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Application of environmentally sound technologies for adaptation to climate change

Technical paper*

Summary

This technical paper provides an overview of (i) the current knowledge and understanding of adaptation to climate change, (ii) a framework for assessing technologies for adaptation to climate change, (iii) the process of technology development and transfer as relevant to adaptation to climate change, (iv) examples of important technologies for adaptation in five sectors (coastal zones, water resources, agriculture, public health, and infrastructure), together with three case studies for each sector, and (v) a synthesis of findings that have implications for climate policy.

The paper argues that many technologies exist to adapt to natural weather related hazards and that these technologies can also play an important part in reducing vulnerability to climate change. Hard and soft technologies are available to develop information and raise awareness, to plan and design adaptation strategies, to implement adaptation strategies, and to monitor and evaluate their performance. The paper provides examples of technologies that can be employed to accomplish them.

* This technical paper was commissioned by the secretariat of the United Nations Framework Convention on Climate Change (UNFCCC) and was prepared by Richard J.T. Klein, Mozaharul Alam, Ian Burton, William W. Dougherty, Kristie L. Ebi, Martha Fernandes, Annette Huber-Lee, Atiq A. Rahman, and Chris Swartz. The paper does not necessarily reflect the views of the secretariat although in some instances the secretariat introduced some modifications. It provides a wide coverage of technologies for adaptation without prejudice to any definition or delineation of these technologies that may be instituted through the UNFCCC process.

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I. Executive summary

1. This technical paper aims to provide an overview of (i) the current knowledge and understanding of adaptation to climate change, (ii) a framework for assessing technologies for adaptation to climate change, (iii) the process of technology development and transfer as relevant to adaptation to climate change, (iv) examples of important technologies for adaptation, together with case studies and (v) a synthesis of findings that have implications for climate policy.

2. The paper is the latest in a series of publications on technologies for adaptation that have been prepared within the UNFCCC process. An initial report, providing an inventory and assessment of technologies to mitigate and adapt to climate change, was prepared by the UNFCCC secretariat in 1996 (FCCC/SBSTA/1996/4). It identified what type of information on technologies and know-how would be most useful to the Parties to the UNFCCC. The emphasis of the initial report was on mitigation, reflecting the predominant political interest and the state of knowledge at the time. Much has changed in the time since that initial paper, reflecting the increasing attention of the Conference of the Parties (COP) on the urgent need for adaptation activities.

3. Climate change is among the most daunting environmental problems faced by the world today. The Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) (2001) has shown that no country and no region of the world will be unaffected, and in many countries the consequences for all human activities will be profound. The development of technologies and practices for adapting to climate related stresses is well under way as societies have been coping for millennia with the extremes of climate variability. Yet, the prospect of long-term climate change is now leading decision makers to do some hard thinking about the role of technology, mechanisms that ensure its access to the sectors and communities that need it to adapt, and how this process of adaptation can fit within and serve the broad goals of sustainable development.

4. Adaptation can be either **reactive** or **anticipatory**. Reactive adaptation occurs after the initial impacts of climate change have become manifest, whereas anticipatory (or proactive) adaptation takes place before impacts are apparent. This type of adaptation is best seen as a process entailing more than merely the implementation of a policy or the application of a technology. It is essentially a multistage and reiterative process, involving four basic steps: **information development and awareness-raising; planning and design; implementation; and monitoring and evaluation**.

5. In considering how vulnerable countries and communities might best adapt to climate change and so reduce their vulnerability, it is often assumed or asserted that part of the solution involves the use of technology and its transfer from place to place. Understanding how to enhance the flows of technologies for adaptation requires attention to four key elements:

(a) The first element involves **improving an understanding of the range in the types of technologies for adaptation**. This is highly linked to the types of risk or hazard involved. It is important to note that the nature of the hazard under a changed climate will likely be no different than it is under the current climate, inferring that many existing technologies that have proven to be effective in reducing vulnerability to weather related hazards will also be important as technologies for adaptation to climate change. At the broadest level of classification, technologies for adaptation can comprise "**hard**" technologies (e.g. irrigation technology) and "**soft**" technologies (e.g. crop rotation patterns). A successful adaptation strategy would typically combine both hard and soft technologies. Within these two broad categories, we have further classified technologies for adaptation to climate change into four major categories: traditional, modern, high technology and future technology.

(b) The second element involves an **identification of the appropriate role of technology**. Successfully identifying the role of technology in adaptation to climate change (i.e. actions that reduce vulnerability to the impacts of climate change) may well include actions that are directed at improving prevailing social, economic and environmental conditions and management practices in a system or sector. For the purposes of this technical paper, we identify the roles of technology within a four-stage process of adaptation consisting of (i) information development and awareness-raising, (ii) planning and design, (iii) implementation and (iv) monitoring and evaluation.

(c) The third element is the actual process for the "**transfer**" of the technology, which in this technical paper is called the "flow of technology". Until very recently, technology transfer to address climate change has focused almost exclusively on mitigation issues. And, given that the overwhelming majority of global greenhouse gas (GHG) emissions are from the energy sector, clean energy supply alternatives have emerged as the dominant focus for technology transfer. As the Convention process has taken up the question of technology for adaptation some of the ideas about technology transfer for mitigation have been carried forward into the adaptation domain. In so doing there is a danger that several important distinctions between the processes of mitigation and adaptation may be overlooked, namely (i) adaptation is not new in the way that mitigation is new, (ii) the sectors that need technology for adaptation are ubiquitous, (iii) many technologies for adaptation are already readily available in developing countries and (iv) the most needed technologies for adaptation are probably not likely to be as capital intensive as those for mitigation.

(d) The fourth and final element is the **criteria applied in the selection** of technologies for adaptation. This is an important element due to the fact that caution needs to be exercised in the introduction of modern technology to avoid unintended side effects. The development and application of suitable criteria, motivated by the exigencies of the adaptation challenge, will help to avoid some of these types of problems. There are three essential criteria, namely (i) benefits, including economic/financial and costs, (ii) equity and (iii) social and legal acceptability.

6. The role, challenge and opportunity of technologies for adaptation have been examined in five sectors: coastal zones, water resources, agriculture, public health and infrastructure. The discussion in each of these sectors focuses upon the nature of the sector, potential adaptation strategies within the sector, the role of technologies within these adaptation strategies, how to enhance flows of technology and a set of three practical case studies in each sector. Major findings for each sector are summarized in the paragraphs that follow.

7. For **coastal zones**, technology has been instrumental in reducing society's vulnerability to ever-present weather related hazards. Many existing technologies that have proven to be effective in reducing vulnerability to weather related hazards will also be important as technologies for adaptation to climate change. Technologies may have to be adjusted to meet local needs, and technological development and innovation will continue to increase the effectiveness and efficiency of existing technologies, but given current projections of climate change, successful adaptation is possible to some extent by relying on existing technologies, without having to rely on the development of new technologies specifically for adaptation. On the other hand, new technologies may also have an important role to play. But climate change is but one of many interacting stresses in coastal zones. The importance of controlling non-climatic stresses in the quest to reduce vulnerability to climate change

must not be underestimated. Vulnerability to climate change is not only determined by the degree of climate change but also by prevailing social, economic and environmental conditions and by the existing management practices in a system or sector. Therefore, successful adaptation to climate change (i.e. actions that reduce vulnerability to the impacts of climate change) may well include actions that are directed at improving such conditions and management practices.

8. For **water resources**, climate change induced variability in the hydrologic cycle superimposes additional challenges on planning and management of water resources. The development of appropriate adaptation strategies to cope with this added uncertainty requires a broad, integrative approach given the multidimensional roles that water plays in sustaining human life, society and the ecosystems on which they depend. The intrinsic characteristics of integrated water resources management (IWRM) make it an ideal overarching framework in which to evaluate, design, implement and monitor adaptation strategies for climate impacts to water resources. Building communities of practice around IWRM can facilitate the mainstreaming of climate adaptation strategies into sustainable development efforts, providing synergy in awareness-raising, capacity-building and in the creation of social, political and institutional environments receptive to technological innovation. These communities of practice aid in the transfer of technologies for adaptation that meet key needs, such as information technologies (remote sensing, forecasting) that enhance understanding of natural (e.g. hydrologic) and engineered (e.g. demand) system components and tools that support decision-making (e.g. scenario-driven processes and multicriteria assessment technologies).

9. For **agriculture**, because there are a number of uncertainties regarding the range of impacts associated with climate variability and climate change, it is important to consider a diverse portfolio of potential technologies for adaptation. This is essential to retain the flexibility to transfer and adopt needed technology. Barriers, such as lack of information, lack of financial and human capital, and unreliable equipment and supplies, can rarely be surmounted unless the transferred technology has high probability of directly addressing climate related impacts in a cost-effective manner. The effectiveness of technology transfer in the agriculture sector, in the context of climate change response strategies, also depends to a great extent on the suitability of transferred technologies to the socio-economic and cultural context of the recipients, considering development, equity and sustainability issues. Constraints to the supply of new technologies, shortage of technological information and shortage of capital are also important aspects of technology transfer. It is evident that integration of both hard and soft technologies and building working partnerships between government and non-governmental organizations may be necessary to increase the effectiveness of different technologies for adaptation to adverse climatic effects. Governments can facilitate the flows of technologies within countries with the aid of incentives, regulation and by institutional strengthening.

10. For **public health**, there is a long history of dealing, with varying degrees of effectiveness, with the impacts of climate variability. Incorporating consideration of where, when and how extensively climate change could affect future disease burdens is important for increasing resilience. Many of the climate-sensitive health outcomes do not need to be addressed individually; health outcomes with common risk factors, such as malnutrition and diarrhoeal diseases associated with the dry season, may be reduced together by the implementation of appropriate interventions. Such interventions include effective health education programmes, improvement of health care infrastructure, disaster preparedness plans, vector monitoring and control, and appropriate sewage and solid-waste management practices. The ability to predict climate variations on a seasonal or inter-annual scale presents communities with the opportunity to develop the capacity and expertise to deal with climate variability, which will also help communities prepare for the effects of climate change.

11. Finally, with regard to **infrastructure**, an integrated and exhaustive governance structure is central to the success of adaptation in infrastructure and urban environments. Improvement in

awareness-building and involvement throughout government, and private and community groups is likely to greatly improve the likelihood of successfully transferring adaptation technologies to infrastructure. Also important is coordinated financial support for the implementation of technologies. Smart Growth development is a good example, as are local environmental action plans. The more successful strategies and means of transferring technologies are those that meet a number of human needs in addition to their provision of environmental benefits. Focus should, therefore, be placed on technologies which serve a variety of purposes above and beyond environmental improvement.

12. There are five key policy related questions that emerge from the findings in this paper. First, what would be the policy implications for further enhancing the deployment and diffusion of technologies for adaptation within countries? Second, what would be the policy implications for further enhancing the technology transfer for adaptation between countries? Third, are new institutional arrangements needed for information, planning, implementation and monitoring purposes in terms of adaptation? Fourth, are there additional criteria that need to be applied in the selection of technologies for adaptation? And fifth, what policy implications does the determination of the relative importance of existing technologies for adaptation to climate change have regarding national and international mechanisms to facilitate flows of such technologies for adaptation?

II. Introduction

A. Mandate

13. The Subsidiary Body for Scientific and Technological Advice (SBSTA), at its twentieth session, requested the secretariat to organize in early 2005 a seminar on the development and transfer of environmentally sound technologies (ESTs) for adaptation to climate change in order to discuss case studies encompassing short-, medium- and long-term examples of their application, taking into consideration the terms of reference to be prepared by the Expert Group on Technology Transfer (EGTT) at its sixth meeting, and to report on the findings of this seminar to the SBSTA at its twenty-second session (FCCC/SBSTA/2004/6, para. 81 (b)). At the same session, the SBSTA requested the secretariat to prepare a technical paper on the applications of ESTs for adaptation to climate change, based on the outcomes of the above-mentioned seminar and on the terms of reference to be prepared by the EGTT at its seventh meeting and make it available for consideration by the SBSTA at its twenty-third session (FCCC/SBSTA/2004/6, para. 81 (c)).

14. The SBSTA, at its twenty-first session, noted that the seminar on the development and transfer of ESTs for adaptation to climate change would be held at the end of June 2005, as mandated by the SBSTA at its twentieth session, and requested the secretariat to prepare the above-mentioned technical paper for consideration by the SBSTA at its twenty-fourth session, based on the outcomes of the seminar and on the terms of reference for the technical paper to be prepared at the eighth meeting of the EGTT (FCCC/SBSTA/2004/13 para. 90 (d)).

B. Scope of the technical paper

15. This technical paper aims to provide the secretariat of the UNFCCC and the EGTT with an overview of (i) the current knowledge and understanding of adaptation to climate change, (ii) a framework for assessing technologies for adaptation to climate change, (iii) the process of technology development and transfer as relevant to adaptation to climate change, (iv) examples of important technologies for adaptation, together with case studies and (v) a discussion of implications for climate policy.

16. The paper could serve as an input to the work of the EGTT on providing recommendations for further enhancing the framework for meaningful and effective actions to enhance the implementation of

Article 4, paragraph 5, of the Convention, as mandated by decision 6/CP.10, and to the SBSTA, when considering, at its twenty-fourth session, possible activities on the development and transfer of technologies for adaptation for its five-year programme of work on impacts, vulnerability and adaptation to climate change.

C. Background

17. This is the latest paper prepared within the UNFCCC process in the series of publications on technologies for adaptation. An initial report, providing an inventory and assessment of technologies to mitigate and adapt to climate change, was prepared by the UNFCCC secretariat in 1996 (FCCC/SBSTA/1996/4). It identified what type of information on technologies and know-how would be most useful to the Parties to the UNFCCC. The emphasis of the initial report was on mitigation, reflecting the predominant political interest and the state of knowledge at the time.

18. Participants in an expert meeting convened by the UNFCCC secretariat in Amsterdam in 1997 recommended the secretariat to develop a work programme to prepare the following papers (FCCC/TP/1997/3):

(a) An overview paper on adaptation;

(b) Papers, initially on technologies relating to human health, food, security, coastal zones, urban areas and water;

(c) A long-term “vision paper” that could set out technological goals in different sectors.

19. The overview paper was produced as a technical paper in 1997 (FCCC/TP/1997/3). It was followed by a focused paper two years later: a technical paper on coastal adaptation technologies (FCCC/TP/1999/1). Since then, the results of a survey of technology and technology information needs of developing countries have become available (FCCC/SBSTA/1998/INF.5).

20. In response to a request by the SBSTA (FCCC/SBSTA/1995/3), the IPCC prepared a Special Report on Methodological and Technological Issues in Technology Transfer (SRTT), which was published in 2000 (IPCC 2000). The SRTT contained two chapters devoted to adaptation (human health and coastal adaptation), and other chapters that discussed both mitigation and adaptation (e.g. agriculture).

21. At COP 7 in 2001, the EGTT was established, with the objective of enhancing the implementation of Article 4, paragraph 5, of the Convention, including, inter alia, by analysing and identifying ways to facilitate and advance technology transfer activities and making recommendations to the SBSTA. The EGTT comprises 20 experts, including three members from each of the developing country regions (Africa, Asia and the Pacific, and Latin America and the Caribbean), one from the small island developing States, seven from Parties included in Annex I to the Convention and three from relevant international organizations. The progress of work and the terms of reference of the EGTT will be reviewed at COP 12 in 2006.

22. In 2003, two technical papers were produced, which addressed issues relevant to technology transfer for both mitigation and adaptation. FCCC/TP/2003/1 discussed issues pertaining to capacity-building in the development and transfer of technologies, and FCCC/TP/2003/2 analysed enabling environments for technology transfer. In addition, the compilation and synthesis of national communications from Parties included in Annex II to the Convention (Annex II Parties) included information containing specific reference to technologies for adaptation. In 2004, the UNFCCC secretariat made available a compendium on methods and tools to evaluate impacts of, and vulnerability and adaptation to, climate change.

23. The EGTT's programme of work for 2004, endorsed at SBSTA 19 in 2003, under the item "cross-cutting activities", included a proposed action aimed at encouraging the development of environmentally sound technologies, in particular technologies for adaptation to climate change. As part of the work programme, a draft scoping paper was prepared by the Chair of the EGTT, outlining the basic concepts of adaptation-relevant technologies. The scoping paper complements secretariat working paper no. 10 (2003): "Review of adaptation activities under the Convention".

24. Most recently at the tenth session of the Conference of the Parties in 2004, Parties decided to initiate a programme of work on adaptation to climate change (decision 1/CP.10). The decision emphasizes technology transfer for adaptation on an urgent basis in priority sectors. Moreover, it instructed SBSTA to develop a structured five-year programme of work encompassing a range of technology transfer issues.

25. As a next step, a background paper was prepared to stimulate discussion at the UNFCCC Seminar on the Development and Transfer of Environmentally Sound Technologies for Adaptation to Climate Change, which took place in Tobago, Trinidad and Tobago from 14 to 16 June 2005. The background paper has served as a starting point for this more comprehensive technical paper.

D. Relevant UNFCCC articles, decisions and definitions

26. This subsection reviews the UNFCCC Articles pertinent to the development and transfer of environmentally sound technologies for adaptation to climate change, and lists a number of key decisions made by the COP. In addition, it presents definitions for several of the terms and concepts that are used throughout this paper.

27. Articles 3 and 4 of the Convention make various references to adaptation – what it is and how it should be considered – that can be summarized as follows:

(a) Article 3.3 states that Parties should take precautionary measures to anticipate, prevent or minimize the causes of climate change and mitigate its adverse effects. Where there are threats of serious or irreversible damage, lack of full scientific certainty should not be used as a reason for postponing such measures, taking into account that policies and measures to deal with climate change should be cost-effective so as to ensure global benefits at the lowest possible cost. To achieve this, such policies and measures should take into account different socio-economic contexts, be comprehensive, cover all relevant sources, sinks and reservoirs of greenhouse gases and adaptation, and comprise all economic sectors.

(b) Article 4.1(b) states that all Parties shall formulate, implement, publish and regularly update national and, where appropriate, regional programmes containing measures to mitigate climate change by addressing 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 measures to facilitate adequate adaptation to climate change.

(c) Article 4.1(e) states that all Parties shall cooperate in preparing for adaptation to the impacts of climate change; develop and elaborate appropriate and integrated plans for coastal zone management, water resources and agriculture, and for the protection and rehabilitation of areas, particularly in Africa, affected by drought and desertification, as well as floods.

(d) Article 4.1(f) states that all Parties shall take climate change considerations into account, to the extent feasible, in their relevant social, economic and environmental policies and actions, and employ appropriate methods, for example impact assessments, formulated and determined nationally, with a view to minimizing adverse effects on the economy, on public health and on the quality of the environment, of projects or measures undertaken by them to mitigate or adapt to climate change.

(e) Article 4.5 states that the developed country Parties and other developed Parties included in Annex II shall take all practicable steps to promote, facilitate and finance, as appropriate, the transfer of, or access to, environmentally sound technologies and know-how to other Parties, particularly developing country Parties, to enable them to implement the provisions of the Convention. In this process, the developed country Parties shall support the development and enhancement of endogenous capacities and technologies of developing country Parties. Other Parties and organizations in a position to do so may also assist in facilitating the transfer of such technologies.

(f) Article 4.8 states that the Parties shall give full consideration to what actions are necessary under the Convention, including actions related to funding, insurance and the transfer of technology, to meet the specific needs and concerns of developing country Parties arising from the adverse effects of climate change and/or the impact of the implementation of response measures.

(g) Finally, Article 4.9 states that the Parties shall take full account of the specific needs and special situations of the least developed countries in their actions with regard to funding and transfer of technology.

28. Annex I summarizes several key decisions relating to the development and transfer of technologies in the context of the UNFCCC.

29. Brief definitions of key concepts that are used throughout this technical paper are summarized in box 1 below. The definitions of the first three concepts are taken from the IPCC Third Assessment Report (TAR; McCarthy et al. 2001). The latter three definitions are taken from the IPCC SRTT (Metz et al. 2000).

Box 1. Brief definitions of key concepts

Adaptation: Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities. Various types of adaptation can be distinguished, including anticipatory and reactive adaptation, private and public adaptation, and autonomous and planned adaptation.

Adaptive capacity: 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.

Vulnerability: The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity.[1]

Technology: A piece of equipment, technique, practical knowledge or skills for performing a particular activity.

Environmentally sound technologies: Technologies that protect the environment, are less polluting, use all resources in a more sustainable manner, recycle more of their wastes and products, and handle residual wastes in a more acceptable manner than the technologies for which they were substitutes and are compatible with nationally determined socio-economic, cultural and environmental priorities. The term includes hard and soft technologies.

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[1] <www.ipcc.ch/pub/syrgloss.pdf>.

Technology transfer: The broad set of processes covering the exchange of knowledge, money, and goods among different stakeholders that lead to the spreading of technology for adapting to or mitigating climate change. The word “transfer” encompasses both diffusion of technologies and cooperation across and within countries.

III. Climate and adaptation

30. Climate change is among the most daunting environmental problems faced by the world today. The Third Assessment Reports of the IPCC (2001) has shown that no country and no region of the world will be unaffected, and in many countries the consequences for all human activities will be profound. The development of technologies and practices for adapting to climate related stresses is well under way as societies have been coping for millennia to the extremes of climate variability. Yet, the prospect of long-term climate change is now leading decision makers to do some hard thinking about the role of technology, mechanisms that ensure its access to the sectors and communities that need it to adapt, and how it can fit within and serve the broad goals of sustainable development.

A. Climate variability and change

31. Human-induced climate change is caused by the emission of GHG gases, which trap long-wave radiation in the upper atmosphere and thus raise atmospheric temperatures, as well as produce other changes in the climate system. Carbon dioxide is the most important of these gases and its atmospheric concentration has increased exponentially since the beginning of the industrial revolution as a result of fossil fuel combustion and land-use change. In 1800, the atmospheric concentration of carbon dioxide was about 280 parts per million (ppm); today it is about 380 ppm and rising. Similar increases have been observed for other GHGs, such as methane and nitrous oxide.

32. Projections of future climate change are based on global scenarios of future emissions of GHGs. These emission scenarios are subject to uncertainty, as they reflect patterns of economic development, population growth, consumption and other factors that are not easy to predict over a 100-year period. A large number of emission scenarios are used to account for this high degree of uncertainty. The most recent emission scenarios, which formed the basis of the climate projections of the IPCC TAR, were published in the IPCC Special Report on Emission Scenarios (SRES; Nakićenović and Swart 2000) and are known as the SRES scenarios.

33. For the illustrative SRES scenarios, carbon cycle models project atmospheric carbon dioxide concentrations of 540 to 970 ppm by 2100, with a range of uncertainty of 490 to 1260 ppm (Houghton et al. 2001). Based on these projections and those of other GHGs and sulphate aerosols, the IPCC TAR projects an increase in globally averaged surface temperature of 1.4 to 5.8 ^{o}C over the period 1990 to 2100, and a global mean sea-level rise of 9 to 88 cm over the same period. These results are for the full range of 35 SRES scenarios, based on a number of state-of-the-art global climate models. The IPCC TAR further states that it is very likely that nearly all land areas will warm more rapidly than the global average, particularly those at northern high latitudes in the cold season (Houghton et al. 2001).

34. Adverse impacts from climate change are expected in each of the sectors discussed in this report – coastal zones, water resources, agriculture, public health and infrastructure. These impacts will be distributed over many ecosystems and groups and sectors in society, but different ecosystems, groups and sectors will be affected differently, for three important reasons. First, the direct effects of climate change will be different in different locations. Climate models project greater warming at high latitudes than in the tropics, sea-level rise will not be uniform around the globe and precipitation patterns will shift such that some regions will experience more intense rainfall, other regions more prolonged dry periods and other regions both.

