- IPCC's Data Distribution Centre – socioeconomic data: http://sres.ciesin.columbia.edu/tgcia

- IPCC Data Distribution Centre – climate data: http://ipcc-ddc.cru.uea.ac.uk

For sources of observed (instrumental) climate data, please contact your national meteorological and hydrological agency.

- Climatic Research Unit: http://www.cru.uea.ac.uk/cru/data

- Center for International Earth Science Information Network (CIESIN): http://www.ciesin.columbia.edu

Health – climate assessment tools

MARA LITe: http://www.mara.org.za/lite/information.htm

The objective of this tool was to develop a user-friendly front-end that facilitates the querying of the MARA database of malaria prevalence and populations at risk in sub-Saharan Africa. Comprehensive online help files exist for all aspects of the tool. At present the tool has the following broad functionality. For any specified target geographical area, down to district level (within Africa), the following queries can be made.

- The time series of data points can be queried and displayed graphically or as a table.

- The prevalence database can be queried and relevant information displayed in graphical and tabular format. Conditions such as the size of a survey, age group, survey period and season can be specified. Summary statistics can then be displayed with both weighted and unweighted means.

- Populations at risk can be queried. Conditions such as geographical area, age category and risk level and pregnancy can be specified.

- Provide summary statistics and population sampling procedures for measuring the impact of interventions. This process uses the summary statistics of the existing MARA prevalence database for a given geographical area (such as a province or district) as a baseline. The target or estimated reduction in transmission can then be specified as well as the required confidence limit. The module will then provide a range of sampling alternatives with different sample sizes, depending on the number of clusters. In the absence of MARA data, estimated values may be entered.

- Provide a bibliographic summary of the data source of all data points for a given geographical area.

- Display MARA products such as seasonality and transmission intensity maps.

All output can be printed or exported. The MARA database itself is a complex relational database comprising 29 separate tables. Thus, the tool converts MARA databases into a flat structure. This tool is currently available as a CD-ROM.

DENSiM and CIMSiM: http://daac.gsfc.nasa.gov/IDP/models/index.html

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www.who.int
For climate change: www.who.int/peh

Health Canada Santé Canada

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www.euro.who.int/globalchange

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