35. Second, there are differences between regions and between groups and sectors in society, which determine the relative importance of such direct effects of climate change. More intense rainfall in some regions may harm nobody; in other regions it could lead to devastating floods. Increased heat stress can be a minor inconvenience to young people; to the elderly it can be fatal. Extra tropical storms could kill tens of thousands of people in South Asia; in the United States they could lead to thousands of millions of dollars worth of damage.

36. Third, there are differences in the extent to which regions, groups and sectors are able to prepare for, respond to, or otherwise address the effects of climate change. When faced with the prospect of more frequent droughts, some farmers will be able to invest in irrigation technology; others may not be able to afford such technology, lack the skills to operate it or have insufficient knowledge to make an informed decision. The countries around the North Sea have in place advanced technological and institutional systems that enable them to respond proactively to sea-level rise; whereas small island States in the South Pacific may lack the resources to avoid impacts on their land, their people and their livelihoods.

37. The IPCC TAR noted that the magnitude of the impacts of climate change will depend on a variety of factors, including the magnitude of climate change and the interaction of climate change with other stresses. These other stresses include demographic pressures (e.g. population growth, rural–urban migration patterns) and socio-economic pressures (e.g. globalization, changing prices of natural resources and energy). In addition, the IPCC TAR noted that the impacts of climate change are likely to be experienced disproportionately by the poorest groups. These groups may include specific populations (e.g. ethnic tribes or nomadic groups) or people with specific livelihoods (e.g. fisher folk, smallholders or livestock herders).

B. Types of adaptation to climate change

38. Article 4.1(b) of the Convention refers to two options to address climate change: mitigation of climate change by reducing GHG emissions and enhancing sinks, and adaptation to the impacts of climate change. Most industrialized countries have committed themselves, as signatories to the Convention and its Kyoto Protocol, to stabilizing GHG emissions at 1990 levels by the year 2000 and to reducing their overall GHG emissions by at least 5 per cent compared to 1990 by the period 2008–2012. However, the lag times in the global climate system mean that no mitigation effort, however rigorous, will prevent climate change from occurring in the next few decades (Wigley 1998; Pittock and Jones 2000; Dessai and Hulme 2001).[2] The warming now being experienced is the result of emissions that took place over many decades. Indeed, the first impacts of climate change are already being observed in natural systems (e.g. Parmesan and Yohe 2003; Root et al. 2003).

39. Adaptation is therefore necessary (Parry et al. 1998). On the other hand, relying on adaptation alone, without taking steps to mitigate climate change, could well lead to a magnitude of climate change to which effective adaptation is no longer possible, or only at very high social and economic costs. In other words, adaptation to climate change is not an alternative to mitigation. Both are required to reduce the risks of climate change (Burton and Van Aalst 2004).

40. In spite of the fact that the Convention refers to both mitigation and adaptation, until recently national and international climate policy focused mainly on mitigation. On the one hand this reflected the concern of some that a stronger focus on adaptation would weaken society's willingness to mitigate climate change, on the other hand it signified the belief of others that the "invisible hand" of natural selection and market forces would bring about adaptation without the need for policy intervention (Kates 1997). Since the IPCC TAR established that humans are, at least in part, responsible for climate change

[2] Similarly, the GHGs presently being emitted will continue to cause warming for many decades to come.

and that some impacts can no longer be avoided, academic and policy attention in regard to adaptation has increased sharply (Burton et al. 2002).

41. There are various ways to classify or distinguish between adaptation options. First, depending on the timing, goal and motive of its implementation, adaptation can be either **reactive** or **anticipatory**. Reactive adaptation occurs after the initial impacts of climate change have become manifest, whereas anticipatory (or proactive) adaptation takes place before impacts are apparent. A second distinction can be based on the system in which the adaptation takes place: the **natural system** (in which adaptation is by definition reactive) or the **human system** (in which both reactive and anticipatory adaptation are observed). Within the human system a third distinction can be based on whether the adaptation decision is motivated by **private** or **public interests**. Private decision makers include both individual households and commercial companies, whereas public interests are served by governments at all levels. Figure 1 shows examples of adaptation activities for each of the five types of adaptation that have thus been defined.

42. An additional distinction that is often made is the one between **planned** and **autonomous** adaptation (Carter et al. 1994). Planned adaptation describes the result of decisions that are based on an awareness that conditions have changed or are about to change, and that some type of action is required to achieve, maintain or return to a desired state. This could, for example, mean building sea walls in anticipation of a rise in sea level, or investing in irrigation in anticipation of drier conditions.

43. In contrast, autonomous adaptation refers to the changes that natural and (most) human systems undergo in response to changing conditions in their immediate environment, irrespective of any broader plan or policy-based decisions. Such changes, for example, can be triggered by observed changes in weather patterns that result in shifting market signals or welfare changes (such as the price of crops and the occurrence of diseases). Examples of autonomous adaptations might include changes in farming practices, the purchase of air conditioning devices, insurance policies taken out by individuals and private companies, and changes in recreational and tourist behaviour. Autonomous adaptation in human systems would therefore be in the actor's rational self-interest, whereas the focus of planned adaptation is on collective needs (Leary 1999).

Figure 1. Matrix showing examples of the five prevalent types of adaptation to climate change, including examples of adaptation

		Anticipatory	Reactive
Natural systems			· Changes in length of growing season · Changes in ecosystem composition · Wetland migration
Human systems	Private	· Purchase of insurance · Construction of houses on stilts · Redesign of oil-rigs	· Changes in farm practices · Changes in insurance premiums · Purchase of air conditioning
	Public	· Early-warning systems · New building codes, design standards · Incentives for relocation	· Compensatory payments, subsidies · Enforcement of building codes · Beach nourishment

Source: Klein 1998; Smit et al. 2001.

44. Many of the actions taken by individuals, communities and companies as they adapt to climate change are likely to be autonomous (i.e. not requiring external intervention), particularly as such autonomous action has, in the past, been taken in response to variations in climate that have been natural, rather than human-induced. There is currently much interest in whether society can rely on autonomous

adaptation to reduce the potential impacts of climate change to an acceptable level, particularly considering that such initiatives would not require government intervention. In many parts of the world, however, the future impacts of climate change are likely to be substantially greater than those that have been experienced in the past as a result of natural climate variability alone. Such impacts may be more than many of those affected are able to handle effectively with autonomous adaptation, particularly given additional constraints, such as limited information, inadequate knowledge and insufficient access to resources.

45. As a result, it is now widely acknowledged that there is a need to start planning for adaptation, thus preparing for the impacts of climate change and facilitating and complementing autonomous adaptation initiatives. Article 3.3 of the Convention suggests that anticipatory planned adaptation, as well as mitigation, deserves particular attention. Anticipatory planned adaptation could take the following forms (Klein and Tol 1997; Huq and Klein 2003):

(a) Increasing the ability of physical infrastructure to withstand the impacts of climate change. One approach, for example, would be to extend the temperature or rainfall range that a system can withstand; another would be to modify a system's tolerance to loss or failure

(b) Increasing the flexibility of potentially vulnerable systems that are managed by humans. This could include allowing for mid-term adjustments in management practices, including changes in use or location

(c) Enhancing the adaptability of vulnerable natural systems. This could involve reducing stresses due to non-climatic effects, or removing barriers to the migration of plants or animals

(d) Reversing trends that increase vulnerability. This could range from reducing human activity in vulnerable areas to preserving natural systems that protect against hazards

(e) Improving public awareness and preparedness. This could include informing the public about the risks and possible consequences of climate change, as well as setting up early warning systems for extreme weather events.

C. The process of adapting to climate change

46. Planned adaptation is best seen as a process entailing more than merely the implementation of a policy or the application of a technology (referred to hereinafter as implementation). The process of **planned adaptation** has been described as a multistage and reiterative process, involving four basic steps (Klein et al. 1999): **information development and awareness-raising; planning and design; implementation; monitoring and evaluation**.

47. This process of planned adaptation can be conceptualized as depicted in figure 2 (Klein et al. 1999). Climate variability and/or climate change – together with other stresses on the environment brought about by existing management practices – produce actual or potential impacts. These impacts trigger efforts at mitigation to remove the cause of the impacts, or adaptation to modify the impacts. The process of adaptation is conditioned by policy criteria and development objectives, and interacts with existing management practices. It is important to note that figure 2 represents a simplified decision framework, which does not capture the multitude of actors involved in decision-making, the uncertainty

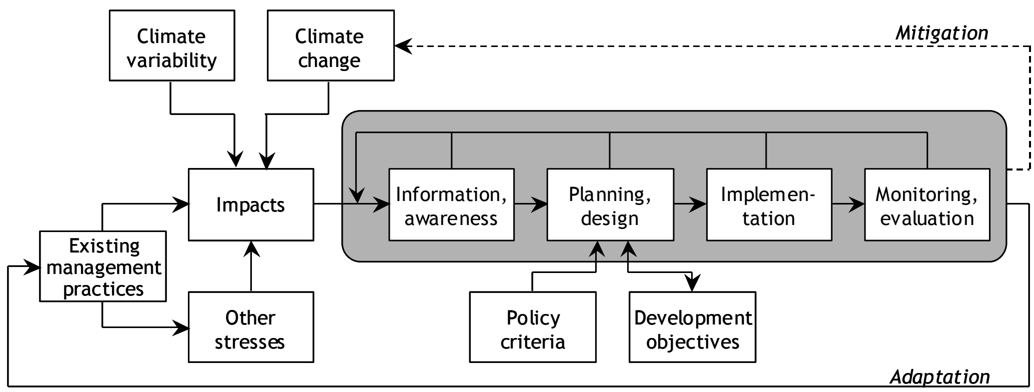
with which these actors are faced, the other interests they have, or the institutional and political environments in which they operate.[3]

48. A key point about figure 2 is that adaptation to climate change is an ongoing and reiterative process that includes information development, awareness-raising, planning, design, implementation and monitoring. Reducing vulnerability requires having mechanisms in place and technologies, expertise and other resources available to complete each part of this process. The mere existence of technologies for adaptation does not mean that every vulnerable community, sector or country has access to these options or is in a position to implement them.

49. As mentioned in section I, the IPCC TAR defined adaptive capacity as 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". Factors that determine a country's or community's adaptive capacity to climate change include its economic wealth, its technology and infrastructure, the information, knowledge and skills that it possesses, the nature of its institutions, its commitment to equity and its social capital (Smit et al. 2001). It is therefore not surprising that most industrialized countries have higher adaptive capacities than developing countries. For example, Bangladesh and the Netherlands share a similar physical susceptibility to sea-level rise, but Bangladesh lacks the economic resources, technology and infrastructure that the Netherlands can call on to respond to the potential impacts (Huq and Klein 2003).

50. On the other hand, having adaptive capacity is no guarantee that it is used successfully. In this respect, the development and use of new and existing information are especially important. For example, major coastal development and urbanization occurred on the east coast of the United States of America from 1966 to 1989, increasing exposure during a period when hurricane activity was well below average. New inhabitants were often ignorant of the hurricane risk, which became manifest with the more frequent and stronger hurricanes that began with Hurricane Hugo in 1989 (Pielke and Landsea 1998).

Figure 2: Conceptual framework showing (in the shaded area) the reiterative steps involved in planned adaptation to climate variability and change



51. The notion of adaptive capacity has brought to light the importance of considering the links between adaptation and development. It is recognized that climate change poses a threat to important development issues, such as water supply, food security, human health, natural resources and protection against natural hazards. This recognition has moved adaptation from being the "handmaiden to impacts

[3] Note also that adaptation can also happen effectively without awareness or coverage of all steps of the conceptual framework, especially when we are dealing with action by vulnerable communities at the subnational level. One needs to acknowledge that the main four steps presented above build on steps shown in figure 2.

research in the mitigation context" (Burton et al. 2002) to an activity that is considered crucial within the broader context of sustainable development. The link between adaptation and sustainable development is particularly relevant when seeking to enhance the capacity of countries and communities to adapt to climate change, which is often limited by a lack of resources, poor institutions and inadequate infrastructure, among other things (Smith et al. 2003). In addition, the notion of adaptive capacity has helped to demonstrate that adaptation is not a new activity only relevant when addressing climate change, but instead an ongoing process to reduce vulnerability both to today's and tomorrow's climate.

IV. Technologies for adaptation

52. In considering how vulnerable countries and communities might best adapt to climate change and so reduce their vulnerability, it is often assumed or asserted that part of the solution involves the use of technology and its transfer from place to place. This is the point of departure for the discussion in this section where we seek to outline a methodological basis underlying the process of transferring technology for adaptation. While there is no attempt to prescribe policy for "technology transfer", it is important to lay out some basic premises regarding the role of technology in the adaptation process. In essence, these premises represent a structure for enhancing the flows of technologies for adaptation that consists of four key elements, as described below. These elements infuse and guide the discussion in the sector-specific sections that follow, and the case study examples provided in chapter IX. Improving our collective understanding of how to better identify and apply technology for adaptation will better inform the policy process by clarifying the context and process in which technology is and might be used.

A. Technologies for adaptation to climate change

53. The idea of using technology to solve or alleviate an adverse situation is deceptively appealing. At its core, it reflects an optimistic view that whatever the complexity of the particular development challenge or environmental threat at hand, there is, or will be, a technological solution that is up to the task of dealing with it. This approach is not the one taken in this technical paper as it is akin to the simplistic notion that complex problems can be effectively addressed by throwing money at them. Those who have been active in working in applying technology to development challenges well understand that much more is involved. Nevertheless, technology has been an important factor in reducing society's vulnerability to ever-present weather related hazards, and will continue to be one among many contributors.

54. The first element involves improving an **understanding of the range of technologies for adaptation**. This is highly linked to the types of risk or hazard involved. As discussed in the previous section, the hazards for many economic sectors and communities are expected to increase because of climate change. It is important to note that the nature of the hazard under a changed climate will likely be no different than it is under the current climate. This implies that many existing technologies that have proven to be effective in reducing vulnerability to weather related hazards will also be important as technologies for adaptation to climate change.[4] Technologies will have to be adjusted to meet local needs, and technological development and innovation will continue to increase the effectiveness and efficiency of existing technologies. But, the technologies themselves are already readily available and widely used. Successful adaptation is possible without having to rely on new technologies developed specifically for adaptation.

55. To understand the implications of this premise, it is important to examine what technology or what kinds of technology are in question. At the broadest level of classification, technologies for

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[4] However, in the long-term these technologies will come under additional pressure from climate change and therefore may not necessarily remain appropriate.

adaptation can comprise **hard** technologies, such as drought-resistant seeds, seawalls and irrigation technology, and **soft** technologies, such as insurance schemes,[5] crop rotation patterns and set-back zones, as well as information and knowledge. A successful adaptation strategy would typically combine both hard and soft technologies. For example, an early warning system would rely on hard technologies such as measuring devices and information technology, but also on knowledge and skills to strengthen awareness and promote appropriate action when a warning is given. Within these two broad categories, we have further classified technologies for adaptation to climate change into four major categories: traditional, modern, high technology and future technology. Each is described briefly below.

56. **Traditional technologies** consist of the many approaches that have been developed and applied to adapt to weather hazards in traditional societies. Examples include the use of herbal or traditional medicine; the building of houses on stilts to keep them above flood waters; the design of buildings to ensure that the interior is warm (when the weather or climate is cold) or cool (when the weather or climate is hot); bunds, levees, or dykes to keep out flood waters and so forth. Traditional technology is not necessarily fixed in either design or use and can be improved upon. For example, traditional herbal medicine is now being expanded as new varieties of natural treatments are found, traditional housing designs can be combined with stronger and lighter modern materials, and the construction of dykes can be improved with modern and stronger designs and materials. Indeed, for traditional technologies the main opportunity is for the improvement of the design and quality of traditional technology using modern knowledge (materials, design, etc.). For this, enhanced research and development capacity in developing countries themselves is essential. In other words, traditional technology can best be improved in the place where it is used and in cooperation with those who use it.[6]

57. **Modern technologies** are those that have been newly created since the industrial revolution beginning in Western Europe in the late eighteenth century. They include many new, synthetic materials, (e.g. plastics, metallic alloys, fabrics), new modes of transport (e.g. steam engine, internal combustion engine, jet engine), new chemicals (e.g. fertilizers, pesticides, solvents), improved designs (e.g. sanitation systems, housing, commercial buildings), new varieties of crops (e.g. hybrid corn) and new water use technology (e.g. drip irrigation). These technologies have been commercialized and are widely, though not universally, available. There are many more possible examples. Modern technology can be adopted and used by developing countries subject to their own criteria of choice, but sometimes it has been imported or imposed without a full realization of its likely consequences. This is not necessarily an argument for not importing modern technology, but it is an argument for doing so in the full knowledge of its implications, so that appropriate measures can be taken to counter adverse effects as well as to reap the benefits.

58. **High technologies** are some of the more recently developed technologies that derive from scientific advances in recent decades including information and communication technology, earth observation systems and geographic information systems (GIS), genetically modified organisms, and the like. **Future technologies** are those that are yet to be invented or developed. Examples might include a malaria vaccine, or various forms of geo-engineering to reduce climate impacts, or crops that need little or no water. The limits to such future technologies if any, are in the human imagination and ingenuity.

59. Each of the above types of technologies may have an important role to play in meeting the challenge of adaptation to climate change. However, the role of each type of technology described above will be determined both by the degree of climate change, and by the prevailing social, economic and

[5] Insurance schemes are a soft technology in the sense that they represent an approach to respond to climatic hazards. They incorporate elements of awareness building, information dissemination, and the funding of adaptation actions.
[6] This does not assume that modern technologies are necessarily better that traditional ones.

environmental conditions in a community and the existing management practices in a system or sector.[7] As discussed in the next section, this requires an understanding of how technology fits into the process of adaptation.

B. The role of technology in adaptation

60. The second element involves an **identification of the appropriate role of technology**. Successfully identifying the role of technology in adaptation to climate change (i.e. actions that reduce vulnerability to the impacts of climate change) may well include actions that are directed at improving prevailing social, economic and environmental conditions and management practices in a system or sector. For the purposes of this technical paper, we identify roles of technology within the four-stage process of adaptation described earlier consisting of (i) information development and awareness-raising, (ii) planning and design, (iii) implementation, and (iv) monitoring and evaluation. Each is briefly described below.

61. **Information development and awareness**. Technologies for data collection and information development are prerequisites for adaptation, particularly to identify adaptation needs and priorities. The more relevant, accurate and up to date the data and information available to the decision maker, the more targeted and effective adaptation strategies can be. There are several large-scale global and regional data repositories that have been established for a great number of climatic and socio-economic variables relevant to economic sectors and communities.

62. **Planning and design**. When the available data and information point towards a potential problem that would justify taking action, the next stage is to decide which action could best be taken and where and when this could best be done. The answers to these questions depend on the prevailing criteria that guide local, national or regional policy preparation, as well as on existing development and management plans that form the broader context for any adaptation initiative. Important policy criteria that could influence technology decisions include cost-effectiveness, environmental sustainability, cultural compatibility and social acceptability.

63. **Implementation**. Once all adaptation options have been considered and the most appropriate strategy has been selected and designed, implementation of the strategy is the next stage. An adaptation strategy can include the application of any of the types of technology described previously. One of the critical components is the presence of appropriate and effective institutions. Institutions vary widely across scales (small to large, local to national), sectors (such as agriculture, water, forestry, transport) and from formal (e.g. ministry or department of environment, National Adaptation Programmes of Actions (NAPA) secretariat) to informal (e.g. a local village community). Whereas formal institutions can respond to adaptation needs and challenges within their regulations, institutional guidelines and allocated resources, informal institutions often respond to specific adaptation challenges, such as drought, flood or cyclones, as self-organized and self-motivated systems.

64. **Monitoring and evaluation**. It is recommended practice in any field of policy that the performance of technological interventions be periodically or continuously evaluated against the original objectives. Such evaluation can yield new insights and information, which could give rise to adjustments in the technology or strategy as appropriate. This process is illustrated in figure 2 by the feedback loop from evaluation within the shaded box. This evaluation must be distinguished from the evaluation exercise that is done to identify the most appropriate technology, and which is part of the planning and design phase.

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[7] These technology types also have a community/regional dimension: what is traditional for one community could be a future technology for another, and may be an advanced technology for a third.

C. Flows of technology transfer in the context of adaptation

65. The third element is the actual process for the **transfer** of the technology, which in this technical paper is being called the "flow of technology" in the sector-specific sections that follow. This term implies and is generally understood to mean that there is more, and different, and better technology in some places than others, and that part of the task in applying technology therefore involves the movement, "transfer", of that technology from where it is found to where it is needed. However, as we argue below this is only part of the story.

66. As currently understood, technology transfer concerns the flow of experience, know-how and equipment between and within countries (IPCC 2000), and has long been a priority under the Convention. Improving access to technology information, creating enabling environments, including removal of barriers, and strengthening local capacity are key elements of an overall integrated framework to enhance technology transfer. Yet, understanding how this framework applies to the unique circumstances posed by the challenge of adapting to climate change is as critical as the process of identifying the range of suitable technologies.

67. The IPCC defines mitigation as an anthropogenic intervention to reduce the sources or enhance the sinks of GHGs. It defines adaptation as an adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects.[8] These are two fundamentally different processes that pose very different entry points and implications for technology transfer. The approach to transferring technologies for adaptation should therefore differ from the approach to mitigation largely because the issues involved are different and the technology needs of countries are different. This is a central theme that permeates the sector-specific discussions of technologies that follow in chapters IV through VIII.

68. Until very recently, technology transfer to address climate change has focused almost exclusively on mitigation issues. And, given that the overwhelming majority of global GHG emissions are from the energy sector, clean energy supply alternatives have emerged as the dominant focus for technology transfer. These include renewable energy technologies (e.g. photovoltaic systems, wind turbines) and high efficiency combustion technologies (e.g. natural gas combined cycle systems).

69. Using the classification system described earlier, these types of technologies are modern to high technologies, and tend to be capital-intensive, involve substantial up-front investments, and require the removal of institutional and economic barriers for successful transfer. Moreover, because the technologies are mostly unavailable in developing countries, it has been a priority on the part of developing country decision makers to gain access as a means of promoting infrastructure development, modernizing energy delivery, and stimulating private sector investment. Hence, it is important to recognize that technology transfer in the climate context has come to focus squarely on flows of experience, know-how and equipment between countries (i.e. from developed to developing countries Parties) rather than within countries.

70. As the Convention process has taken up the question of technology for adaptation there has been a tendency for some of the ideas about technology transfer for mitigation to be carried forward into the adaptation domain. In so doing there is a danger that some important distinctions between the processes of mitigation and adaptation may be overlooked. It is important therefore to recognize some of the ways in which adaptation is different.

71. First, **adaptation is not new** in the way that mitigation is new. Before the climate change problem came to be identified and recognized first by atmospheric scientists and then by the global community there was no perceived need to reduce GHG emissions. On the other hand, people

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[8] For additional information, see the *User's Guidebook for the Adaptation Policy Framework*, UNDP/GEF, 2004.

everywhere and always have adapted to their local climatic conditions, including the way in which weather varies from year to year and sometimes is manifested in extreme events. Initially in the climate negotiations it was sometimes assumed that a clear distinction could be made between “normal” climate and climate change. Gradually it has come to be accepted that from the perspective of adaptation there is no scientific basis for such a distinction, and that adaptation to climate change can best begin by improvements in adaptation to current climate including its variability and extremes.

72. Second, the **sectors that need technology for adaptation are ubiquitous**. Rather than a dominant sector like energy, it is clear that technologies for adaptation are and will be needed in all socio-economic sectors (health, water, agriculture, etc.), with each sector providing its own unique set of institutional, economic and regulatory barriers that need to be addressed. Hence, the stakeholders involved and barriers confronted will likely be quite different and display uneven levels of overlap across sectors.

73. Third, **most technologies for adaptation are already readily available in developing countries**. Whether it is a coastal revetment, a vaccination programme, or a drip irrigation system, examples abound within developing countries of successful implementation and operation. Adaptation technology is rich in variety and often is related to the local environmental and socio-economic circumstances where it is used and has been developed. It is by no means concentrated in developed countries. Clearly, however, although the world is rich in technology for adaptation, people are not making satisfactory use of it.

74. Fourth, the **most needed technologies for adaptation** are probably **not likely to be as capital intensive** as those for mitigation. Some technologies will be, such as coastal protection structures for example, but for the most part technology investment levels for adaptation will tend to be more amenable to small-scale intervention. Fifth, the **stakeholders involved and barriers confronted** will likely be **quite different and display uneven levels of overlap across sectors**.

75. Technology transfer for adapting to climate change poses a different, more complex challenge than mitigation on at least one more level. There is inherently more uncertainty regarding vulnerability, as impacts tend to be highly site-specific and not easily generalizable across spatial and temporal scales. Transfer of technologies for mitigating GHG emissions is fairly straightforward insofar as such technologies have a simple and clear objective (i.e. the reduction or avoidance of GHG emissions) and tend to target specific, well-known emitting sectors where considerable case study literature exists of mitigation technology applications from which lessons can be learned and taken into account. For adaptation, the inherent uncertainty carries over to identification of appropriate adaptation measures, options and technologies, as well as the stakeholders that are affected and barriers that need to be confronted.

76. There are likely to be several beneficial policy implications of differential treatment of mitigation and adaptation in the area of technology transfer. First, it may lead to an emphasis on the more efficient diffusion of experience, know-how and equipment within countries. Second, it may lead to a policy emphasis on existing technologies that are currently proving to be effective in addressing current climatic extremes and shocks. Indeed, **the most effective technologies for adaptation may be those that are already available elsewhere in the country, and which are simple and well-understood**. Finally, insofar as the diffusion of technology is well suited to the specific challenges posed by adaptation, a strategically effective allocation of resources would likely ensue.

77. In conclusion, the way in which technology transfer has been fundamentally understood and practised in terms of mitigation does not apply in the same way to adaptation. This is due to the fact that to a substantial degree – as the following chapters will aim to demonstrate – most of the technologies already exist and are theoretically available in the developing countries where they are needed. In fact,

much of the technology is already being used to some extent. Instead, technology transfer as understood in the context of adaptation requires careful attention to two complementary elements: the existence of barriers to the accessibility of locally available technologies and the need for strengthened local capacity to address and overcome these barriers. Much of the discussion in chapters IV through VIII suggests modalities for addressing these two elements.

D. Criteria in selecting technologies for adaptation

78. In the case of modern technology, the history of development over the past 200 years has been the history of the adoption of modern technology in developing countries. This has been a complex process and has involved, and still involves, much controversy. In many instances the import of modern technology has brought substantial costs as well as benefits. Modern medicine, for example, has contributed substantially to health, and has led to increases in longevity and consequently to substantial growth in population.

79. The fourth and final element referred to in paragraph 52 above is the criteria applied in the selection of technologies for adaptation. This is an important element due to the fact that caution needs to be exercised in the introduction of modern technology to avoid unintended side effects. In agriculture the introduction of large-scale monoculture to increase productivity can generate more unemployment or underemployment among those displaced, and can create new vulnerabilities to plant diseases and pest infestations which would be less likely to occur under traditional practices of mixed agriculture and inter-cropping.

80. The development and application of suitable criteria, motivated by the exigencies of the adaptation challenge, will help to avoid some of these types of problems. For the purposes of this technical paper, there are three essential criteria, as briefly described below.

81. **Benefits, including economic/financial and costs**. Any chosen technology should be subject to some efficiency criterion. Before adopting any specific adaptation measure or set of measures it is important to be satisfied that the benefits of doing so exceed the costs. It is important to note that “benefits” as used here is broadly defined to include monetary and non-monetary benefits. Even when it is the case that benefits exceed costs, it does not necessarily follow that funds will be available to invest in the proposed adaptation measures (technology). This constraint can be eased by the provision of additional funds to assist the adaptation process as is currently being done on a relatively small scale under the Least Developed Country Fund, the Special Climate Change Fund, and the Strategic Priority on Adaptation funds under the Global Environment Facility and the Adaptation Fund to be generated by the clean development mechanism under the Kyoto Protocol. Policy implications: consider expansion of funds for adaptation where benefits exceed costs. The indications are that these funds will have to grow considerably if the need for additional adaptation funds is to be met as the climate changes. Alternatively, some new or consolidated funds might be created especially with technology transfer in mind.

82. **Equity**. An important consideration in the choice of technology for adaptation is its distributional effects. In choosing among alternatives for adaptation to climate change, developing country governments may wish to consider which segments of the population will particularly benefit, and where and upon whom the adverse effects may fall. Policy implications: Consideration needs to be given to other policy objectives in selecting adaptation measures for climate change. Some options may serve to reduce poverty (a common development objective), whereas others may serve to benefit only a few and tend to increase inequity.

83. **Social and legal acceptability**. Some adaptation options, while efficient (favourable benefit-cost ratio) and reasonably equitable, may be politically, socially, or legally unacceptable. In some

instances a simple change in law may be sufficient. Often, changes in cultural values and attitudes are involved, which can be much harder to change. Policy implication: attempts to introduce adaptation measures that are not well supported or accepted by the community are likely to fail. A fourth consideration is **technological** change itself. Sometimes technologies which can serve as means of adaptation to climate change are old or obsolete technologies from another part of the world (or are about to become so).

V. Coastal zones

84. After introducing the challenge of climate change in coastal zones, this section presents and discusses technologies for adaptation to climate change in coastal zones, following the framework outlined in chapter II. It then describes the role of technology in coastal adaptation, including three recent trends in technology use, and discusses opportunities for technological innovation. The section builds on earlier work by the UNFCCC (in particular the technical paper on coastal adaptation technologies; FCCC/TP/1999/1) and the IPCC (in particular the chapter "Coastal Adaptation" of the IPCC Special Report on Methodological and Technological Issues in Technology Transfer; Klein et al. 2000).

A. Introduction

85. The interface of land, sea and air features the most dynamic natural environments on Earth. A variety of coastal systems produce a large number of goods and services that are valuable to society. This diversity has attracted many people and major investments to coastal zones, even to places that are susceptible to hazards, such as storm surges and coastal erosion. A large part of the global human population now lives in coastal areas and many coastal locations exhibit a growth in population and gross domestic product (GDP) higher than their national averages, as well as substantial urbanization.

86. Extensive research has shown that today's hazard potential will increase in many coastal areas because of climate change. Many climate factors have relevance to the coast, most notably sea level and the frequency and intensity of extreme events, such as cyclones and storm surges. Global mean sea level is projected to rise between 9 and 88 cm between 1990 and 2100, with a central value of 48 cm, for the full range of SRES scenarios (Church et al. 2001). The projected central value of 48 cm gives an average rate of sea-level rise of 2.2 to 4.4 times the observed rate over the 20th century. Even with drastic reductions in greenhouse gas emissions, sea level will continue to rise for centuries beyond 2100 because of the long response time of the global ocean system.

87. A major uncertainty is how the global mean sea-level rise will manifest itself on a regional scale. All models analysed by the IPCC TAR show a very uneven spatial distribution of sea-level rise. Some regions show a sea-level rise substantially higher than the global average (in many cases more than twice the average) and others a sea-level fall (Church et al. 2001). However, the patterns produced by the different models are not similar in detail. This lack of similarity means that confidence in projections of regional sea-level changes is low, although it is clear that they are important with respect to impacts of sea-level rise on coastal zones.

88. Sea-level rise is not the only climate related effect relevant to coastal zones. However, confidence in model projections of other manifestations of climate change is generally still low. An important issue is the extent to which the frequency, intensity and spatial patterns of extreme events will change. A rise in mean sea level will lead to a decrease in the return period of storm surges, but it is unclear if the variability of storm surges itself will change. Changes that are considered likely over some areas are increases in peak wind intensities and mean and peak precipitation intensities of tropical cyclones. However, changes in tropical cyclone location and frequency are still uncertain (Houghton et al. 2001).

89. When considering the potential impacts of sea-level rise on coastal zones, it is not the global, absolute sea level that matters but the locally observed, relative sea level, which takes into account regional sea-level variations and vertical movements of the land. For example, some densely populated deltas are characterized by a strong downward movement of the land, which will add to absolute sea-level rise. Excessive groundwater withdrawal is a particular problem in many coastal cities, exacerbated by the cities' rapid growth. As the water table beneath a city drops, formerly saturated sediments can consolidate irreversibly, causing the ground surface to subside rapidly. Subsidence rates can be rapid, locally reaching one metre per decade. For example, land subsidence around Tianjin, China, was about 5 cm/year in the late 1980s and locally up to 11 cm/year (Nicholls 1995).

90. Irrespective of the primary cause of sea-level rise (climate change, natural or human-induced subsidence, dynamic ocean effects), exposed natural coastal systems can be affected in a variety of ways. From a societal perspective, the six most important biogeophysical effects are: increasing flood frequency probabilities; erosion; inundation; rising water tables; saltwater intrusion; and biological effects (Klein and Nicholls 1998).

91. These biogeophysical effects will have consequent effects on ecosystems and eventually affect socio-economic systems in the coastal zone. However, owing to the great diversity and variation of natural coastal systems and to the local and regional differences in relative sea-level rise, the occurrence of and response to these effects will not be uniform around the globe. Coastal environments particularly at risk include tidal deltas and low-lying coastal plains, sandy beaches and barrier islands, coastal wetlands, estuaries and lagoons, and coral reefs and atolls (Bijlsma et al. 1996). Increased coastal flooding is expected to be most severe in South and South-East Asia, Africa, the southern Mediterranean coasts, the Caribbean and most islands in the Indian and Pacific Oceans (Watson et al. 1998; Nicholls et al. 1999).

92. The effects of climate change and associated sea-level rise threaten economic sectors to a varying extent. The potential socio-economic impacts of sea-level rise can be categorized as follows (Klein and Nicholls 1998):

(a) Direct loss of economic, ecological, cultural and subsistence values through loss of land, infrastructure and coastal habitats

(b) Increased flood risk to people, land and infrastructure and economic, ecological, cultural and subsistence values

(c) Other impacts relating to changes in water management, salinity and biological activity.

93. Table 1 lists the most important socio-economic sectors in coastal zones and indicates from which of the aforementioned biogeophysical effects of climate change they are expected to suffer direct impacts. Indirect impacts, for example impacts on human health resulting from deteriorating water quality, are also likely to be important to many sectors, but these are not shown in table 1.

Table 1. Qualitative overview of direct socio-economic impacts of climate change on a number of sectors in coastal zones

Sector	Biogeophysical effect					
	Flood frequency	Erosion	Inundation	Water table rise	Saltwater intrusion	Biological effects
Water resources			✓	✓	✓	✓
Agriculture	✓		✓	✓	✓	
Human health	✓		✓			✓
Fisheries	✓	✓	✓		✓	✓
Tourism	✓	✓	✓			✓
Human settlements	✓	✓	✓	✓		

Source: Klein and Nicholls 1998.

B. Adaptation strategies

94. In line with the conceptual framework presented in chapter II, this section presents examples of technologies that can be employed to develop information and raise awareness for adaptation in coastal zones, to plan and design adaptation strategies, to implement them, and to monitor and evaluate their performance. Note that no attempt has been made to provide all-inclusive lists of technologies for various types of coastal environments (e.g. coral atolls, coasts of inland waters, continental coasts). The technologies listed in this section are meant to be illustrative and to encourage the reader to consider as wide a spectrum of technologies for adaptation as possible.

1. Information development and awareness-raising

95. Data collection and information development are prerequisites for coastal adaptation, in particular to identify adaptation needs and priorities. The more relevant, accurate and up to date the data and information available to the coastal manager, the more targeted and effective adaptation strategies can be. Coastal adaptation requires data and information on coastal characteristics and dynamics, patterns of human behaviour, as well as an understanding of the potential consequences of climate change. It is also essential that there is a general awareness among the public, coastal managers and decision makers of these consequences and of the possible need to take appropriate action.

96. Large-scale global and regional data repositories have been established for a great number of climatic and socio-economic variables relevant to coastal zones. These sources of data may be accessed, displayed and downloaded from the Internet. Sea-level data, for example, may be obtained from the Permanent Service for Mean Sea Level (http://www.nbi.ac.uk/psmsl/index.html), the Global Sea Level Observing System (http://www.pol.ac.uk/psmsl/programmes/gloss.info.html) and the University of Hawaii Sea Level Center (http://uhslc.soest.hawaii.edu/). Additional global data sets can be accessed via the International Research Institute for Climate and Society/Lamont-Doherty Earth Observatory of Columbia University (IRI/LDEO) Climate Data Library (http://ingrid.ldeo.columbia.edu/), the International Council for Science (ICSU) World Data Center (http://www.wdc.rl.ac.uk/wdcmain/), IGBP/IHDP-LOICZ (http://www.loicz.org/), the Center for International Earth Science Information Network (http://www.ciesin.org/) and the IPCC Data Distribution Centre (http://ipcc-ddc.cru.uea.ac.uk/). The last centre also provides climate and socio-economic scenarios.

97. The Global Earth Observation System of Systems, adopted in 2004, complements these data repositories. It represents an international cooperative to enhance preparedness for environmental disasters, bringing together existing and new hardware and software. In addition, the World Meteorological Organization has ongoing weather-watch programmes for short-range weather prediction and emergency response.

98. Useful as they may be, adaptation to climate change will often require additional, more detailed information than these global data sets and initiatives can provide. Table 2 lists a number of technologies that can serve to increase the understanding of the coastal system (which involves data collection and analysis), to conduct climate impact assessment in coastal zones (so that potential impacts can be quantified for given scenarios) and to raise public awareness (that some form of adaptation is necessary).[9] Many technologies listed in table 2 represent “soft” options that are vital to building capacity to cope with climatic hazards. Where appropriate, reference is made to publications that either describe the technology in detail or provide examples of its application. Further information on a broad range of technologies for coastal system description can be found in Morang et al. (1997a), Larson et al. (1997), Morang et al. (1997b) and Gorman et al. (1998). Capobianco (1999) discussed technologies in relation to integrated coastal zone management.

99. Some technologies listed in table 2 make use of GIS. GIS combines computer mapping and visualization techniques with spatial databases and statistical, modelling and analytical tools. It offers powerful methods to collect, manage, retrieve, integrate, manipulate, combine, visualize and analyse spatial data and to derive information from these data. GIS is an example of a technology that is cross-cutting, in the sense that it contributes not only to information development and awareness-raising but also to the other three steps presented in chapter II. Collected data can be stored in a geographical information systems, combined to develop new insights and information, and visualized for interpretation and educational purposes. As an example, chapter IX presents a case study of the new coastal vulnerability assessment tool DIVA (Dynamic and Interactive Vulnerability Assessment).[10]

2. Planning and design

100. When the available data and information point towards a potential problem that would justify taking action, the next stage is to decide which action could best be taken and where and when this could best be done. The answers to these questions depend on the prevailing criteria that guide local, national or regional policy preparation, as well as on existing development and management plans that form the broader context for any adaptation initiative. Important policy criteria that could influence adaptation decisions include cost-effectiveness, environmental sustainability, cultural compatibility and social acceptability. In addition, countries may choose to take a precautionary approach when postponing action would involve substantial risks, even though uncertainty may still be considerable.

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[9] Many of the technologies presented in table 2 are not necessarily readily available in many countries and some of them are capital intensive.

[10] See FCCC/TP/1999/1, annex III, for additional examples of technologies to assess coastal processes, characteristics and vulnerabilities including data gathering technologies and data management and decision support technologies and for examples of demonstrated technologies to support implementation of coastal adaptation options for retreat (managed), accommodation or protection against sea-level rises.

Table 2. Examples of important technologies for coastal adaptation to climate change for collecting data, providing information and increasing awareness.

Application	Technology	Additional information
Coastal system description		
• Coastal topography and bathymetry	- Mapping and surveying	- Birkemeier *et al.* (1985, 1999); Stauble and Grosskopf (1993)
	- Videography	- Debusschere *et al.* (1991); Holman *et al.* (1994); Plant and Holman (1997)
	- Airborne laser scanning (lidar)	- Lillycrop and Estep (1995); Sallenger *et al.* (1999)
	- Satellite remote sensing	- Leu *et al.* (1999)
• Wind and wave regime	- Wave rider buoys	- Morang *et al.* (1997a)
	- Satellite remote sensing	- Martinez-Diaz-de-Leon *et al.* (1999)
• Tidal and surge regime	- Tide gauges	- Pugh (1987); Zhang *et al.* (1997)
• Relative sea level	- Tide gauges	- Emery and Aubrey (1991); Woodworth (1991); Gröger and Plag (1993); Nicholls and Leatherman (1996); NOAA (1998)
	- Historical and geological methods	- Van de Plassche (1986)
• Absolute sea level	- Satellite remote sensing	- Nerem (1995); Fu *et al.* (1996); Nerem *et al.* (1997); Cazenave *et al.* (1998)
	- Tide gauges, satellite altimetry, global positioning systems	- Douglas (1991); Baker (1993); Miller *et al.* (1993); Zerbini *et al.* (1996); Neilan *et al.* (1997)
• Past shoreline positions	- Historical and geological methods	- Crowell *et al.* (1991); Beets *et al.* (1992); Crowell *et al.* (1993); Moore (2000)
• Land use	- Airborne and satellite remote sensing	- Redfern and Williams (1996); Clark *et al.* (1997); Henderson *et al.* (1999)
• Natural values	- Resource surveys	- Lipton and Wellman (1995); Turner and Adger (1996)
• Socio-economic aspects	- Mapping and surveying	- Penning-Rowsell *et al.* (1992)
• Legal and institutional arrangements	- Interviews, questionnaires	- English Nature (1992)
• Socio-cultural factors	- Interviews, questionnaires	- Tunstall and Penning-Rowsell (1998); Tunstall (2000)
Climate impact assessment		
• Index-based methods	- Coastal vulnerability index	- Hughes and Brundrit (1992); Gornitz *et al.* (1994); Shaw *et al.* (1998)
	- Sustainable capacity index	- Kay and Hay (1993); Yamada *et al.* (1995); Nunn *et al.* (1994a,b)
• (Semi-) quantitative methods	- IPCC common methodology	- IPCC CZMS (1992); Bijlsma *et al.* (1996)
	- Aerial-videotape assisted vulnerability assessment	- Leatherman *et al.* (1995); Nicholls and Leatherman (1995)
	- UNEP impact and adaptation assessment	- Klein and Nicholls (1998, 1999)
• Integrated assessment	- Coupled models	- Engelen *et al.* (1993); Ruth and Pieper (1994); West and Dowlatabadi (1999)
Awareness-raising		
• Printed information	- Brochures, leaflets, newsletters	
• Audio-visual media	- Newspapers, radio, television, cinema	
• Interactive tools	- Board-games	
	- Internet	
	- Computerized simulation models	

Source: Klein et al. 2000, 2001.

Note: This table is not intended to provide an exhaustive list of applications and technologies.

101. Coastal planners will always face a certain degree of uncertainty, not only because the future is by definition uncertain, but also because knowledge of natural and socio-economic processes is and always will remain incomplete. This uncertainty requires planners to assess the environmental and societal risks of climate change with and without adaptation. The information thus obtained can help to determine the optimal adaptation strategy and timing of implementation. There are a number of decision tools available to assist in this process. Examples of these tools include cost-benefit analysis, cost-effectiveness analysis, risk-effectiveness analysis and multicriteria analysis. The last technique is particularly relevant when great significance is attached to values that cannot be easily expressed in monetary terms.

102. In combination with scenarios of relevant developments and models to assess and evaluate changes in important natural and socio-economic variables (including climate), GIS can assist planners in identifying appropriate technologies for adaptation, as well as the optimal locations for their application, depending on the criteria of the decision maker. One simple, first-order application of GIS in coastal adaptation would be overlaying scenarios of sea-level rise with elevation and coastal development data to define impact zones. More sophisticated applications may include the modelling of morphodynamic and ecological responses to climate change. In addition, GIS allows for the non-invasive, reversible and refinable testing of specific technologies for adaptation before these are implemented in the real world. After implementation, newly acquired data can be analysed to evaluate technology performance. Once created, a GIS database will have further utility in other aspects of management and policy.

103. The modelling of potential futures based on plausible scenarios is pertinent for the planning and design of technologies for adaptation, when relevant impacts are quantified, alternative adaptation options are evaluated and one course of action is selected. Climate impact assessment requires models of relevant changes in morphological, ecological and human factors, as well as their interaction over appropriate time scales (i.e. a decade or longer). The necessary modelling capabilities are increasing rapidly and current developments in information technology are facilitating the transfer and application of these tools as they are developed. However, the limitations inherent in all models (i.e. they are representations of a part of reality for a specific purpose) must not be overlooked. Human expertise and interpretation remain essential for the intelligent use of any model.

104. The quality and effectiveness of the planning and design process is influenced by the context in which decisions are made. For example, coastal management in many countries used to be top-down by nature, but as public interest and involvement in coastal issues have grown, so has resistance to top-down decision-making (e.g. Taiepa et al. 1997). The successful implementation of many coastal policies, including adaptation to climate change, is now increasingly dependent on public acceptance at the community level. Hence, in addition to informing the public so as to raise their awareness of the issues at stake (see above), it is also important to involve them throughout the planning process. Gaining public acceptance is an important prerequisite for identifying and transferring appropriate technologies for adaptation. Further, local expertise will be required for successful technology implementation, application, maintenance and enforcement.

105. In some settings, however, public involvement can be difficult to accomplish. In situations where there is little truly private land, coastal inhabitants may have little long-term stake and therefore interest in the land they occupy (e.g. in parts of Tonga; Nunn and Waddell 1992). Further, governments may have neither the resources to address countrywide coastal or other forms of natural resource management nor, compared to long-resident inhabitants, the local knowledge or experience that are essential for effective management (e.g. in parts of Fiji; Nunn et al. 1994a).

106. In response to difficulties encountered in planning and designing adaptation strategies, a number of frameworks have been developed to assist in these activities. One recent decision framework that has

relevance to the planning and design of adaptation is the Adaptation Policy Framework of the United Nations Development Programme (APF; Lim and Spanger-Siegfried 2005). The APF is intended to complement existing policymaking relating to climate change in developing countries, including processes of assessment, project development and monitoring. It is structured around the following four major principles:

(a) Adaptation to short-term climate variability and extreme events is explicitly included as a step towards reducing vulnerability to longer-term climate change

(b) Adaptation policy and measures should be assessed within a developmental context

(c) Adaptation occurs at different levels in society, including the local level

(d) Both the strategy and process by which adaptation activities are implemented are equally important.

3. Implementation

107. Once all options for coastal adaptation have been considered and the most appropriate strategy has been selected and designed, implementation of the strategy is the next stage. An adaptation strategy can include the application of technology, but this does not have to be the case. In coastal zones, an adaptation strategy to sea-level rise can comprise one or more options that fall under the three broad categories protect, retreat and accommodate (IPCC CZMS 1992). Table 3 provides an overview of these options and the technologies that make them possible (see also NRC, 1987; IPCC CZMS 1990; Bijlsma et al. 1996). It should be noted that, in addition to the subdivision between protect, retreat and accommodate, there are various other ways to classify or distinguish between different adaptation strategies, both in generic terms (e.g. Smit et al. 2000) and for coastal zones (e.g. Kay et al. 1996; Pope 1997).

108. Klein and Nicholls (1998) concluded that most of the options listed in table 3 require strategic planning, whereas few would occur autonomously. In addition, options to protect against sea-level rise can be implemented both reactively and proactively, whereas most retreat and accommodation options are best implemented in an anticipatory manner. To date, the assessment of possible adaptation strategies in coastal zones has focused mainly on protection. Bijlsma et al. (1996) noted the need to identify and evaluate the full range of options listed in table 3. The range of appropriate options will vary among and within countries, and different socio-economic sectors may prefer competing adaptation options for the same area. The existence of such a broad range of options is one of the reasons why adaptation to climate change is recommended to take place within the framework of integrated coastal zone management.

109. Table 3 combines hard technologies, such as dikes, levees and floodwalls, and soft technologies, such as evacuation systems. Note that there are also a range of applications that require only limited technology, such as increasing or establishing set-back zones and creating upland buffers.

110. In countries with insurance markets that cover climate risks, insurance can have a positive or a negative role in promoting adaptation to climate change and any associated technology transfer. This may happen directly via contacts with customers or indirectly via the lobby institutions of the insurance industry. Technology underpins this interaction, as improving data management and modelling capability give the insurance industry more detailed information of both the risks and opportunities that climate variability and change present. However, more knowledge may benefit the insurance industry, but it does not necessarily lead to overall social benefits. Clark (1998) argued that partnerships between governments and the insurance industry can benefit both the industry and wider society in terms of reduced exposure and maintain the long-term viability of the insurance industry.

Table 3. Examples of important technologies to protect against, retreat from or accommodate sea-level rise

Application	Technology	Additional information
Protect		
• Hard structural options	- Dikes, levees, floodwalls - Seawalls, revetments, bulkheads - Groynes - Detached breakwaters	- Pilarczyk (1990); Silvester and Hsu (1993)
	- Floodgates, tidal barriers	- Gilbert and Horner (1984); Kelly (1991); Penning-Rowsell et al. (1998)
	- Saltwater intrusion barriers	- Sorensen et al. (1984)
• Soft structural options	- Periodic beach nourishment	- Delft Hydraulics and Rijkswaterstaat (1987); Davison et al. (1992); Stauble and Kraus (1993); Hamm et al. (1999)
	- Dune restoration and creation	- Doody (1985); Vellinga (1986); Nordstrom and Arens (1998); Nordstrom et al. (1998)
	- Wetland restoration and creation	- NRC (1992, 1994); Boesch et al. (1994); Tri et al. (1998)
• Indigenous options	- Afforestation - Coconut leaf walls - Coconut fibre stone units - Wooden walls - Stone walls	- McLean et al. (1998); Mimura and Nunn (1998)
(Managed) Retreat		
• Increasing or establishing set-back zones	- Limited technology required	- NRC (1990); Kay (1990); Owens and Cope (1992); Caton and Eliot (1993); OTA (1993)
• Relocating threatened buildings	- Various technologies	- Rogers (1993)
• Phased-out or no development in exposed areas	- Limited technology required	- OTA (1993); DETR (2000)
• Presumed mobility, rolling easements	- Limited technology required	- Titus (1991, 1998)
• Managed realignment	- Various technologies, depending on location	- Burd (1995); English Nature (1997); French (1997, 1999)
• Creating upland buffers	- Limited technology required	- Kaly and Jones (1998)
Accommodate		
• Emergency planning	- Early warning systems	- Penning-Rowsell and Fordham (1994); Haque (1995, 1997); Handmer (1997); Rosenthal and Hart (1998); Elliot and Stewart (2000)
	- Evacuation systems	- Parker and Handmer (1997); Rosenthal and 't Hart (1998)
• Hazard insurance	- Limited technology required	- Davison (1993); OTA (1993); Crichton and Mounsey (1997); Clark (1998); Arnell (2000)
• Modification of land use and agricultural practices	- Various technologies (e.g. aquaculture, salt-resistant crops), depending on location and purpose	
• Modification of building styles and codes	- Various technologies	- FEMA (1986, 1994, 1997)
• Strict regulation of hazard zones	- Limited technology required	- May et al. (1996)
• Improved drainage	- Increased diameter of pipes	- Titus et al. (1987)
	- Increased pump capacity	- Titus et al. (1987)
• Desalination	- Desalination plants	- Ribeiro (1996)

Source: Klein et al. 2000, 2001.

Note: This table is not intended to provide an exhaustive list of applications and technologies.

4. Monitoring and evaluation

111. Effective evaluation requires a reliable set of data or indicators, to be collected at some regular interval by means of an appropriate monitoring system. Indicators are a tool for reporting and communicating with decision makers and the general public. They should have a range of properties, including (i) a relationship to functional concepts, (ii) be representative and responsive to relevant changes in conditions and (iii) be easily integrated within a broader evaluation framework. Evaluation is an ongoing process and the monitoring should be planned accordingly. There is limited experience of such long-term monitoring, so in many situations it is unclear which are the most appropriate data or indicators (Basher 1999).

112. For coastal physical systems, experience can be drawn from countries where the coast has been monitored for long periods. In The Netherlands, for instance, data on the position of high water have been collected annually for nearly a century and cross-shore profiles have been measured annually since 1963 (Verhagen 1989; Wijnberg and Terwindt 1995). Observations of the natural evolution of the coast allow trends to be estimated reliably and hence the impact of human interventions on the coast (breakwaters, nourishment, etc.) to be evaluated.

113. In general, the technologies to be used for monitoring are the same as those used for the initial description of the coastal system. They are therefore listed in the upper part of table 2 and discussed by Morang et al. (1997a), Larson et al. (1997), Morang et al. (1997b) and Gorman et al. (1998).

C. Role of technology in adaptation

114. The emphasis of adaptation to coastal hazards has traditionally been on protecting developed areas using hard structures. The skills and technologies required to plan, design and build these structures depend on their required scale and level of sophistication. On a small scale, local communities can use readily available materials to build protective structures. However, these communities often lack the information to know whether or not these structures are appropriate and whether or not their design standards are acceptable. For larger-scale, more sophisticated structures, technical advice would often be required, as well as a contracting firm to build the structure.

115. Until recently, it was rarely questioned whether a country's coastline could be protected effectively if optimal management conditions prevail. It has become clear, however, that even with massive amounts of external funding, coastlines in the developing world (particularly of archipelagic countries) cannot be effectively protected by hard structures. In addition, increasing awareness of unwanted effects of hard structures on erosion and sedimentation patterns has led to growing recognition of the benefits of "soft" protection (e.g. beach nourishment, wetland restoration and creation) and of the adaptation strategies retreat and accommodate. An increasing number of private companies in the industrialized world are now discovering market opportunities for implementing soft-protection options. Interest in the retreat and accommodate strategies is also growing among coastal managers, but these strategies require a more integrated approach to coastal management than is currently present in many countries, so their application is still less developed.

116. In spite of this trend to consider technologies for adaptation other than hard protection, many structures are still being built without a full evaluation of the alternatives. One reason could be that hard structures are more tangible and hence appeal more strongly to the imagination of decision makers and stakeholders and, by their visibility, may be perceived to provide more safety and hold the sea at bay forever. In addition, it is generally felt that hard structures are less maintenance-intensive than soft structures. However, past experiences suggest that the design of soft structures is particularly important in determining the level of maintenance required, but that appropriate design and implementation often require good knowledge of coastal dynamics as well as effective coastal management institutions.

117. A second trend in the use of technologies for adaptation in coastal zones is an increasing reliance on technologies to develop and manage information. This trend stems from the recognition that designing an appropriate technology to protect, retreat or accommodate requires a considerable amount of data on a range of coastal parameters, as well as a good understanding of the uncertainties involved in the impacts to be addressed. National, regional and global monitoring networks are being set up to help to assess technology needs and opportunities.

118. Third, many efforts have been initiated to enhance awareness of the need for appropriate coastal technologies, often as maladaptive practices have become apparent. For example, before a new hospital was built in Kiribati in 1992, a substantial site-selection document had been prepared, examining numerous aspects of three alternative sites, but without consideration of coastal processes. A serious shoreline erosion problem, advancing rapidly to within eight metres of the hospital, was discovered by 1995 (Forbes and Hosoi 1995). Options to enhance awareness include national and international workshops and conferences, training programmes, online courses and technical assistance and capacity-building as part of bilateral or multilateral projects. In view of the many sectoral interests in coastal zones, it will become increasingly important to involve decision makers without direct responsibility for coastal issues and other stakeholders in this ongoing learning process.

D. Enhancing flows of technology for adaptation

119. The IPCC Special Report on Methodological and Technological Issues in Technology Transfer identified three fundamentally different pathways of technology transfer (Metz et al. 2000). These pathways are defined by the stakeholder who is the primary driving force behind the technology transfer: the government, the private sector or the community. Most of the literature describing and analysing climate-relevant technology transfer deals with mitigation technologies. In the transfer of technology for mitigation, the private sector usually plays a crucial part along the entire pathway from development to diffusion. Market opportunities, investment procedures and profitability criteria are key words to discuss the incentives and behaviour of both the provider and recipient of mitigation technology.

120. Most coastal impacts of climate change will impinge on collective goods and systems, such as food and water security, biodiversity and human health and safety. These impacts could affect commercial interests indirectly, but usually the strongest and most direct incentives to adapt are with the public sector. Coastal management is therefore usually a public sector responsibility, and the planning and design of coastal adaptation to climate change needs to be tuned to existing policy criteria and development objectives (Klein et al. 1999). Only in cases where a particular stretch of coastline provides direct financial benefits is the private sector likely to invest in coastal management. Examples of this situation are coastal tourist resorts, for which beach erosion represents a direct threat to their profitability, and ports and harbours, which will have to raise their infrastructure as sea level rises. In most industrialized countries, however, the private sector is typically not the stakeholder that drives technology transfer for coastal adaptation. Benefits are small or uncertain and action is expected from the government to protect private sector interests.

121. In developing countries the private sector is generally a less substantial economic force, so again governments are expected to lead the way in climate change adaptation strategies. Community-driven pathways may be found in places where a local need for adaptation is recognized but no government or private sector interest is anticipated. For example, on Viti Levu, Fiji, a traditional village community has been actively involved in a mangrove rehabilitation project. This donor-funded project has been strongly driven by local concerns, taking into account the particular cultural and political settings (Nunn 1999).

122. Official development assistance (ODA) will remain crucial for vulnerable developing countries to obtain access to appropriate technologies. Currently, the majority of ODA-funded coastal projects are carried out for economic purposes, such as fisheries, tourism and port development. In this context,

technology is often equated with hardware, transferable in single, point-in-time transactions. Such technology implementation has proven maladaptive in many occasions (WCC'93 1994). Successful coastal adaptation to sea-level rise requires the use of soft technologies, which enhance human skills and capacity needed to adopt, and adjust new approaches to, coastal management. Long-term relationships involving technical assistance and in situ training are important in this context.

123. Effective coastal adaptation and associated technology transfer may have to overcome a large number of very diverse obstacles. Many of these are site-specific and require site-specific solutions. The four major general barriers to the transfer of technologies for coastal adaptation are the following (Klein et al. 2000):

(a) Lack of data, information and knowledge to identify adaptation needs and appropriate technologies

(b) Lack of local capacity and consequent dependence of customers on suppliers of technology for operation, maintenance and duplication

(c) Disconnected organizational and institutional relationships between relevant actors

(d) Access to financial means.

124. In addition, coastal adaptation itself is often hampered by a number of factors:

(a) The uncertainty about the location, rate and magnitude of climate-change impacts;

(b) The local nature of coastal adaptation requirements;

(c) The absence of global benefits of coastal adaptation, which constrains its international financing;

(d) The fact that adaptation is often not considered a development objective.

125. The barriers identified above will not be overcome overnight. Many relate to fundamental and intrinsic characteristics and principles of today's society. Adjusting the process of technology transfer to accommodate societal imperfections will be easier to accomplish than the reverse. There are a number of important opportunities to promote technology transfer for coastal adaptation. All relevant stakeholders have important responsibilities to seize these opportunities. Each of them has a specific role in the transfer of technology, but generally, none of them can trigger all the steps involved. It is therefore essential that there is true collaboration and interaction amongst all stakeholders. All stakeholders' interests must be known and considered to prevent the transfer of inappropriate technology, including technology that is culturally or socially unacceptable or cannot be operated or maintained using local expertise. Already in the project formulation stage, it is crucial to consult and involve local experts.

126. In the annex to decision 4/CP.4, Parties raised a number of questions concerning technology transfer. These questions can be summarized and reinterpreted as (Klein et al. 2000):

(a) How can a receptive environment for technology transfer be created?

(b) What additional bilateral and multilateral efforts are needed, if any?

(c) What steps can be taken by Annex II Parties?

(d) What additional role can the private sector play?

127. The number and magnitude of ongoing coastal infrastructure projects suggest that coastal planners and managers are already receptive to technology transfer of a particular kind. However, there

is a need to proceed from single transactions involving only hardware to long-term partnerships that concentrate on enhancing human capacity by providing technical assistance and in situ training. Moreover, awareness that protection is often not the most appropriate strategy to adapt to climate change is growing, but it remains difficult for coastal planners to oversee the entire spectrum of available options. The establishment of a clearing house for technologies for coastal adaptation could facilitate the task of technology selection and evaluation. Such a clearing house would develop and hold an extensive catalogue of available technologies, including information on their costs, performance, owner (if not publicly owned), availability, implementation requirements and other relevant issues.

128. Addressing the prevalent barriers does not require setting up new bilateral and multilateral institutions or mechanisms. Instead, existing activities and institutions need to be refocused to improve the efficiency and effectiveness of coastal technology transfer, taking climate change into account. Technology transfer will be served by regional collaboration, especially when it concerns countries that do not have the necessary human or financial resources to develop or manage large projects independently. Examples of successful projects involving technology transfer that are the result of regional collaborations are the Pacific Islands Climate Change Assistance Programme (PICCAP) and Caribbean Planning for Adaptation to Climate Change (CPACC). Primarily aimed at developing information, these projects recognize that effective coastal adaptation and related technology transfer require a better understanding of local adaptation needs.

129. Annex II Parties have an important responsibility to facilitate coastal adaptation in vulnerable countries. Many donors have traditionally attached a higher priority to projects aimed at mitigating climate change than to adaptation projects, although this is gradually changing as the pressing need for adaptation is increasingly being recognized. For most coastal locations, there is no need to invest in the development of new technologies. Rather, the evaluation, adjustment and replication of existing technologies need to be stimulated.

130. The private sector may be able to extend its role in technology transfer when provided with the right incentives. These incentives would tend to increase the profitability of socially desirable technology-transfer projects and could include subsidies for investment and tax exemptions. The role of the private sector may also be extended by regulation. In transnational technology transfer, for example, the home company could be required to involve a partner company in the host country. Finally, professional organizations can stimulate private sector involvement by lobbying and engaging in relevant networks.

131. NGOs can play an important part as intermediaries and knowledge translators in the technology transfer process. As intermediaries they can identify sources of currently available and emerging technologies, facilitate investment arrangements, and provide management, technical and other assistance to developing countries. As knowledge translators they can ensure that technology transfer is designed to create adaptive capabilities within the receiving country to adapt technology rather than simply to encourage its passive acceptance after transfer. NGOs are also particularly suited to link technology transfer to training and human resource development and to public awareness-raising.

132. Finally, continued impact and adaptation assessment, combined with fundamental research on coastal system responses and economic, institutional, legal and socio-cultural aspects of adaptation, is required to understand which technologies for adaptation might be most appropriate in a given coastal setting.

E. Conclusions

133. In many coastal locations technology has been instrumental in reducing society's vulnerability to ever-present weather related hazards. Today's hazard potential for many sectors and communities will

increase because of climate change. However, in many cases the nature of the hazard will not change. Many existing technologies that have proven to be effective in reducing vulnerability to weather related hazards will therefore also be important as technologies for adaptation to climate change. Technologies may have to be adjusted to meet local needs, and technological development and innovation will continue to increase the effectiveness and efficiency of existing technologies, but given current projections of climate change, successful adaptation is possible without having to rely on the development of new technologies specifically for adaptation.

134. Nonetheless, many of the world's vulnerable coastal countries and communities do not have access to technologies necessary for adaptation, nor to the knowledge that is required to develop or implement them. Effective coastal adaptation by these countries could benefit from increasing current technology transfer efforts. These efforts require the involvement and collaboration of governments at all levels, the private sector, NGOs, international organizations and academic institutes.

135. Climate change is but one of many interacting stresses in coastal zones. The importance of controlling non-climatic stresses in the quest to reduce vulnerability to climate change must not be underestimated. Vulnerability to climate change is not only determined by the degree of climate change but also by prevailing social, economic and environmental conditions and by the existing management practices in a system or sector. Therefore, successful adaptation to climate change (i.e. actions that reduce vulnerability to the impacts of climate change) may well include actions that are directed at improving such conditions and management practices.

136. Finally, technology alone is not a panacea. It can make an important contribution towards the sustainable development of coastal zones, provided it is implemented within an enabling economic, institutional, legal and socio-cultural environment. Technologies for adaptation are therefore most effective as part of a broader, integrated coastal zone management framework that recognizes immediate as well as longer-term sectoral needs. A successful adaptation strategy will comprise a mix of various adaptation approaches, tailored to the particular needs of the area at risk and aimed at reducing implementation constraints.

VI. Water resources

137. After introducing the challenge of climate change vis-a-vis water resources, this section presents and discusses technologies for adaptation to climate change for water resources, following the framework outlined in chapter III. It then describes the role of technology in adaptation, including recent trends in water resource management, and discusses opportunities for technological innovation. The chapter builds on earlier work by the IPCC (in particular the chapter "Water resources" of the IPCC Special Report on Methodological and Technological Issues in Technology Transfer).

A. Introduction

138. The hydrologic cycle links human and ecological functioning in complex, multidimensional ways rooted in a common basis – water supports all life. Quite apart from climate change considerations, awareness has increasingly grown around the concept that planning and development of water resources to meet human requirements must integrate broader dimensions of land use stewardship, equity in water allocation and water governance, and cannot ignore considerations of ecological security, at least not without consequences for the sustainability of the resource. Water for food, for livelihoods, and for other basic needs depends critically upon healthy ecosystems. Attempting to understand and accommodate this delicate and necessary balance between human and ecosystem requirements for water is the reality being confronted by water users at all levels of development, from national, regional, and watershed scale planning initiatives down to local subsistence farmers, fisherfolk, and households.

139. Yet, even as water users worldwide seek to internalize these fundamentally new paradigms into their value systems and planning and governance structures around water, impacts due to climate change add an additional layer of complexity and urgency to these efforts (Milly et al. 2002, Trenberth et al. 2003). Enumerating these considerations in a planning regime under a presumption that past hydrologic patterns provide a basis from which the future can be predicted and visualized is not valid given the uncertainty that climate change impacts superimpose on both the supply side and demand side of the hydrologic cycle.

140. Climate change induced variability brings uncertainty to both the demand and supply sides of the water balance. Precipitation and precipitation intensity largely drive patterns of run-off and streamflow, surface water impoundment and soil moisture storage, groundwater recharge and saline intrusion, and drought and flood magnitude and frequency. Changes in rainfall therefore substantially alter the dynamics of planning around droughts, flood protection, food production, transportation along water courses and many other water-based livelihood activities that depend on historical knowledge. Where snowfall occurs seasonally, the timing of snowmelt ultimately results in temperature changes in these processes also. On the demand side, greater evaporative demands due to temperature-induced increases in vapour pressure deficits, changes in plant transpirative demands and water use efficiency due to increased atmospheric CO_2 levels must be considered in conjunction with altered patterns of human water withdrawals and water requirements to maintain resilient terrestrial and aquatic ecosystems.

141. Modelled results of climate change induced impacts – on both the supply and demand side of the hydrologic cycle – vary substantially by geographic area and assumptions. Even so, one can distil from these findings a number of physical and socio-economic characteristics that are key determinants of the general susceptibility of water resource systems to climate change induced impacts (table 4).

Table 4. Characteristics of climate-change sensitivity in water resource systems

Physical	Socio-economic
• Currently marginal hydrologic and climatic conditions with regard to agriculture and livestock • Highly seasonal hydrology due to precipitation or snowmelt • High rates of sedimentation in reservoir storage • Topography and land-use patterns that promote soil erosion and flash flooding • Lack of options to relocate activities in response to climate change due to low variation in climatic conditions across national territory	• Poverty prevents long-term planning and provisioning at the household level • Lack of water control infrastructure • Lack of maintenance on deteriorating existing infrastructure • Lack of human capital for system planning and management

Source: adapted from Arnell et al. 2001.

142. The information provided in table 4 indicates that the systems most vulnerable to climate change induced hydrologic variability are, expectedly, those already functioning under extreme climatic and hydrologic stress. These systems represent approximately 40 per cent of the world's land area (Kabat *et al.*, 2002) and are typically populated by the economically impoverished who have little capacity for meeting the livelihood challenges that additional climate variability may bring.

B. Adaptation strategies

143. The development of adaptive strategies has long been an essential component of water management, independent of anticipatory or reactionary stances to climate change induced impacts. Freshwater is a finite resource that naturally varies spatially and temporally, often substantially, and planning around water must accommodate uncertain and shifting growth pressures exerted by competing

users and uses, both human and ecological. Indeed, the global trend toward an increasingly urban population and estimated growth in total population by as much as 25–50 per cent by 2025 (Cosgrove and Rijsberman 2000) provides substantial motivation for developing adaptive strategies.

144. The traditional supply-side focus of water management has failed to deal with these growth pressures, sparking a new philosophy of water management, centred around several core principles first outlined at the 1992 International Conference on Water and Environment, Dublin, Ireland:

(a) Freshwater is finite and has economic and social value in its competing uses;

(b) Water is essential to sustain life and safe water should be accessible to all;

(c) Water development and management should be participatory, involving users, planners, and policy makers at all levels, and recognizing that women in particular play a central role in water provision for families and communities.

145. The approach of this water management paradigm, integrated water resources management (IWRM), promotes the coordinated development and management of water, land, and related resources in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems (GWP, 2004). This includes more coordinated development and management of:

(a) Land and water;

(b) Surface water and groundwater;

(c) The river basin and its adjacent coastal and marine environment;

(d) Upstream and downstream interests.

146. But IWRM is not just about managing physical resources, it is also about reforming human systems to enable people to benefit from those resources. For policymaking and planning, taking an IWRM approach requires that:

(a) Policies and priorities take the implications of water resources into account, including the two-way relationship between macro-economic policies and water development, management, and use;

(b) There is cross-sectoral integration in policy development;

(c) Stakeholders are given a voice in water planning and management, with particular attention to securing the participation of women and the poor;

(d) Water related decisions made at local and river basin levels are in line with, or at least do not conflict with, the achievement of broader national objectives;

(e) Water planning and strategies are integrated into broader social, economic, and environmental goals.

147. In practice, this means giving water an appropriate place on national agendas; creating greater "water awareness" among decision makers responsible for economic policy and policy in water related sectors; creating more effective channels for communication and shared decision-making between government agencies, organizations, interest groups and communities; and encouraging people to think "outside the box" of traditional sectoral definitions.

148. The IWRM paradigm recognizes the value of a coordinated analysis framework that seeks to consider all interdependencies among all relevant components of the natural and engineered water systems, as well as the social and economic forces that affect demand, in determining an efficient, equitable and sustainable water outcome. IWRM rejects the economic inefficiency and lack of adaptive capacity inherent in conventional, top-down approaches that view water issues individually by sector and predominantly, if not wholly, through a supply-oriented lens. It addresses these traditional shortcomings by invoking a demand-responsive approach in which stakeholders have a shared voice with planners and policy makers in constructing a vision of their water future.

149. Implications for water governance and administration include a shift to a more transparent, inclusive, responsive, and accountable process where integration of information occurs across as many as five different levels, including (Kabat et al. 2002):

(a) Vertical integration from the level of the individual user to the highest levels of government;

(b) Horizontal integration among all resource management related institutions;

(c) Interdisciplinary integration of all relevant disciplines, including socio-economic, political, cultural, engineering, hydrologic, and ecological;

(d) Functional integration of planning, regulations, design, operations, maintenance and monitoring;

(e) Stakeholder integration of government and non-governmental interests, user groups, and native populations.

150. Adaptation to climate change induced variability will require effective communication across institutions, disciplines, and stakeholder groups, with consideration of different spatial and temporal scales in hydrologic processes, land-use dynamics, and water allocation, use, and governance. Although IWRM was conceived to aid in advancing sustainability in water resources management, its multidimensional integrative character makes it potentially powerful as an overarching framework within which to conceive and implement adaptation strategies for coping with the pressures associated with climate change induced variability in the supply- and demand-side components of the hydrologic cycle as well. Indeed, IWRM provides an effective platform with which to mainstream climate adaptation into development.

151. The inherent flexibility of the IWRM framework facilitates its use within and across spatial and temporal scales, and accommodates the intrinsic differences between circumstances and issues arising for industrialized as opposed to developing countries (table 5). This flexibility, in combination with the requirement of an effective governance structure that embraces a participatory decision-making process, makes the IWRM framework particularly valuable as an adaptation strategy for climate change induced hydrologic variability. It will be especially important to have those presently with little voice – such as the poor, particularly women, and the sector of civil society that represents their water needs and the safeguarding of the ecosystems on which they depend for cropping, livestock, fisheries and forestry – included in the adaptive planning and development process. These stakeholders will bear a disproportionate share of the impacts of climate change. Good governance requires that the water management objectives of these communities be articulated and evaluated alongside those of other water use sectors, towards implementing fully subscribed, thereby balanced, adaptation strategies that will further equity and poverty eradication, even in the face of climate change.

Table 5. Characteristics influencing IWRM in industrialized versus developing countries

Industrialized countries	Developing countries
Infrastructure	
• high level of infrastructure that generally improves over time • infrastructure decreases vulnerability to natural disasters • high ethos of infrastructure maintenance • high quality, well-coordinated data and information available	• infrastructure often fragile and in state of retrogression • high vulnerability to natural disasters with heavy damage and death toll • low ethos of infrastructure maintenance • data and information not always readily available
Capacity	
• scientific and administrative skills abundantly available • expertise developed to local levels • flexibility to adapt to technological advances	• limited scientific and administrative skills available • expertise highly centralized • often in survival mode; technological advances may pass by
Economy	
• mixed, service-driven economics buffered by diversity, highly complex interactions • economically independent and sustainable • multiple planning options available • take a long-term planning perspective • countries wealthy, with money available for planning and IWRM	• high dependence on land, i.e. agricultural production; high vulnerability to climatic variability • high dependence on donor aid, NGOs • fewer options available in planning • take a shorter term planning perspective • wealth of countries limited, with less scope for planning and IWRM
Socio-political	
• population growth low or negative • generally well-informed public with appreciation for planning • high political empowerment of stakeholders • decision-making decentralized • high level of expectation of planning and IWRM • desire for aesthetic conservation	• high population growth rates and demographic pressures on land • more poorly informed public, less appreciation for science and planning • stakeholders often not empowered, afraid to act or exert pressure • decision-making centralized • lower level of expectation and attainment of goals • need for basics of living

IWRM = integrated water resource management
NGO = non-governmental organization

152. The principles embodied in IWRM provide an inclusive and versatile framework for conceiving, developing, and implementing water-centred adaptation strategies to climate change induced variability towards an ultimate goal of sustainability. This framework is necessary, but not sufficient, however. Rather, IWRM requires infusion with technologies that address one or more particular adaptation issues and needs. These technologies, whether relating to the information/awareness, planning/design, implementation, or monitoring components of the adaptation process, make this framework real and operational in a particular context.

153. Many of these technologies already exist and are broadly diffused to the local level, both among developed and lesser developed regions. Others technologies are more familiar to the water planning and management sector in developed nations, and require transfer to less-developed regions. Finally, there are a number of technologies emerging from research and development that have the potential to provide substantial benefits to adaptation efforts in both developed and developing regions, but considerable thought will be required to determine how best, or even whether, these types of technologies can be transferred for use at local level, particularly in developing regions. Technologies which come under the first two categories are discussed below – those broadly known and used and those known but limited in

use. These technologies are discussed in the context of the four-stage process of adaptation. Emerging, promising technologies are discussed under subsequent headings.

1. Information and awareness-raising

154. **Building communities of practice**. To make IWRM operational, it is important to foster a community, or network, of water professionals who are informed, knowledgeable and committed to the principles of IWRM, and who are actively engaging civil, governmental, non-governmental and private sector stakeholders in a dialogue and building capacity around decision-making on water issues (Kabat et al. 2002). Such networks sustain the propagation of the core principles of IWRM (participatory, holistic decision-making), which draws together the conceptualization, planning and implementation of necessary adaptation mechanisms around water sustainability in the face of climate uncertainty. One example of an existing community of practice is the Global Water Partnership (GWP) (www.gwpforum.org), a working partnership of government agencies, public institutions, private companies and multilateral development agencies committed to supporting countries in the sustainable management of their water resources. GWP maintains the IWRM ToolBox, an online resource for information and guidance on all facets of IWRM for all water use sectors.[11]

155. Communities of practice also support educational programmes that both further professional development and build awareness within the public and private sectors. WaterNet, a network of university academic departments and research and training institutes in Southern Africa, SWMnet, or the Soil and Water Research Network for Eastern and Central Africa, and the newly established SumerNet, or Sustainable Mekong Research Network, are three such communities. The activities of SWMnet are described further as a water resource case study in chapter IX.

156. **Data access**. Access to information is key to conceiving and implementing adaptive strategies. Online repositories for hydrologic data, human and ecological demands or estimation methods, and other variables relevant to the water balance facilitate decision-making around water issues, including adaptation strategies. For example, the Global Runoff Data Center (http://grdc.bafg.de), which operates under the WMO, supports the collection and dissemination of a worldwide database of river flows on a continuous, long-term basis. These measurements span global, regional and catchment scales, consistent with the goals of IWRM.

157. **Forecasting tools**. On-the-ground instrumentation for the measurement of precipitation, streamflow and stream stage, for example, can provide critical data in support of adaptation strategies such as flood protection early warning systems and drought management strategies. Often, however, these instruments are sparse or absent, particularly in developing regions, due to the cost of introduction or maintenance. Furthermore, forecasts based on real-time, ground-based measurements provide only a short lead time, in the order of hours to perhaps several days, for situations such as in Bangladesh, for example (Paudyal 2002). These lead times are typically insufficient to safeguard community assets, infrastructure and agricultural and aquacultural products during extended flood and drought periods. Another challenge for forecasting and early warning systems is the lack of political agreements between riparian nations to share hydrologic information on international river basins (Hossain and Katiyar 2006). Emerging innovations in remote sensing technologies, discussed in a later section, can fill this data gap, extend lead times and provide access to hydrologic information regardless of political boundaries, adding substantial benefits to forecasting tools.

[11] See <http://gwpforum.netmasters05.netmasters.nl/en/index.html>.

2. Planning and design

158. **Decision support tools**. The planning and design of effective adaptation strategies around water resource issues requires the clarification of complex, multidisciplinary factors that are involved in water related adaptation strategies. Here, decision support systems (DSS) that embody the principles of IWRM will provide greatest utility.

159. An IWRM-based DSS will consider both the demand and supply side of the water equation in fully integrating the biophysical, socio-economic, cultural and political considerations of adaptation issues. Ideally, such a DSS includes the ability to simulate biophysical factors, such as climate, land cover, surface and groundwater hydrology, water quality, and ecosystem processes that shape the availability of water in the system in concert with human and ecosystem demands and the rules that dictate how water is stored and allocated. Tools that link the simulation of climate-driven hydrology with water demand and allocation, such as the Water Evaluation and Planning system (Yates et al. 2005), provide a powerful means for studying possible human and ecosystem adaptation strategies to cope with uncertain climate conditions.

160. Traditionally, water managers and water users have dealt with natural hydrologic uncertainty by looking to the past to forecast water availability. However, climate change may cause water availability to deviate from past trends perhaps in non-linear ways, and this presents added challenges to planners. Planners cannot anticipate just one possible water resource scenario in the future, but must consider a range of possible scenarios, and planners at all levels will benefit from technologies that facilitate the incorporation of this uncertainty into their decision-making processes.

161. Scenario analysis, although still not widespread in its use in the water sector, is one DSS tool that supports a systematic approach to thinking about the future (Lienert et al. 2006). Scenario analysis does not predict the future, but it does facilitate the characterization of uncertainty by allowing one to explore, for example, the magnitude of influence that a system variable may have under a given set of circumstances. By systematically varying the circumstances, one can elucidate the range of influence or sensitivity (e.g. in cost, vulnerability) that specific variables may have with regard to a system.

162. With the information provided by scenario analyses, one can then prioritize with the aid of multicriteria assessment (MCA) tools where resources, both in terms of financial and human capital, may best be utilized. MCA tools allow one to combine qualitative and quantitative inputs of risk, cost and benefit, as well as stakeholder views and values in a platform that facilitates comparison and ranking of planning and management alternatives (Kiker et al. 2005).

3. Implementation

163. **Existing technologies**. There are a number of existing implementation technologies used in developed and developing regions. A matrix of adaptation options available to water resource managers is presented in table 6. Examples relate to both the supply and demand sides of the water balance equation. While many of these technologies fall under the category of hard technologies (e.g. reservoir capacity, desalinization capacity, treatment capacity, leakage reduction, non-water-based sanitation) in the adaptation process, other technologies can be categorized as soft, with a greater focus on process modification and information dissemination (e.g. cropping patterns, weather forecasting, flood warning systems).

164. A number of implementation technologies involve demand management. The strategy is to reduce vulnerability to variability in water availability by reducing water dependence. Agriculture is typically the largest consumer of water, so substantial benefit can be derived from improving irrigation efficiency through drip irrigation and leakage detection and repair. Relatively less water is used in sectors such as sanitation, but adaptation strategies here can make an impact. For example, efforts to

decouple water from sanitation through ecological, or dry, sanitation, have several synergetic effects: (i) the often small amounts of water left over for domestic needs after agricultural withdrawals are conserved both by decreasing volume used and by protecting water quality for downstream users, as wastewater flows are decreased, and (ii) nutrients retrieved can be used to improve yields of household subsistence farming (Rosemarin 2005).

Table 6. Possible implementation technologies

Use category		Supply-side	Demand-side
Municipal/domestic		▪ Increase reservoir capacity *(hard technology)* ▪ Desalinization *(hard)* ▪ Inter-basin transfers *(hard)* ▪ Alter system operating rules (*soft technology*)	▪ Increase use of 'grey' water, e.g. facilitated by use of enhanced filtration (*hard*) ▪ Reduce leakage in distribution system (*hard*) ▪ Non-water-based sanitation (*hard*) ▪ Seasonal forecasting (*soft*) ▪ Legally enforceable water quality standards (*soft*) ▪ Water demand management (*soft*)
Industrial and power station cooling		▪ Use lower grade water (*soft*)	▪ Increase water use efficiency and water recycling (*hard*)
Hydropower		▪ Increase reservoir capacity (*hard*)	▪ Increase turbine efficiency (*hard*) ▪ Encourage energy efficiency (*soft*) ▪ Energy demand management (*soft*)
Navigation		▪ Build weirs and locks (*hard*) ▪ Alternative transport (*hard*)	▪ Alter ship size (*hard*) and frequency (*soft*)
Pollution control		▪ Enhance treatment works (*hard*) ▪ Reuse and reclamation (*hard*)	▪ Reduce volume of effluent to treat (*soft*) ▪ Promote alternatives to chemical use (*soft*)
Flood management		▪ Increase flood protection, e.g. levees, reservoirs (*hard*) ▪ Wetland protection and restoration (*soft*)	▪ Improve flood warning and dissemination (*soft*); ▪ Curb floodplain development (*soft*)
Agriculture	Rain-fed	▪ Better soil conservation, e.g. nutrient replacement (*hard*) ▪ Better forecasting (*soft*)	▪ Increase drought tolerant crops (*hard*)
	Irrigated	▪ Alternative tilling practices (*soft*) ▪ Rain harvesting (*hard*)	▪ Increase efficiency of irrigation use, e.g. drip irrigation (*hard*) ▪ Change irrigation water pricing (*soft*) ▪ Increase drought tolerant crops (*hard*) ▪ Change crop patterns (*soft*)

Source: modified from IPCC, 2001.

4. Monitoring and evaluation

165. **Indicators of water stress and poverty**. Indicators can serve a critical monitoring and communication function for adaptation strategies, helping to identify trends in water stress (volume reduction and quality) and livelihood impacts. Indicators span a range of complexity, from the very simple (ratio of withdrawals to volume available; Falkenmark and Lindh 1978) to the complex (water poverty index; Lawrence et al. 2002). The water poverty index, for example, aggregates a number of indicators designed to gauge links between household welfare and water availability. These indicators reflect the degree to which water scarcity impacts a population and covers five main areas: resource balance (inflows versus outflows); access to safe water, sanitation and the proportion of arable land to water availability; capacity described as functions of economic (GDP), health (childhood mortality), education and the inequality of income distribution; use per capita in domestic, industrial and agricultural sectors; and environmental criteria, such as water quality measures, fertilizer consumed per unit area, management and regulatory capacity measures, and biodiversity measures.

C. Role of technology in adaptation

166. Effective adaptation strategies to cope with climate-driven uncertainty around water availability require consideration of stakeholder vulnerability and resilience, as well as resource sustainability. Development of well-targeted strategies requires access to and dissemination of information on a range of broad categories (e.g. hydrologic, ecological, socio-economic, political), analytical distillation of that information into possible courses of action, fully participatory deliberation mechanisms to select appropriate courses of action to implement, and efficient means to judge the success of those strategies towards attainment of the original adaptation objectives. As highlighted above, technologies play an integral role in each step of that process. Support for the information (e.g. online resources for river flow); awareness-raising (e.g. communities of practice), planning and design (e.g. multicriteria analysis tools) and monitoring (e.g. water-poverty indicators) are behind every successful implementation strategy.

167. There is evidence that many of the technologies discussed above are needed to fill the gaps currently existing in Parties' ability to plan for adaptation. Several less-developed countries have been involved in the self-assessment process to develop national adaptation programmes of action (NAPA) relating to climate change adaptation needs. The results to date of these assessments can be prepared with the technologies presented earlier. Excerpts of needs assessments from Mauritania and Guyana (table 7) indicate that improving irrigation efficiency, understanding more clearly catchments and groundwater hydrology, as well as protecting groundwater resources, are high priority strategies for adaptation in these countries. The results suggest that information technologies in particular, represented as hydrologic and groundwater monitoring networks, are needed to carry out these strategies.

Table 7. Preliminary national climate change adaptation policy needs for two least developed countries

Country	Intervention option	Technology/activity
Mauritania (Ahmedou 2004)	• Promote water-saving irrigation methods	• Install drip irrigation pumps and networks and provide training on their use
	• Improve knowledge of catchment hydrology	• Install hydrologic monitoring network and provide training on data collection/processing
	• Improve management of underground water resources	• Raise community awareness on use of groundwater • Establish protection zones for groundwater use • Obtain community participation in determining cost of water • Organize community stewardship committees • Install piezometric networks
Guyana (Khan 2001)	• Cope with groundwater salinity increase	• Detect leaks • Set up water conservancies and designate protection areas
	• Mitigate increasing demand	• Regulate via water tariffs
	• Mitigate contamination of water supplies	• Design septic systems better • Improve storm water drainage systems • Increase standards to enhance resilience of natural water systems

168. **IWRM framework refinements**. Two additional frameworks have recently emerged that build further on IWRM concepts: soft paths and the concept of green and blue water. The soft path approach to water planning and management brings a new perspective – the starting point is an understanding of the service that water provides, rather than seeing water as an end-product. The central question

becomes, "How can we deliver services currently provided by water in ways that recognize the need for economic, social and ecological sustainability" (Brooks 2005). The soft water approach takes much greater advantage of local hydrologic resources (e.g. urban rainwater/storm water harvesting and aquifer storage recovery systems versus distant surface supply and storage facilities); uses the treatment capacities of urban watershed soils and vegetation to much greater effect for storm water management (so called 'green infrastructure'); utilizes all types of wastewater treatment and reclamation systems (including newly adapted technologies such as sand filter systems and constructed ecological systems, such as treatment wetlands and EcoMachines); and incorporates a high degree of reuse (http://www.rmi.org/sitepages/pid278.php).

169. The soft path specifically considers the quality and other characteristics of water – chemical and biological quality, reliability of supply, and perhaps temperature and other qualities – that are necessary for the provision of a given service. As a matter of principle, the soft path works within ecological limits and promotes local public participation to ensure sustainability of water resources. Soft path planning looks 20 to 50 years into the future and proposes major changes in water infrastructure and institutions. The focus is on designing and implementing policies and strategies today that can reduce or even eliminate the need for further supply-side developments for the foreseeable future.

170. Another important innovation in water related frameworks is to incorporate into planning dialogues the discussion of both green and blue water. Green water flows are defined as the flows not seen – evapotranspirative vapour fluxes to the atmosphere (Falkenmark and Rockström 2004). Blue water flows are the more tangible and visible volume of water above and below the ground. Green water flow represents more than 67 per cent of precipitation, and often does not get the attention that blue water flows do relative to their respective roles in supporting ecosystems and human water demands. Rain-fed agriculture is the primary livelihood for the world's poor, and climate change inherently introduces more risk to this vulnerable population. Thus, it is critical that green flows be central to discussions and planning around adaptation strategies in the water sector.

171. **Filling hydrologic data gaps**. Adaptation to climate change induced variability will benefit greatly from improved understanding of hydrologic fluxes. In this regard, data are critically needed to complete water balances, couple hydrologic and meteorological models, and determine pollutant fluxes, as well as for forecasting of future processes and impacts (Brakenridge et al. 2005). These data are needed particularly in basins where data are currently sparse due to limited or no monitoring infrastructure (e.g. river gauging stations).

172. Here, advances in remote sensing can play a substantial role, bridging the current inadequacy of data collection. For example, orbital sensors, such as interferometric radar, are gaining the capability to make observations of river inundation areas, water levels and flow variability (Brakenridge et al. 2005; Alsdorf and Lettenmaier 2003; Alsdorf et al. 2000). Such capabilities would allow data collection for systems outside political boundaries, which can act as a hindrance to the transfer of information.

173. **Hydrologic forecasting**. There is a need for improved ability to forecast hydrologic/climatic responses on a shorter term (15- to 90-day periods) (Kabat et al. 2002), as there is increased realization that skilful and timely forecasts of precipitation and river discharge at these temporal scales will provide optimal information for regional agriculture, water resources and disaster management. For example, a number of studies have shown that crop yields in India are negatively correlated to the occurrence of El-Niño (Selvaraju 2003).

174. However, for forecasting outputs to be effective, a number of criteria must be met, including that the forecasts must address a real and perceived need; that the forecasting output be applicable to decision-making on options that are similarly time-sensitive and that they be delivered in appropriate form and with adequate lead time to the correct audience; that the forecasts be at an appropriate spatial

scale; and that proper institutional and policy commitments be secured for long-term use of forecasting data (Hansen 2002).

175. **Membrane technology for water reuse.** Water demands for livestock and crop production typically consume the largest share of available water resources, often leaving limited amounts available for domestic needs, particularly in regions suffering from water scarcity. These allocation disparities will only be magnified by variability in water availability induced by climate change. With few opportunities for accessing new sources of water, water reuse can provide a means to augment water supply.

176. Developments in membrane technology could lead to their use in treatment of wastewater, and their capacity for pollutant removal, as well as their modular nature, could facilitate the introduction of the technology even down to the level of households (Fane et al. 2005). Membrane technology, like ecological sanitation, has the potential to facilitate nutrient retrieval, and could help improve household subsistence farming yields.

D. Enhancing flows of technology for adaptation

177. There are a number of steps in the transfer of technologies for adaptation that are broadly applicable to all sectors, including water (UNFCCC, 1998). On the supplier side, research and development, project preparation, demonstrations of viability, technology commercialization and feedback analysis are important. For the recipients, transfer is facilitated through raising awareness about the need for specific technologies, developing the capacity for adoption, assessing technological options, implementing and operating the technologies, and feedback analysis.

178. One can discuss transfer mechanisms in the context of at least one water-sector-specific issue – IWRM. The development, more than a decade ago, of IWRM as a framework for reaching sustainability goals and the progress made in its broad adoption since, end to its utilization in development of strategies for adaptation to climate variability. Furthermore, the principles behind IWRM explicitly accommodate local and region-specific values, perceptions, and knowledge in a broadly participatory planning process and place more emphasis on the human dimension to managing water.

179. Efforts aimed at building and strengthening communities of practice in IWRM will aid in further advancing its use for climate-specific adaptation strategies while mainstreaming adaptation activities, all in the context of sustainability. Communities of practice are particularly relevant for the dissemination of technologies for adaptation within a country, and specifically address the need for collaborative networks for technology research, demonstration and capacity-building identified by Agenda 21 as one activity to promote technology transfer (UNFCCC 1998).

180. A number of sector-non-specific barriers to the transfer of technologies for adaptation can be discussed for the water sector. These include an absence of legal and regulatory frameworks; corruption and political instability; lack of a knowledge base and support structure to accept and sustain technologies; poor economic conditions, such as inflation; a simple lack of information, investment capital and financing instruments; and cultural preferences and social biases (UNFCCC 1998).

181. Schulze (2001) elaborates on barriers particularly relevant to water, noting that water is often a source of conflict that makes integrative coordination difficult. From the local to the international level, power structures associated with sectoral, geographic (i.e. upstream/downstream) and geopolitical (transboundary) water constituencies complicate integrative activities and inhibit inter-agency and stakeholder communication and data sharing because of a hesitancy to relinquish control, even for the greater good of integrative management. Real and perceived disparities in political, economic and social capital heighten this unwillingness to cooperate.

182. Innovative technologies, such as remote sensing technology, show particular promise in filling critical information gaps where greater understanding of regional hydrologic and land use dynamics are required to inform decision-making around water use and protection from extreme water events such as floods. The challenges here pertain to bringing the benefits of these technologies to bear at the local level. The relevant issues include not only that of bridging a gap in understanding of the science behind the technology, but in downscaling and packaging this information in a form that can be readily used for developing adaptation strategies by stakeholders most in need, such as subsistence farmers.

E. Conclusions

183. Climate change induced variability in the hydrologic cycle superimposes additional challenges on the planning and management of water resources. The development of appropriate adaptation strategies to cope with this added uncertainty requires a broad, integrative approach given the multidimensional roles that water plays in sustaining human life, society and the ecosystems on which they depend.

184. The intrinsic characteristics of IWRM make it an ideal overarching framework in which to evaluate, design, implement and monitor adaptation strategies for climate impacts on water resources. Its cross-sectoral, broadly participatory approach increases the likelihood that the needs of the most vulnerable will be accommodated in decision-making around water and that adaptation strategies will consider all relevant interrelated factors, producing an outcome that is robust and sustainable from the water perspective.

185. Building communities of practice around IWRM can facilitate the mainstreaming of climate adaptation strategies into sustainable development efforts, providing synergy in awareness-raising, capacity-building and in the creation of social, political, and institutional environments receptive to technological innovation. These communities of practice aid in the transfer of technologies for adaptation that meet key needs, such as information technologies (remote sensing, forecasting) that enhance understanding of natural (e.g. hydrologic) and engineered (e.g. demand) system components and tools that support decision-making (e.g. scenario-driven processes and multicriteria assessment technologies).

186. The necessity of water for all facets of livelihoods sets up inherent conflict among users and uses; manifestations of this conflict (e.g. reluctance to cede power or share information) can serve as a substantial barrier at local, regional and national levels to the transfer and dissemination of technologies for adapting to uncertainty around water access and availability. Participatory planning and decision-making approaches that recognize and seek to level political, social and economic inequities behind such conflict have the potential to substantially benefit the climate adaptation process around water.

VII. Agriculture

187. Chapter II of this technical paper outlined a framework and four steps for planned adaptation and introduced impacts of climate variability and change on the agriculture sector. This chapter describes adaptation strategies and the role of existing technologies to improve agriculture, barriers to technology promotion and the potential for technology development and innovation. It is based on earlier work of the IPCC particularly the “Agriculture Sector” of the IPCC Special Report on Methodological and Technological Issues in Technology Transfer (IPCC 2000). Information was also derived from several reports of the Food and Agriculture Organization of the United Nations, the Consultative Group on International Agriculture Research (CGIAR) and other reports.

A. Introduction

188. Agriculture is a worldwide critical, strategic sector, and food production is expected to double in the next 30 years to feed the planet's growing human population. A majority of the existing land is given over to agricultural usage and food production, and agriculture is the main economic activity of most of the developing world. About 75 per cent of the world's population is either directly or indirectly involved in agricultural activities. Furthermore, there is a very direct relationship between agricultural productivity and the environment, especially natural resources and climatic conditions. Changes in one component have a tremendous impact on the other. Over the years it has been observed that minor shifts/changes in climatic conditions have had major implications on agricultural productivity and the food security of countries.

189. Agriculture is the single most important sector in the economies of most low-income countries, accounting for a quarter to a half of GDP. Low productivity in agriculture is a major cause of poverty, food insecurity and poor nutrition in low-income developing countries. Broad-based agricultural growth spurs overall economic development, because every dollar earned by farmers in low-income countries raises incomes in the economy as a whole by up to USD 2.60. A one per cent increase in crop yields reduces the number of people living on under USD 1 per day by 6.25 million. Agricultural productivity is able to reduce poverty because it increases the incomes of poor farmers, and also increases the demand for off-farm goods and services (CGIAR-GEF 2002).

190. The scale and intensity of adverse effects of climate variability and change on agriculture will not be the same for all. The Third Assessment Report of the IPCC stated that grain yields are projected to decrease for many scenarios, diminishing food security, particularly in small food-importing countries in Africa. It also revealed that increases in droughts, floods and other extreme events would add to stresses on water resources, food security, human health and infrastructures, and would constrain development in Africa. Decreases in agricultural productivity and aquaculture due to thermal and water stress, sea-level rise, floods and droughts, and tropical cyclones would diminish food security in many countries of arid, tropical, and temperate Asia. In South America, floods and droughts would become more frequent, with floods increasing sediment loads and degrading water quality in some areas. Yields of important crops are projected to decrease in many locations in Latin America, even when the effects of CO_2 are taken into account; subsistence farming in some regions of Latin America could be threatened.

191. Very little work has been done to investigate prospects for natural adaptation of crop species to climate change, and the results of the few studies that have been done are inconclusive. However, there appears to be a wide range of resistance to high-temperature stress within and among crop species. For example, moderately large genetic variation in the tolerance to high-temperature-induced spikelet sterility has been reported among and between indica and japonica-type rice genotypes (Matsui et al. 1997) and some rice cultivars have the ability to flower early in the morning, thereby potentially avoiding the damaging effects of higher temperatures later in the day (Imaki et al. 1987).

192. Over the decades the agriculture sector has adopted a number of technologies, both hard and soft, for addressing adverse effects of climatic events, such as drought, flood and salinity. Commonly adopted technologies are irrigation, high yielding crop varieties, diversification of crops, and drought and salt tolerant varieties. Early warning systems and seasonal forecasts are also effective in some parts of the world. Different types of infrastructure, such as embankments in coastal and floodplain areas, awareness-raising, and enhance of capacity to cope with adverse effects are also effective. It is evident that integration of both hard and soft technologies and building partnerships between government and NGOs is necessary for increasing the effectiveness of different technologies for adaptation to adverse effects.

193. The ability of world agriculture to meet the needs of an ever expanding population has been due to the development and adoption of new technologies, rather than to the expansion of cultivated land (IPCC Working Group I 1996). In the face of limits to unused arable land or additional water for irrigation, it is realistic to anticipate that meeting future agricultural needs in the face of uncertain and, perhaps, changing climatic conditions will rest even more heavily upon technology development and transfer.

B. Adaptation strategies

194. This section of the paper provides examples of the technologies that can be employed according to the framework presented in chapter II. It is to be noted that the list of technologies in this section is not all-inclusive, but rather illustrative. This section was also developed based on work of the IPCC particularly the "Agriculture Sector" of the IPCC Special Report on Methodological and Technological Issues in Technology Transfer, NAPAs prepared by least developed countries, national adaptation strategies prepared by some developed countries and national communications of Parties included in Annex I to the Convention and Parities not included in Annex I to the Convention.

195. Specific adaptation strategies and measures for the agriculture sector range from modelling for crop yield, seasonal forecasting, development of stress tolerant varieties, e.g. drought and salt tolerant varieties, alternative crop research, introduction of new varieties, promotion of economical irrigation techniques, intensification and diversification of agriculture, to training and awareness. Adaptation strategies in developed countries, for example Finland's national adaptation strategy, highlighted the need to reinforce and increase the capacity of society to adapt to climate change through mainstreaming, observation and warning systems, and research.

1. Information and awareness-raising

196. The development of information and raising of awareness are essential and are the first steps in designing, implementing, and monitoring and evaluating the performance of adaptation strategies and measures. Information on impacts of climate variability and change on agricultural production, available technologies for reducing impacts, assessment of people's needs, and awareness-raising of the different stakeholders, including policy makers, will help in designing adaptation strategies for the agriculture sector. Reducing the uncertainty of impact assessment, and raising the cost effectiveness of agricultural technologies and level of acceptability by different communities will make the adaptation strategies and measures more effective. It is also essential that there is a general awareness among the public sector about how climate change could adversely impact food security at the global level, thus highlighting the necessity for appropriate action.

197. **Crop simulation models** have proved themselves to be powerful tools for analysing the causes of production variations in many crops, and some have been incorporated into decision support systems. A number of crop simulation models are available globally for assessing the adverse effects of climate change incorporating outputs from general circulation models.

198. Studies have shown that **long-term and medium-term weather forecasts** are beneficial to the agriculture sector. For example, improved long-range forecasts of El Niño/Southern Oscillation (ENSO) from the United States National Weather Service can result in an economic benefit worth USD 100-125 million per year to the agriculture sector in the south-eastern United States (Contemporary Economic Policy journal). The European Centre for Medium-Range Weather Forecasts is developing numerical methods for medium-range weather forecasting for distribution to the meteorological services of the member States of the European Union. They also collect and store meteorological data. The centre has a collaborative arrangement with the World Meteorological Organization.

199. The Green Revolution was based on the breeding of **new high-yielding crop varieties** to address increasing food demand. The contribution of the Consultative Group on International Agricultural Research (CGIAR) to agriculture and food production has been substantial: world food and feed grain prices would have been 18–21 per cent higher without the work of CGIAR, thus adversely affecting poor consumers (Evenson and Rosegrant 2003).[12]

200. Information on technologies for **water harvesting** and **soil moisture conservation** in small watersheds for **small-scale irrigation** (R.K. Sivanappan, Saivy Pumps Ltd., Coimbatore India), and low-cost irrigation technologies for food security in sub-Saharan Africa (E. Perry, Appropriate Technology International, Washington D.C., USA), with technical details, are available on the FAO website. Information is also available on how low cost technologies have been transferred within the South. For example, **treadle pumps** were developed in Bangladesh in the early 1980s. In late 1990 and mid-1995, commercial dissemination began in Senegal and in Mali, respectively. By the end of December 1996, 25 manufacturers in Senegal had produced and sold more than 1,900 pumps, by which tone 10 such producers in Mali had sold approximately 600.

2. Planning and design

201. Addressing the adverse effects of present climate variability and extreme weather events through the design of projects supported by policy decisions is a common approach to combating food insufficiency. However, a response to the threat of future climate change on agricultural systems has yet to be incorporated in national planning processes. Once data and information on potential impacts and problems are available, policies and plans can be adjusted to meet the need for adaptation. To pursue planning it is also necessary to highlight how changes in planning and design will address national goals and objectives in the long run.

202. Planning for agricultural and design projects depends on a number of issues including national development priorities, such as attaining self sufficiency in food production and economic development, taking into consideration socio-economic conditions, the situation of farmers, availability of resources (land, water and climatic conditions, etc). It also requires information on climate and water availability, among other information, at the micro level and with seasonal variation. Therefore, the agriculture sector requires a cross-sectoral approach in planning and designing adaptation measures.

203. A combination of different assessment and decision-making tools may be used to facilitate the planning and design of adaptation measures for the agriculture sector. It is possible to develop an integrated model comprising a hydrological model, crop simulation model and climate model. A number of decision support models/analyses may also be useful, such as cost-effectiveness, cost-benefit and multicriteria analyses. It is also necessary to involve multidisciplinary teams in planning and designing adaptation measures for agriculture. Consultation with farmers and agricultural extension agents at the local level is essential.

204. Depending on the circumstances, the strategy can be comprehensive at a national level, across sectors, regions and vulnerable populations, or it can be more limited, focusing on just one or two sectors or regions (UNDP 2004 chapter 8, APF). A policy objective might be drawn from the overall policy goals of the country – for instance, the maintenance or strengthening of food security. Ways to achieve this objective might include: farmer advice and information services, agricultural research and

[12] Information on different, high-yielding varieties is available on the website of CGIAR and its member organizations (www.cgiar.org).

development, seasonal climate forecasting, and subsidies or incentives for the development of irrigation systems.

205. The setting of time horizons is needed when defining a strategy, policy or measure, and also for monitoring the implementation of an adaptation strategy (UNDP 2004, TP9). Generally, strategies would be long-term in nature, and policies targeted at the medium- to long-term. Measures may have an implementation time of any length, but are expected to have sustained effects. Prioritization, mostly of measures, but in some cases also of (alternative) policies, would take the whole period into account.

3. Implementation

206. Without the implementation of identified adaptation measures, there is no benefit to be gained from planning and designing adaptation measures. Adequate resources are the primary prerequisite for the implementation of measures. There are several sources of funding for adaptation measures, including bilateral and multilateral sources. An access mechanism and capacity are also necessary.

Table 8. Examples of adaptation opportunities vis-à-vis climate change impacts on agricultural systems

Response strategy	Adaptation options and technologies
• Use of different crops or varieties to match changing water supply and temperature conditions	• Conduct research to develop new crop varieties • Improve distribution networks
• Change of land topography to reduce run-off, improve water uptake and reduce wind erosion	• Subdivision of large fields • Grass waterways • Land levelling • Waterway-levelled pans • Bench terracing • Tied ridges • Deep ploughing • Roughening of land surface • Windbreaks
• Introduction of systems to improve water use and availability and control soil erosion	• Low-cost pumps and water supplies • Dormant season irrigation • Line canals or install pipes • Use brackish water where possible • Concentrate irrigation water during peak growth period • Level fields, recycle tail water, irrigate alternate furrows • Drip irrigation systems • Diversions
• Change in farming practices to conserve soil moisture and nutrients, reduce run-off and control soil erosion	• Conventional bare fallow • Stubble/straw mulching • Minimum tillage • Crop rotation • Contour cropping to slope • Avoid monocropping • Chisel up soil clods • Use of lower planting densities
• Change in timing of farm operations to better fit new climatic conditions	• Advance sowing dates to offset moisture stress during warm period

Source: Smit 1993.

207. Many adaptation measures (hard and soft) for protecting agriculture from flood, drought and salinity have been implemented in many parts of the world (e.g. hard technologies - flood control, drainage and irrigation, soft technologies - training on how to use water infrastructure). Learning from existing projects and measures would be helpful. Table 8 provides a list of currently available adaptation options and technologies that can be applied at the farm or farmer community level. Most available options take advantage of the general flexibility of agricultural systems, relating to the short management cycles involved. It is likely that autonomous adjustment by farmers will continue to be important as the climate changes, provided that farmers have access to the right information and tools. However, some agricultural systems are less flexible, for example because they are constrained by soil quality or water availability, or because they face economic, technological, institutional or cultural barriers. In such cases, autonomous adjustments may not be implemented in time because of a lack of awareness (of both problems and solutions), and anticipatory planned adaptation would be required to provide the right conditions (i.e. information and tools) to farmers for autonomous adjustment (Klein and Tol 1997).

208. Anticipatory strategies for adaptation to climate change and climate variability aim to increase flexibility so as to allow the type of adjustments shown in table 8. For example, increasing the variety of crops may require the introduction of new knowledge and machinery to a farming community. However, as the climate changes, the technologies listed in table 8 may not be sufficient, and the need may arise for the development of new technologies to allow farmers to cope better with the anticipated impacts of climate change, and to reduce the costs of adaptation (Klein and Tol 1997).

4. Monitoring and evaluation

209. Periodic or continuous monitoring and evaluation of the performance of adaptation measures is necessary to allow for modification and readjustment, taking into consideration changing circumstances and the original objectives. Evaluation brings new insights and information, including regarding effectiveness and acceptability vis-à-vis the stakeholders. Monitoring and evaluation of performance can be done with the aid of different communities involved in a project’s implementation and its beneficiaries at local level. It is also necessary to identify appropriate indicators, and monitoring must be easy and the cost nominal.

C. Role of technology in adaptation

210. The IPCC Special Report on Methodological and Technological Issues in Technological Transfer stated that changes in crops and crop varieties, improved water management and irrigation systems, and changes in planting schedules and tillage practices will be important in limiting negative effects and taking advantage of beneficial changes in climate. The extent of adaptation depends on the affordability of such measures, particularly in developing countries: access to know-how and technology, the rate of climate change and biophysical constraints, such as water availability, soil characteristics and crop genetics (IPCC 1996, Summary for policy makers, working group II).

1. Existing system for the development and transfer of agricultural technology at the global level

211. The agriculture sector is unique in that a global network of research, development and technology transfer has already been in place for a number of decades. Before World War II, most countries developed agricultural technologies in relative isolation. This is no longer the case. Today major elements of what can be described as a **global agricultural research system** are in place, where any country can link its research efforts to the international system to help solve important problems.

212. The global system is made up of three major players: National agricultural research systems of developing countries, international agricultural research centres (IARCs), and advanced laboratories and institutions in developed countries. These players interact in a variety of ways, including through bilateral agreements, multilateral agreements, contracts and research networks. The global system, being

informal, depends largely on the meshing of perceived needs of numerous research organizations. With its growth and development, it has become the world's largest and most collaborative scientific enterprise. Almost every country is involved in some way and has invested some of its own funds, mostly at home, to participate. Community-driven technology transfers often proceed in the system.

213. The CGIAR is a strategic alliance of countries, international and regional organizations, and private foundations supporting 15 international agricultural centres that work with national agricultural research systems and civil society organizations and the private sector. The alliance mobilizes agricultural science to reduce poverty, foster human well-being, promote agricultural growth and protect the environment. The CGIAR generates global public goods that are available to all.

2. Existing coping strategies and measures for the agricultural sector at national and community level

214. **Traditional** (endogenous) **technologies,** such as hydroponics (floating agriculture) and diversification of cropping patterns, to cope with a long flood duration or a late flood are common in many regions in South Asia. A number of community based adaptation practices were presented at the First International Workshop on Community Level Adaptation to Climate Change held in Dhaka, Bangladesh, in January 2005. Details are available at <www.bcas.net>.

D. Enhancing flows of technology for adaptation

215. Global climate models (GCMs), the tools most widely used for climate prediction, are very complex and their demand for computational power limits their output to spatial and temporal scales inappropriate for crop simulation. Output is on the scale of hundreds of kilometres and the associated timescale is monthly, which means that sub-grid-scale processes on a short timescale, such as precipitation, are not adequately represented. Stochastic weather generators lack the predictive power of GCMs, but are able to reproduce site-specific climates on a daily timescale quite well. The combination of these two methodologies should allow the production of climate scenarios for agricultural applications that: are site-specific with daily temporal resolution; include the full set of climate variables required by the crop model; contain an adequate number of years to permit risk analysis; and include changes in means and climate variability.

216. To address adverse effects of global warming it is necessary to have a new generation of varieties. Breeding will continue to be important, but **gene technology** will help to speed up the process. This process can be expensive, and vulnerable countries will require international assistance, for example through the CGIAR network of agricultural research centres. Many of the conditions that can be expected in the future are already problems for marginal areas: drought, heat stress, salinity, pests and pathogens. Drought and temperature resistance are two forms of stress resistance particularly relevant to climate change. A number of studies have demonstrated that genetic modifications to crop varieties can increase drought tolerance. Breeding and genetic modification for heat resistance will also be important. However, caution should be exercised to minimize potential socio-economic, health and environmental impacts of introducing genetically modified crops (Cheikh and others 2000, FAO 2004, Pilon-Smits and others 1995, Drennen and others 1993, Kishor and others 1995, Hinderhofer and others 1998).

217. While yield growth has accounted for over 90 per cent of recent agricultural output growth, scholars credit genetic improvements in crop varieties with half of this yield growth (Duvick, 1992; Byerlee, 1996; Wright 1996). The remainder of the growth is attributed to improved management practices, irrigation, and increased use of fertilizers and other inputs. In the future, genetic improvements are likely to play an even greater role. This is particularly true given other environmental considerations that limit the extent to which higher yields can come from more intensive use of chemical fertilizers and pesticides. The efficient conservation, exchange and use of agricultural genetic resources will be critical for the future development and transfer of agricultural technology. Despite the impressive achievements

of the Green Revolution, nearly 1 billion poor people in developing countries still achieve their sustenance from agriculture using their own traditional plant genetic material (World Bank, 1992).

218. Because the performance of crop varieties is sensitive to agro-climatic conditions, much of the transfer of improved crop varieties has been North-North between temperate regions and South-South across tropical or sub-tropical regions. The advances of the Green Revolution may be thought of as "North-assisted" South-South technology transfer. The semi-dwarf wheat varieties now widely adopted in India's Punjab were originally developed in Mexico; and Indian rice yields are substantially higher thanks to infusions of germplasm collected by the International Rice Research Institute from other parts of Asia. In the future, biotechnology may offer important opportunities to address the need for crop adaptation to changing climate across all countries.

219. However, the cost of grain increases annually, and funding for plant breeding, especially for developing countries, is now decreasing. Breeders must decrease the cost per unit of genetic improvement if gains are to continue. Developing countries must look for more efficient operations and for economies of scale through collaboration with breeding programmes in other countries or the IARCs.

220. For the past 20 years, great hopes have been placed on **biotechnology**. Biotechnology, as an aid to plant breeding, was first used in the industrialized nations, but will be available for use in developing countries with very little delay. In some cases the improvements will be publicly available; in other cases, the products will be available on a commercial basis.

221. Local communities manage an important part of these technologies and hold ownership. This is important in the development of systems for integrated gene management (e.g. the CGIAR's programme) that combine modern and traditional methods of genetic crop improvement, and include the interests of all the stakeholders (including the rights of farmers, local communities, breeders and biotechnology companies).

222. A major constraint to plant breeding for developing countries is the reduction in public funds for agricultural research. Such reductions, originating in the developed countries, have especially strong adverse effects on developing countries.

223. A wide range of coping strategies and measures at local level are available in the developing countries. However, it is necessary to understand the effectiveness and potential of these technologies to address anticipated adverse effects of climate change, including variability and extreme events, also to assess the changes or modifications that will be necessary for making those technologies applicable under a warmer climate. It is also necessary to identify new development and transfer mechanisms, both financial and institutional.

1. Current limitations and responses

224. The IPCC special report reported that there are five common limitations for technology transfer in agriculture:

(a) Impacts primarily driven by changing patterns of extreme weather events

(b) Opportunities and risks associated with incorporation of climate change projections in large infrastructure projects that are currently being planned and implemented, and which will still be in place 50 to 100 years from now

(c) The considerable time it will take to plan and implement a number of technologies for adaptation

(d) Society's vulnerability to climate change, which largely depends on its economic, technical, institutional and socio-cultural capabilities to cope with adverse effects

(e) The uncertainty of the impact of future climate change.

225. The international system of plant genetic resource exchange and research has succeeded in maintaining steady crop yield, while controlling yield variability. There is growing concern that this may not be sustainable in the longer term given current funding levels (United States Congress, Office of Technology Assessment, 1987; NRC, 1993; UN/FAO, 1997). Funding problems arise in part because individual nations do not capture the full gains from improved crop yields (Frisvold, 1997). This implies that national governments will underfund germ plasm storage (NRC, 1991). The United States National Research Council has noted that many public gene banks are not effectively preventing genetic erosion within their collections (NRC, 1993). Public gene banks have even been characterized as "gene morgues" (Goodman, 1990). Multilateral funding of international crop research facilities partly overcomes this problem . Yet, “free-rider” problems imply that funding for international centres will also be difficult. New technologies that are freely available to those who do not pay for their development may discourage potential funding sources.

226. A recent comprehensive study shows that:

(a) The number of gene banks has increased dramatically since 1970. While much of the emphasis has been placed on collecting materials, less has been given to maintaining the long-term viability of accessions;

(b) While representation of many major crops in gene banks is relatively good, coverage of many others (such as root crops, fruits and vegetables) is poor;

(c) Only a small fraction of accessions have been characterized;

(d) Many countries have reported that funding has been too unstable and uncertain, year to year, hampering investment and planning.

227. Thus, while plant breeders appear confident that the current germ plasm stock, if properly maintained, is adequate to produce steady yield growth over the next 20–50 years (Knudson, 1999; Frisvold and Condon, 1998), there is widespread concern that this genetic stock is depreciating. Of particular concern is the status of the collections of the Vavilov Institute in Russia, one of the largest collections in the world. It is facing critical financial and structural problems (Zohrabian, 1995).

228. **Limitations of the CGIAR system.** As the new seed–fertilizer technology generated at the CGIAR centres, particularly for rice and wheat, began to become available, some donors assumed that the CGIAR centres could bypass the more difficult and often frustrating efforts to strengthen national agricultural research systems. Strong national research centres are essential if the prototype technologies developed at international centres are to be broadly transferred, adopted and made available to producers.

229. Apart from financial difficulties, a number of the CGIAR centres are experiencing the difficulties associated with organizational maturity. There is a natural “life cycle” sequence in the history of research organizations and research programmes (Ruttan, 1992). The challenges associated with climate change might re-invigorate international agricultural research. On the other hand, efforts to strengthen national research institutes have been only partially successful.

230. **Growing role of the private sector**. Many studies have considered the public good aspects of genetic resources. Naturally occurring plants are not considered patentable inventions. Genetic resources are easily transported and replicated, making it difficult for a country or individual to exclude others from their use. This discourages private actors from making investments to preserve and collect

genetic resources and to screen them for their potential usefulness. Intellectual property protection historically has been weak for biological inventions. While patents on mechanical processes date back hundreds of years, intellectual property rights (IPRs) for commercially developed seed varieties began only this century, and remain considerably weaker than other forms of IPR protection.

231. Historically, there have been two major institutional responses to the private sector's inability to gain from and invest in plant breeding. The first has been the extensive public funding of an international network of public research facilities and institutions. The second response has been the evolution of increasingly strict IPRs for biological inventions. Both stricter IPRs and advances in hybridization have stimulated private research and development in plant breeding. The progeny of hybrids have substantially lower yields. This naturally deters purchasers of seed from regenerating new seed for their own use or for resale. The requirement that farmers repurchase seed annually greatly increases returns to private plant (seed) breeders. While public research and development investment has slowed considerably in recent years, private research and development has grown substantially. For example, private plant breeding research in the United States more than quadrupled in real terms between 1970 and 1990.

2. Adoption barriers/constraints (within country and between countries)

232. **Generic farm-level adoption constraints**. For farm-level adoption, the barriers include small farm size, credit constraints, risk aversion, lack of access to information, lack of human capital, inappropriate transportation infrastructure, inadequate incentives associated with tenurial arrangements and unreliable supplies of complementary inputs. Because strategies for new technologies are often imposed from the top down, implementation fails when local people are not consulted or are treated as labourers only, or when local research and extension staff are not sufficiently trained in the specific techniques. Consequently, positive measures to improve soil and water productivity, for example, both through individual and communal action, should receive higher priority for research, extension and training in the future. Some agricultural measures should also form part of an integrated biotechnical approach that provides appropriate expertise and equipment, seeds of improved cultivars, plant nutrients and pest management, with strong social and economic incentives.

233. **Constraints of supply of new technologies.** The supply of new technologies to address adaptation to climate change is constrained by a number of factors and also varies by region and stage of planned adaptation. Technological information needed by different groups of stakeholders involved at different stages of planned adaptation is limited and sometimes not accessible. Many developing and least developed countries have a shortage of capital that they can commit to new technologies. It is also evident that the growth of funding for agricultural research is slowing down over time.

234. **Constraints of technology developments relative to local conditions.** Vulnerability to climate variability and change is context-specific and therefore technologies for adaptation must match local conditions both biophysical and social. There are a number of examples of development of technologies for the agriculture sector aimed at addressing present climatic stress, but not many examples of how to deal with additional stress, under which local condition will be changed.

E. Conclusions

235. As this section has discussed, there are a number of uncertainties regarding the range of impacts associated with climate variability and climate change on agricultural activities. Therefore, when considering technologies that are appropriate for adaptation in the agriculture sector, a diverse portfolio of technologies is desirable as it helps to retain the flexibility to transfer and adopt needed technology. Lack of information and financial and human capital, and unreliable equipment and supplies discourage the transfer of technology in many cases. These hindrances can rarely be surmounted unless the

transferred technology has a high probability of directly addressing the climate related impact in a cost-effective manner.

236. The effectiveness of technology transfer in the agriculture sector in the context of climate change response strategies also depends to a great extent on the suitability of transferred technologies to the socio-economic and cultural context of the recipients, considering development, equity and sustainability issues. Constraints of supply of new technologies, shortage of technological information and shortage of capital are also important aspects of technology transfer. It is evident that integration of both 'hard' and 'soft' technologies and building working partnerships between government and non-governmental organizations is necessary to increase the effectiveness of different technologies for adaptation to adverse climatic effects. Governments can facilitate the flows of technologies within countries with incentives, regulation and by institutional strengthening.

VIII. Public health

237. After introducing the challenge of climate change for public health, this section presents and discusses technologies for adaptation to climate change for health, following the framework outlined in chapter II. It then describes the role of technology in adaptation, including recent trends in public health protection, and discusses opportunities for technological innovation. The section builds on earlier work by the IPCC (in particular the chapter "Health" of the IPCC Special Report on Methodological and Technological Issues in Technology Transfer).

A. Introduction

238. Climate is one of multiple factors that determine the incidence and range of many health determinants and outcomes. The IPCC Third Assessment Report concluded that overall, climate change is projected to increase threats to human health, particularly in lower income populations, predominantly within tropical/subtropical countries (McMichael et al. 2001). Three broad categories of health impacts are associated with climatic conditions: impacts relatively directly relating to weather and climate variability; impacts resulting from environmental changes that occur in response to climatic change; and impacts resulting from consequences of climate-induced economic dislocation and environmental decline. The first two categories of climate-sensitive health determinants and outcomes include changes in the frequency and intensity of thermal extremes and extreme weather events (i.e. floods and droughts) that directly affect population health, and indirect impacts that occur through changes in the range and intensity of transmission of infectious diseases and food- and waterborne diseases, and changes in the prevalence of diseases associated with air pollutants and aeroallergens.

239. Ecosystem changes can facilitate the emergence and re-emergence of disease, even under current climatic conditions (NAS 2001). Climate change can further change or disrupt natural systems, making it possible for diseases to spread or emerge in areas where they had been limited or had not existed, or for diseases to disappear by making areas less hospitable to the vector or the pathogen. The cause-and-effect chain from climate change to changing patterns of health determinants and outcomes is often extremely complex and includes factors such as wealth, distribution of income, status of the public health infrastructure, provision of medical care, and access to adequate nutrition, safe water, and sanitation. Therefore, the severity of impacts actually experienced will be determined by changes in climate as well as by concurrent changes in non-climatic factors and by the adaptation measures implemented to reduce negative impacts. Table 9 summarizes the health effects of weather and climate.

Table 9. Summary of the health effects of weather and climate

Health outcome	Effects of weather and climate
Cardiovascular, respiratory 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, which can cause morbidity from a range of respiratory and cardiovascular diseases
Deaths and injuries, infectious diseases, and mental disorders	• Floods, landslides, and windstorms cause death and injuries • 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, which adversely affect air quality • Drought reduces food availability in populations that are highly dependent on household agriculture productivity and/or are economically weak
Mosquito, tick-borne diseases, and rodent-borne diseases (such as malaria, dengue, tick-borne encephalitis, and Lyme disease)	• Higher temperatures shorten the development time of pathogens in vectors and increase the potential transmission to humans • Each vector species has specific climatic conditions (temperature and humidity) necessary to be sufficiently abundant to maintain transmission
Malnutrition and undernutrition	• Climate change may decrease food supplies (crop yields and fish stocks) or access to food supplies
Waterborne and food-borne 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

Source: Kovats et al. 2003.

240. The World Health Organization conducted a regional and global comparative risk assessment to quantify the amount of premature morbidity and mortality due to a range of risk factors, including climate change, and to estimate the benefit of interventions to remove or reduce these risk factors. In 2000, climate change is estimated to have caused the loss of over 150,000 lives and 5,500,000 DALYs (disability-adjusted life years) (McMichael et al., 2004; Patz et al. 2005). The assessment also addressed how much of the future burden of climate change could be avoided by stabilizing GHG emissions. The health outcomes included were chosen based on known sensitivity to climate variation, predicted future importance, and availability of quantitative global models (or feasibility of constructing them): episodes of diarrhoeal disease, cases of falciparum malaria, fatal unintentional injuries in coastal floods and inland floods/landslides, and non-availability of recommended daily calorie intake (as an indicator for the prevalence of malnutrition). The models made only crude adjustments for the effects of other factors, such as poverty, that can influence vulnerability.

241. The projected relative risks attributable to climate change in 2030 vary by health outcome and region, and are largely negative, with the majority of the projected disease burden due to increases in diarrhoeal disease and malnutrition, primarily in low-income populations already experiencing a large burden of disease (McMichael et al., 2004). Absolute disease burdens depend on assumptions of population growth, future baseline disease incidence, and the extent of adaptation. Warmer winter temperatures are projected to result in a small proportional decrease in cardiovascular and respiratory disease mortality attributable to climate extremes in tropical regions, with a slightly larger benefit in

temperate regions. The relative risk for diarrhoea in 2030 in low-income countries is projected to be between 1.0 and 1.1 under unmitigated emissions, compared with baseline climate. Countries with an annual GDP of USD 6,000 or more are assumed to have no additional risk of diarrhoea. The projected impacts of malnutrition vary from a large increase (relative risk = 1.1–1.3) in the World Health Organization (WHO) region SEAR-D (Bangladesh, Bhutan, Democratic People's Republic of Korea, India, Maldives, Myanmar, Nepal) to no change or a small decrease (relative risk = 0.99–1.0) in WHO region WPR-B (Cambodia, China, Cook Islands, Fiji, Kiribati, Lao People's Democratic Republic, Malaysia, Marshall Islands, Micronesia, Mongolia, Nauru, Niue, Palau, Papua New Guinea, Philippines, Republic of Korea, Samoa, Solomon Islands, Tonga, Tuvulu, Vanuatu, Viet Nam). Developed countries are assumed to suffer no malnutrition impacts related to climate change. Coastal flooding is projected to result in a large proportional increase under unmitigated emissions; however, this is applied to a very low burden of disease. The projected increase in relative risk is as high in high-income counries as in low-income ones. Large changes are projected in the risk of falciparum malaria in countries at the edge of the current distribution, with relative changes much smaller in areas that are currently highly endemic for malaria.

242. For each health determinant and outcome, there are population subgroups and regions that are likely to be more vulnerable. Vulnerability depends on factors such as population density, level of economic development, food availability, income level and distribution, local environmental conditions, pre-existing health status, and the quality and availability of health care. These factors are not uniformly distributed across a region or country or across time and differ based on geography, demography, and socio-economic 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.

243. Not surprisingly, poor health conditions and high vulnerability to disease within communities is often associated with, and caused by, poverty. One of the outcomes of poverty (although perhaps also a cause) is inadequate public health infrastructure and access to health care, leading to a reduced ability to prevent and control the spread of disease. Substantially reducing or eliminating poverty would enhance the ability of societies to cope with many aspects of climate variability and change, increase adaptive capacity, and perhaps dramatically reduce vulnerability. However, reducing poverty alone will not eliminate vulnerability; even wealthy countries with high adaptive capacity have pockets of poverty and groups of people who tend to be more vulnerable to climate variability and change, as demonstrated by the 2003 heat wave across Europe.

1. Levels of prevention

244. Public health traditionally categorizes measures to reduce disease and save lives into primary, secondary and tertiary prevention. Primary prevention is the "protection of health by personal and community wide efforts" (Last 2001). It aims to prevent the onset of disease in an otherwise unaffected population (e.g. supply of bed nets to all members of a population at risk of exposure to malaria). When primary prevention is not feasible, secondary prevention includes "measures available to individuals and populations for the early detection and prompt and effective intervention to correct departures from good health" (Last 2001). It focuses on preventive actions taken in response to early evidence of health impacts (e.g. strengthening disease surveillance and responding adequately to disease outbreaks such as the West Nile virus outbreak in the United States). Surveillance is necessary to gather early evidence of adverse health impacts. Finally, tertiary prevention "consists of the measures available to reduce or eliminate long-term impairments and disabilities, minimize suffering caused by existing departures from good health, and to promote the patient's adjustment to irremediable conditions" (Last 2001). These measures include health-care actions taken to lessen the morbidity or mortality caused by the disease (e.g. improved diagnosis and treatment of cases of malaria). For many health determinants and

outcomes, secondary and tertiary prevention is generally less effective and more expensive than primary prevention.

245. The ability to influence a public health problem can only occur when all of the following are present (Last 1998):

(a) An awareness that a problem exists

(b) A sense that the problem matters

(c) Understanding of what causes the problem (including what possible solutions exist)

(d) Capability to influence

(e) Political will to influence the problem.

246. To plan and implement effective responses, there needs to be an understanding of what causes the problem (Yohe and Ebi 2005). For example, to formulate adaptation options to a climate stress, it is necessary to understand how the stress translates into exposure and sensitivity. Is the exposure gradual or sudden? Is it a manifestation of mean conditions or the extremes of variability? Is sensitivity linear in exposure, or are there thresholds of exposure beyond which sensitivity is exaggerated? Once sufficient understanding of what causes the problem exists, then capacity to deal with the problem is needed. This is the focus of much of the research on adaptive capacity, including the search for required technologies. Finally, even when all the other factors are present, policies and measures will not be instituted without the political will to address the problem. A sufficient example is an informal comparison of the approaches of different countries with similar resources to adaptation to climate change. An important and implicit issue is that society plays a critical role in determining when a problem matters.

2. Individual- versus population-based approaches to prevention

247. Health benefits to populations may differ from health benefits to individuals. There are individual- and population-based approaches to prevention. In the first approach, public health entities seek to identify high-risk individuals and to offer them some individual protection (e.g. identify individuals more likely to suffer from heat stroke and give them access to air conditioning) (Ebi et al. 2005). The purpose of identifying susceptible individuals is to detect and treat those who are at risk, some of whom may not be aware that they are at risk. Advantages of this approach include that the intervention is appropriate to the individual, there is greater motivation, it is a cost-effective use of resources, and there is a favourable ratio of benefit to risk (Rose 1992). Disadvantages include the difficulties and costs of screening, that treatment does not try to alter the underlying causes of the disease and so is palliative and temporary, and the limited long-term potential for individuals and populations.

248. The population strategy seeks to control the determinants of incidence in the population (e.g. understanding why some populations experience more heat stroke than others in order to plan effective interventions). It aims to lower the mean level of risk factors and to shift the whole distribution of exposure in a favourable direction (Rose 1992). Advantages include the large potential for prevention and that the measures undertaken are behaviourally appropriate. For example, lowering everyone's blood pressure by 10 per cent would correspond to about a 30 per cent reduction in total mortality attributable to increased blood pressure (Rose 1985). Disadvantages include the small benefit for each individual (many of whom will not go on to develop disease), poor motivation, and a poor ratio of benefit to risk. With a mass intervention, each individual has only a small expectation of benefit, and this small benefit can easily be outweighed by a small risk.

249. The preventive paradox is a preventive measure that brings much benefit to the population but offers little to each participating individual (Rose 1992). Public health measures reduce the incidence

and mortality rates of many diseases within populations; these savings are of real lives and real disease, but the savings cannot be linked to specific persons. Further, improvements in the health of populations often result in disappointingly small improvements to the health of any given individual. In most instances, the health of an individual next year is not likely to be much better or worse if they accept or reject prevention advice. This is a particular challenge in disease control programmes.

250. Anticipatory adaptations to climate change may have similar tensions between individual and population level approaches, with similar advantages and disadvantages. An anticipatory measure such as spending public funds to subsidize air-conditioning units in public buildings in a city may impose costs on those who ultimately do not benefit individually (through increased taxes or reduced availability of public funding for other needed measures), but the expectation is that society will benefit through reduced morbidity and mortality during periods of extreme temperatures (Ebi et al. 2005).

B. Adaptation strategies

251. Based on the framework presented in chapter III, this chapter presents examples of technologies that can be employed to develop information and raise awareness, to plan and design adaptation strategies, to implement them, and to monitor and evaluate their performance. No attempt has been made to provide all-inclusive lists of technologies; the technologies discussed are meant to be illustrative.

1. Information development and awareness-raising

252. Awareness of the possible risks and appropriate responses to climate variability and change is needed at the level of individuals, communities, nations, and international organizations and agencies. The current level of awareness with regard to potential health impacts is not high, so climate variability and change are infrequently considered in disease control activities. This is changing as impacts occur, such as the 2003 heat wave across Europe.

253. A key approach to raise awareness and develop information needed for adaptation planning is to conduct national assessments of the risks associated with climate variability and change. Historically, two important dynamics have driven the design of public health interventions, including the management of environmental risks: scientific and technical knowledge, including the level of confidence in that knowledge; and public values and popular opinion (Kovats et al. 2003). Environmental risk management is the process by which environmental assessment results are integrated with other information to make decisions about the need for, approaches to, and possible extent of reducing risk. Policy makers decide what interventions to implement, if any, to address current vulnerability, including vulnerability resulting from climate variability and change, even as research continues to provide additional information.

254. As part of the assessment, for each health outcome the activities and measures that individuals, communities and institutions currently undertake to reduce the burden of disease should be identified and evaluated for effectiveness (Kovats et al. 2003). 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). Reviewing adaptation measures implemented in other regions with similar health concerns may be valuable. The results of the assessment can be used to prioritize issues of concern and to identify where (and when) additional adaptation is needed.

2. Planning and design

255. The climate-sensitive health determinants and outcomes projected to increase with climate change are problems today. Therefore, national and community-level public health efforts to control

these health outcomes will need to be revised, reoriented, and/or expanded just to maintain current levels of disease control. Adaptation options will range from incremental changes in current activities and interventions, to implementation of interventions from other countries/regions to address changes in the geographic range of diseases, to development of new interventions to address new disease threats. The degree of response will depend on factors such as who is expected to take action; the current burden of climate-sensitive health determinants and outcomes; the effectiveness of current interventions to protect the population from weather- and climate-related hazards; projections of where, when and how the burden of outcome could change as the climate changes (including changes in climate variability); the feasibility of implementing additional cost-effective interventions; other stressors that could increase or decrease resilience to impacts; and the social, economic and political context within which interventions are implemented (Yohe and Ebi 2005).

256. There are two fundamental approaches to the identification of adaptation options: the first asks whether current interventions are sufficient to cope with present-day climate risks, and the second identifies additional adaptation options that are needed to cope with projected climate change related health impacts, while maintaining or improving current public health standards (Ebi and Burton, submitted). As evidenced by the burden of climate-sensitive health determinants and outcomes, despite considerable public health efforts directed at their control, there is room for improvement in current adaptation. The design and implementation of incremental adaptations will draw on the considerable experience in the public health sector with responding to both gradual long-term changes (such as disease rates changing over decades) and stimuli with severe consequences over short time scales (such as disease outbreaks).

257. Current adaptations may be insufficient if changes in climatic and socio-economic variables create favourable conditions for increasing the range or intensity of climate-sensitive diseases. For example, developed countries have policies and measures designed to prevent salmonella, a food-borne disease (Kovats et al. 2004). Because the risk of salmonella increases with warmer ambient temperatures that favour the growth and spread of the bacteria, current programmes may need to be enhanced to encourage proper food handling in a warmer world. In another example, climate change may facilitate changes in the range and intensity of transmission of diseases such as dengue and malaria. Current disease management programmes may need to be augmented in current areas of transmission and implemented in adjoining regions.

258. Within this approach is the identification of adaptation options for situations where thresholds could be crossed either because a disease was close to its boundary conditions or because there was a critical change in prevailing weather conditions. For example, although climate change likely played a small role in past reductions in malaria incidence in temperate developed countries, this does not provide reassurance that climate will not play a larger role in determining the future range and intensity of malaria transmission (Kuhn et al. 2003).

259. Programmes to reduce the burden of specific health risks often include a mixture of measures on the individual scale to the community-level scale. For example, depending upon the policymaking structure, administrative units at the community or national level can facilitate heat acclimatization in a number of ways (Kovats and Koppe 2005). Programmes can be implemented that educate individuals on appropriate behavioural responses to high temperatures, such as increased fluid intake. Cooling centres can be provided during days with high ambient temperature. Heat-health warning systems (including intervention plans) can be developed. Consideration of climate change projections can be required in the design and construction of new buildings and in the planning of new urban areas. Energy efficiency programmes can be further developed to reduce heat in urban areas (heat island).

260. Many possible measures for adapting to climate change exist outside the health sector in areas such as sanitation and safe water supply, education, agriculture, trade, tourism, transport, development and housing.

3. Implementation

261. Table 10 shows examples of adaptation options to reduce the potential health impacts of climate change, categorized into legislative, technical, educational–advisory, and cultural and behavioural. The most effective approaches to reducing the potential health impacts of climate change will be through adaptation technologies that reduce the overall level of population vulnerability and that ensure that the measures implemented in all sectors are resilient to projected changes in climate variability and change.

Table 10. Adaptation options to reduce the potential health impacts of climate change

Health outcome	Legislative	Technical	Educational-advisory	Cultural and behavioural
Thermal stress	• Building guidelines	• Housing, public buildings, urban planning to reduce heat island effects, air conditioning	• Early warning systems	• Clothing, siesta
Extreme weather events	• Planning laws • Building guidelines • Forced migration • Economic incentives for building	• Urban planning • Storm shelters	• Early warning systems	• Use of storm shelters
Air quality	• Emission controls • Traffic restrictions	• Improved public transport, catalytic converters, smokestacks	• Pollution warning	• Carpooling
Vector-borne diseases		• Vector control • Vaccination, impregnated bednets • Sustainable surveillance, prevention and control programmes	• Health education	• Water storage practices
Water-borne diseases	• Watershed protection laws • Water quality regulation	• Genetic/molecular screening of pathogens • Improved water treatment (e.g. filters) • Improved sanitation (e.g. latrines)	• Boil water alerts	• Washing hands, and other hygiene behaviour • Use of pit latrines

Source: McMichael et al. 2001.

4. Monitoring and evaluation

262. Monitoring and evaluation are key components of public health methods for evaluating the efficacy and effectiveness of a particular intervention; they often include routine evaluation of indicators, such as morbidity and mortality data. For example, if an early warning system for heat events is in place, evaluation can determine whether morbidity and/or mortality is lower with the system, based on comparison with similar heat events.

C. Role of technology in adaptation

263. The capacity to adapt will depend on many factors, including improving the current level of public health infrastructure, ensuring active surveillance for important health outcomes, and continuing research on how weather and climate affect health and the possible options for mitigating those effects (McMichael et al. 2001). In addition, continuing research is needed on disease prevention, control and treatment.

264. Interventions designed to increase the adaptive capacity of a community or region can also facilitate achievement of mitigation targets. For example, measures to reduce the urban heat island effect, such as planting trees, roof gardens, planned growth, etc., increase the resilience of communities to heat waves while reducing energy requirements. Mitigation policies that reduce fossil fuel emissions, particularly in the transport sector, will directly benefit health through immediate improvements in urban air quality. Reductions in air pollutant concentrations can be linked to quantifiable health benefits (c.f., Li 2002; West et al. 2004).

265. A range of barriers exists to the development and implementation of effective and efficient strategies, policies and measures to reduce current and future vulnerability to climate change-related health impacts. Fundamental barriers exist in low-income countries where adaptation will depend on improvements in not only the public health infrastructure, but also in the medical, water, agriculture, transport and housing sectors. Lack of information, data, knowledge, and human and financial resources to identify and implement appropriate technologies exist in low- and middle-income countries.

266. Just as impacts are site-specific, so barriers depend on the local situation. Local constraints to adaptation include environmental acceptability, economic viability, human skills and institutional capacity, and social and legal acceptability. Adaptation measures may have environmental consequences that are unacceptable. For example, draining of wetlands can have adverse ecological consequences. Resources, including financial resources, human skills and institutional capacity, need to be available to implement the measure, and there needs to be political will on the part of those who influence the distribution of these resources to spend them on adaptation. Measures not in accordance with local laws and social customs and conventions are unlikely to succeed. For example, although application of pesticides for vector control may be an effective adaptation measure, even in communities with regulations to assure appropriate use, residents may object to spraying.

Table 11. Barriers to implementation of measures to reduce public health vulnerability to climate variability and change

Barrier	Manifestation	Example
Low income	Some people unable to purchase the means to improve health – either directly from health care provider or via other means	During cholera epidemic in Brazil, the very poor had difficulties in purchasing filtering devices or rain collecting devices
Institutional decentralization	Political – administrative decentralization of the health systems and disease control programmes	Local governments are not prepared to take responsibility for health services, such as malaria control, sanitation, infrastructure building, etc.
Lack of funding from central government	Sometimes linked to regional or global economic crises; often linked to high levels of military spending or to debt repayment programmes from World Bank and IMF	Susceptibility of populations in Tajikistan, Somalia, and northern Kenya to mosquito-borne infectious diseases, in wake of political crises, military action and lack of centrally provided funds
Lack of technological capacity	Lack of investment in new / up-to-date equipment, trained personnel, transport, etc.	Lack of refrigerators / cold chain for vaccines, etc. No meteorological radar for weather early warning system. Lack of aeroplanes for the control of forest fires
Poor communication between institutions	Inefficient use of limited resources	Poor inter-institutional coordination between disaster relief and public health agencies.
Lack of understanding of the underlying issues	Lack of education and understanding on the links between environment, ecology and human health	Ignorance in some traditional communities about the vector-borne basis of certain infectious diseases. Low appreciation of the physiological stressfulness of prolonged thermal extremes
Poor policy decisions	Indiscriminate use of pesticides and anti-malarial drugs	Rise of resistant mosquitoes and parasites, leading to increased disease transmission
Discrimination	Vulnerable populations (e.g. poor, illiterate, powerless) may not be seen as a priority by the politicians and decision makers	Refugee or ethnic minority populations often do not receive equal access to services

Source: McMichael et al. 2000.

267. Barriers exist when either proposed measures are not technically feasible or their effectiveness has not been demonstrated. For example, possible adaptation measures frequently mentioned include

vaccinations for a range of climate-sensitive diseases such as malaria. Although desirable, debate exists about when these vaccines will be feasible. Moreover, feasibility does not ensure effectiveness. For example, the control of vector breeding may be technically feasible but not possible in situations where sites are too numerous and expertise limited, or a vaccine may be feasible but not practical in the face of constraints such as special storage and transport requirements or frequent revaccination. Table 11 lists some of the current barriers to the implementation of measures to reduce public health vulnerability to climate variability and change.

D. Enhancing flows of technology for adaptation

268. The challenges to maintaining population health are daunting. Billions of people, particularly in low-income countries, lack adequate nutrition, access to clean water and a viable public health system. Many of these countries face the additional challenges of diseases such as HIV/AIDS, tuberculosis and malaria, which consume economic and human capital resources. The worldwide burden of disease is large, with substantial negative impacts on the quality of life, including economic productivity. Climate change is an additional challenge that could work for or against efforts to control climate-sensitive health determinants and outcomes. However, there is currently limited awareness of the risks posed by climate change, limited technical capacity, and insufficient human and financial resources. Although WHO, The International Federation of Red Cross and Crescent Societies, and many other institutions and organizations continually strive to reduce population vulnerability to climate-sensitive health determinants and outcomes, most of the work is done without consideration of how climate variability and change could influence current and planned interventions. The large number of climate related disasters over the past few years has increased awareness of the impacts of climate variability, but limited resources are being devoted to this issue. Further, overcoming the barriers to transferring technologies for adaptation will require actions by the public health and other sectors.

269. One constraint is that there is no central source for information on downscaled climate projections for a region (and health outcome) and help with conducting vulnerability and adaptation assessments based on those projections. Kovats et al. (2003) published guidelines on conducting vulnerability and adaptation assessments, but there is limited capacity within most ministries of health to implement them. Although not health related, one example of a successful programme is the UK Climate Impacts Programme (UKCIP). UKCIP provides a bridge between researchers and decision makers in communities and organizations within the United Kingdom to assess how they might be affected by climate change, so that they can prepare for impacts. UKCIP is a central source for information that is provided in user-friendly formats. In addition, UKCIP can provide guidance and training on conducting regional and sectoral studies into both impacts of, and adaptation to, climate change. Such a resource is needed worldwide because there will never be sufficient capacity for each ministry of health to have at least one person devoted to understanding climate change issues.

270. Funding is another key constraint because resources used for adaptation to climate change will be shared across a range of public health problems, along with other problems of concern to society. In addition, issues will be raised about equity (i.e. a decision that leads to differential health impacts among different demographic groups), efficiency (i.e. targeting those programmes that will yield the greatest improvements in public health), and political feasibility (Scheraga et al. 2003). Lack of economic development and other factors can contribute to increasing vulnerability in addition to climate related stresses. Many of the policies and measures that can be used to reduce future vulnerability to climate change are of value in adapting to current climate, and can be used to achieve other environmental and social objectives. Therefore, policies and measures for adaptation to climate change are best developed in the context of development and environment policies.

271. However, there are a number of opportunities for increasing resilience to current and future climate variability and change, including early warning systems and disease surveillance and control

programmes. Because the health determinants and outcomes of concern are current problems, ongoing research and development are needed to improve control activities. For example, see the SMARTNET case study (page 85).

1. Early warning systems

272. A number of early warning systems (e.g. for heat waves and malaria outbreaks) have been implemented, or are under development, to alert populations and relevant authorities that a disease outbreak can be expected based on climatic and environmental projections. Early warning systems can be effective in preventing injuries, diseases, and deaths (e.g. Ebi et al. 2004). The effectiveness of disease prediction depends on an understanding of the mechanisms of disease transmission or occurrence, reliable and up-to-date information on exposures and health outcomes, and a disease prediction model that is accurate, specific and timely (Woodruff 2005). An early warning of a potential outbreak will be inadequate if not accompanied by an effective response capability, including a specific intervention plan. Once a warning is given, the public health system must have the capability to take effective measures to reduce the predicted risks. For example, the combination of a heat watch warning system and a response plan to reduce the exposure of vulnerable population groups to extreme heat led to a substantial reduction in deaths from extreme heat in Chicago in 1999 over that experienced in 1995 (Palecki et al. 2001).

273. An example of an effective early warning system is the one developed by the Pacific ENSO Application Center (PEAC) in preparation for the 1997–1978 El Niño. In June 1997, PEAC alerted governments that a strong El Niño was developing, that changes in rainfall and storm patterns could be expected, that severe droughts could occur as early as December, and that some islands were at unusually high risk of typhoons and hurricanes (Hamnett et al. 1999). The Pacific region did experience extreme drought during the event, as well as several severe storms. Decreases in water availability and agricultural production were the main causes of adverse health outcomes (Hamnett et al. 1999). The successes of the interventions launched, such as public education and awareness campaigns designed to reduce the risk of waterborne diarrhoeal diseases and vector-borne diseases, limited the resulting disease burdens. For example, despite the water shortage in Phonpei, Micronesia, fewer children were admitted to hospital with severe diarrhoeal disease than normal; this was attributed to frequent public health messages about water safety. On the other hand, micronutrient deficiencies were found in pregnant women in Fiji, especially in regions where the drought was extreme.

274. Kuhn et al. (2005) created a framework for developing disease early warning systems as a basis for identifying diseases for which climate-based prediction offers the most potential for disease control. Candidate diseases for which early warning systems can be developed include cholera, malaria, meningococcal meningitis, dengue, African trypanosomiasis, yellow fever, Japanese and St. Louis encephalitis, Rift Valley fever, leishmaniasis, West Nile virus, Ross River virus and Murray Valley encephalitis. Steps that should be taken to address current limitations in the development of early warning systems include:

(a) Maintain and strengthen disease surveillance systems for monitoring the incidence of infectious diseases. High quality, long-term data sets are essential

(b) Develop generally agreed criteria for assessing the predictive accuracy of early warning systems

(c) Test for non-climatic influences on disease fluctuations

(d) Base final recommendations on cost-effectiveness analyses.

2. Surveillance and disease control activities

275. A core function of the WHO, in collaboration with other agencies, is the establishment and maintenance of communicable disease surveillance programmes to identify, verify and respond to public health emergencies of international concern. A key activity is the establishment of surveillance systems to provide early intelligence on the emergence or re-emergence of health risks at specific locations in time for effective responses to be mounted (Wilson and Anker 2005). However, to capitalize on this possibility, conventional surveillance systems need to account for and anticipate the potential effects of climate change. Surveillance systems will be needed in locations where changes in weather and climate may foster the spread of climate-sensitive diseases and vectors into new regions (NAS 2001). Similarly, information about the timing, location and potential severity of possible changes in climate-sensitive sectors other than public health can be used to prioritize the placement of surveillance and early warning systems to alert populations to changing risk conditions (e.g. the spread of pests into agricultural areas and managed forests). Increased understanding is needed of how to design these systems where there is limited knowledge of the interactions of climate, ecosystems and infectious diseases (NAS 2001).

276. Table 12 summarizes elements needed for a comprehensive surveillance programme to monitor the potential health impacts of climate variability and change.

Table 12. Elements needed for a comprehensive surveillance programme

What	Where	How
• Heat stress	• Urban centres in developed and developing countries	• Daily morbidity and mortality data
• Changes in seasonal patterns of disease (e.g. asthma, allergies)	• "Sentinel" populations at different levels	• Primary health care morbidity data, hospital admissions, emergency room attendance
• Vector-borne diseases	• Margins of distribution (latitude and altitude). Areas with seasonal and sporadic incidence	• Primary health care data; local field surveys, communicable disease surveillance centres; remote sensing data. Surveillance of infectious disease must be active and laboratory-based
• Marine ecosystems	• Coastal populations, coastal zones	• Sampling of phytoplankton for biotoxins, pathogens. Remote sensing of algal blooms. Epidemiology of cholera, other Vibrios and shellfish poisoning
• Natural disasters	• All regions	• Morbidity and mortality data
• Effects on health of sea-level rise	• Low-lying regions	• Local population surveillance
• Freshwater supply	• Critical regions especially in the interior of continents	• Measures of run-off; irrigation patterns; pollutant concentrations
• Food supply	• Critical regions	• Remote sensing; measures of crop yield; food access and nutrition from local surveys. Agricultural pest and disease surveillance.
• Emerging diseases	• Areas of population movement or ecological change	• Identification of new syndrome or disease outbreak; population-based time series; laboratory characterization

Source: McMichael and Kovats 2000.

E. Conclusions

277. Public health has a long history of dealing, with varying degrees of effectiveness, with the impacts of climate variability. However, the fact that the health impacts of climate variability and change can be direct, indirect, multiple, simultaneous and substantial poses major challenges to governments, policy makers, decision makers and resource managers. Incorporating consideration of

where, when and how extensively climate change could affect future disease burdens is important for increasing resilience. Many of the climate-sensitive health outcomes do not need to be addressed individually; health outcomes with common risk factors, such as malnutrition and diarrhoeal diseases associated with the dry season, may be reduced together by the implementation of appropriate interventions.

278. Interventions for reducing the health impacts of climate variability include effective health education programs, improvement of health care infrastructure, disaster preparedness plans, vector monitoring and control, and appropriate sewage and solid-waste management practices. The ability to predict climate variations on a seasonal or inter-annual scale presents communities with the opportunity to develop the capacity and expertise to deal with climate variability, which will also help communities prepare for the effects of climate change.

279. Priorities for further research and development include expanding our knowledge of the associations between weather/climate and human health. It would be helpful to identify and map locations, hazards and communities that are especially vulnerable. It is important to improve our understanding of the complex relationships between the risks posed by climate variability and change, and other factors that influence the range and incidence of climate-sensitive health determinants and outcomes. Underlying this is the need to collect more valid and comprehensive health, meteorological, environmental and socio-economic data at appropriate scales. Institutional arrangements are needed to share knowledge at national and international levels, including improving education and training. All of these activities require funding for capacity-building, interdisciplinary research and regional/national assessments. Technology is fundamental to the effectiveness of the interventions developed and implemented.

IX. Infrastructure

280. This section on infrastructure focuses on the human settlements dimension of infrastructure, and in particular urban communities. After introducing the challenge of climate change for human settlements, this section presents and discusses technologies for adaptation to climate change for use in urban areas, following the framework outlined in chapter II. It then describes the role of technology in adaptation, including recent trends in land use planning, and discusses opportunities for technological innovation. The section builds on earlier work by the IPCC (in particular the chapter “Infrastructure” of the IPCC Special Report on Methodological and Technological Issues in Technology Transfer).

A. Introduction

281. Human settlements throughout the world are extremely varied in size and constitution, as are the components of infrastructure that support such settlements. Infrastructural components in human settlements include energy supply and demand, water supply and demand and drains, waste disposal, transportation, construction, manufacturing, and financial services and insurance, all of which are vulnerable to the effects of climate change as well as non-climatic trends in the economic and social structure of settlements and forces of development. Although human settlements are expected to be among the sectors that could be most easily adapted to climate change, they are evolving far more quickly than the natural environment. Timely technologies to build appropriate technical, institutional and political capacity in this sector are, therefore, integral to adaptation.

282. The degree of vulnerability to climate change among human settlements is as wide-ranging and varied as the nature of these settlements; from villages with several families to large cities with populations in the tens of millions. In addition to the wide range in vulnerability, economic and social trends are expected to interact with the natural effects of climate change to further complicate the effects of climate change. While these trends may serve to mitigate or exacerbate the effects of climate change

in a particular region in the future, human settlements are already at increased risk as a result of population growth, urban migration, increasing poverty, and growing transportation activity, among other factors.

283. Existing problems in urban settlements have already been identified in the course of various projects, such as the development of local Agenda 21 initiatives, which will be discussed further in a case study in chapter IX. As noted in the IPCC's Third Assessment Report, these problems may be interrelated with climate change and its impacts and include those outlined in table 13, which provides an overview of the available literature and scientific consensus within that literature of the major effects of climate change on human settlements.

284. In addition to these already pressing problems facing urban settlements, adaptation of urban settlements is inevitably dependant on "linkage systems" to local, regional, national and international areas. These systems include transport of various goods, services and waste, as well as lines of communication, all essential to the functioning of urban areas and all vulnerable to the impacts of climate change (IPCC, 2001).

285. The IPCC classifies human settlements in several sectors including resource-dependent, riverine, coastal and steepland, and urban. Impacts of climate change in urban areas, although the same as those in other settlements, could take unusually or particularly costly forms. This analysis, therefore, **focuses on technologies for adaptation within urban settlements**.

Table 13. Human settlements impacts, categorized by state of scientific knowledge

Established but incomplete • Increased vulnerability of infrastructure to urban flooding and landslides • Tropical cyclones more destructive • Fire damage to urban/wildland fringe infrastructure increased • Sea-level rise increases cost/vulnerability of resource-based industry • Water supplies more vulnerable	**Well-established** • Sea-level rise increases cost/vulnerability of coastal infrastructure • Energy demand sensitive; parts of energy supply vulnerable • Local capacity critical to successful adaptation • Infrastructure in permafrost regions vulnerable
Speculative • Fire damage to key resources increased • More hail and windstorm damage	**Competing explanations** • Agroindustry and artisanal fisheries vulnerable • Heat waves more serious for human health, resources • Nonclimate effects more important than climate effects • Heat island effects increase summer energy demand, reduce winter energy demand • Increased air and water quality problems

Source: adapted from TAR, 2001.

286. Although water and air pollution resulting from climate change will affect human settlements around the world, they might prove extremely costly in concentrated urban areas. In addition, climate change is expected to create and exacerbate water deficits and surpluses, sometimes creating both seasonally in a given geographic location. This will be of particular concern in urban areas where storm drains, water supply, and waste management systems are not designed with sufficient foresight of such events. Urban settlements will also be affected by the "heat island" effect as the warming of urban air increases. Urban settlements will bear the brunt of accommodating migrant populations resulting in response to environmental impacts of climate change, and urban settlements located in coastal zones are also vulnerable to the effects of sea-level rise (IPCC 2001). The impact of climate change on human

health, discussed in chapter VII, may be of particular concern in urban settlements beleaguered by overcrowding, poverty and poor sanitation.

287. Impacts of climate change on human settlements are an amalgam of many impacts initially felt in other sectors (water, agriculture, industry, etc.) and are highly location-specific, varying significantly as a result of the social and economic components of a settlement and its infrastructure. Peltonen et al. (2005) divided the risks associated with climate change in urban settlements into biophysical changes, primary risks and indirect risks, as outlined in table 14.

Table 14. Risks associated with climate change

Biophysical change	Primary risk	Indirect effects
Climate change • Changes in temperature, precipitation, winds • Changing weather conditions, sea-level rise, extreme weather events, flooding, changes in groundwater levels	• Risk of direct physical damage to structures (e.g. roads and waterways, housing) • Risks of erosion, humidity in construction, construction stability, drying out of soil	• Socio-economic effects, effects on production and consumption, housing and lifestyles. • Effects on urban ecology (wildlife, parks and recreation areas)

Source: recreated from Peltonen et al. 2005.

288. The world's urban population rose significantly throughout the 20th century, continues to grow today and is expected to reach 58 per cent of the world population by 2025 (UNESCO 2003). Each of the potential effects of climate change on human settlements presented in tables 14 and 15 has particular relevance in the context of urban settlements as will be discussed in the following sections.

B. Adaptation strategies

289. Coping with and reducing the effects of environmental hazards has been at the core of the management and governance of human settlements throughout recent history. While most settlements are designed with some capacity to endure the consequences of environmental vulnerability, climate change will result in some changes for which settlements are not yet adequately prepared. Sea-level rise will increase the risk of inundation of coastal settlements and infrastructure. In addition, an increased probability of extreme weather events may also jeopardize the human systems upon which a community depends. Most infrastructure exists in order to limit the impacts of environmental hazards. In urban areas, in particular, legislation and administration relating to infrastructure, including buildings, land use, waste management and transportation, all have integral environmental facets. Adaptation strategies for human settlements must therefore focus on improving the resistance of infrastructure to climate related impacts and infrastructure's ability to recover from them (IPCC 2001).

290. As a result of existing pressures and growing concern over human settlements' capacity to adapt to climate change, planning to reduce sensitivity, designing resilience and flexibility into infrastructure, and management of settlements in a climate-resilient manner are all an essential part of environmental management and planning and, hence, adaptation strategies (IPCC 2001). By necessity, these processes are integrated and multifaceted, and include aspects such as land-use planning, environmental assessment, information and education, targeted anti-poverty work, economic approaches (e.g. pricing and taxing) and administrative reform (Haughton, 1999).

291. As previously discussed in chapter II, planned adaptation has been defined as a multistage process including information development and awareness-raising, planning and design, implementation, and monitoring and evaluation. This process of adaptation was reviewed for several sectors in urban settlements including the building, transportation and industry sectors.

1. Information development and awareness-raising

292. Information and awareness-raising are pivotal in the management, and hence, adaptation capacity of urban settlements for a variety of reasons. Inaccurate and/or inadequate information on environmental issues leads to poor decision-making at all levels of society, from the village level to that of international policy. In addition to insufficient or inappropriate information, unequal access to environmental information can be used by those in power to undermine less powerful individuals and groups (Haughton 1999). Information development and awareness-raising are, therefore, a very important first step in the iterative adaptation process.

293. Awareness-raising activities have played a major role in the housing and commercial building sectors, which continue to grow considerably as a result of urbanization. The diversity of these same sectors of human development has made them favourite fields for technological innovation. Because of the large number and diversity of individuals and groups involved in the building sector, awareness-raising has required special education and information programmes as well as the establishment of permanent consulting infrastructure within countries. Strategies in the building sector and in other sectors have included homeowner guides, adult training programmes, business and finance classes, and innovative school curricula, among other programmes. Among countries, information-sharing technologies include mechanisms such as the Centre for the Analysis and Dissemination of Demonstrated Energy Technologies (CADDET), which provides a large database of energy efficiency and renewable energy demonstration projects (IPCC 2000).

294. An example of in-country collaboration and information development can be found with InfraGuide, a group created by Infrastructure Canada, the Federation of Canadian Municipalities, the National Research Council, and the Canadian Public Works Association. The group is dedicated to sharing its knowledge of, and experience with, municipal infrastructure with individuals and entities throughout Canada for the development of best practices.

295. As discussed in chapter V, geographic information systems are also invaluable in planning and management of urban settlements at all stages of adaptation. Accurate and comprehensive land use data, as well as information regarding the location and state of existing physical infrastructure (e.g. roads, wastewater treatment plants, water treatment plants), are necessary for decision makers at all levels. The programmes also serve as a storehouse for information and data collected through the adaptation process and can be updated as plans are implemented.

2. Planning and design

296. Planning and design begin when adequate work has been done in the information development and awareness-raising stage of adaptation. For infrastructure in urban areas, adaptation efforts must be guided by the fact that urban areas are, by nature, directly and closely connected with other places and other systems (e.g. water resources, agriculture). Planning and design in this sector must address the three determinants of vulnerability, as defined by Peltonen et al. (2005):

(a) Level of awareness

(b) Place-based, geographical, and socio-economic characteristics

(c) Institutional factors.

297. Improving awareness in all sectors of society (e.g. among urban planners, individuals, government officials) is an invaluable step in the planning and design process. An adequate understanding and appreciation for the potential impacts of climate change in urban areas must be translated to all stakeholders involved in and/or impacted by the decision-making process.

Peltonen et al. (2005) provide the example of improving awareness using familiar events, such as floods and droughts, or by contrasting the impacts of climate change with other risks facing planners, individuals and communities. These and other methods can be used in instances where the long-term effects of climate change are difficult to convey to the various stakeholders (Peltonen et al. 2005).

298. Planning and design in this sector must also be focused on effectively identifying and accommodating the various geographic and socio-economic characteristics existing throughout the area of study.

299. Institutional structure, including regulations and organizational capacity, is also central to the planning and design of sustainable infrastructure. The importance of government regulations and organization (as will be discussed) is evident in each example of urban planning. Current legislation typically provides for simple hazard mapping, beyond which environmental impact assessments and strategic environmental assessments do not often incorporate adaptation issues (Peltonen et al. 2005). These tools require some probabilistic and uncertain information for their success. In contrast, vulnerability-based assessment tools do not require accurate prediction of extreme climatic events, rather they require a comprehensive understanding and consideration of the *context* of the problem, and should be incorporated in urban planning (Peltonen et al. 2005).

300. Planning for adaptation in infrastructure must also consider the changing nature of the urban landscape as a result of development: planned adaptation must not only be in response to climatic changes, but must also incorporate consideration of secondary and tertiary changes must also be incorporated. As an example, Peltonen et al. (2005) refer to the trends in construction which increase vulnerability and include denser and wide sprawling urban patterns.

301. Programmes such as CASE (UNEP programme), Smart Growth, QUEST scenarios, and Sheltair directly respond to this need for consideration of the interconnected nature of urban systems, considering all of the determinants of vulnerability previously mentioned (www.icsc.ca). The "Smart Growth" method combines a number of planning practices in an effort to reduce the environmental impacts of climate change, as outlined in the Smart Growth case study in chapter IX.

3. Implementation

302. The IPCC's Third Assessment Report divides the implementation of adaptation into three strategy types: planning and design, management, and institutional frameworks. Adaptation strategies in the planning and design of urban settlements include actions towards ensuring the provision and improvement of infrastructure and services through site and infrastructure planning and design (e.g. building codes which promote health and safety, site design that moderates temperature extremes indoors).

303. Management adaptation strategies include developing suitable regulation and control of activities (e.g. creating and enforcing pollution controls for solid, liquid and gaseous wastes; instituting emergency preparedness; efficiently operating public transportation systems; improving neighbourhood response systems; improving health education), integrating economic tools within regulatory systems (such actions as neighbourhood water wholesaling), facilitating participatory processes (e.g. for local Agenda 21 initiatives), and incorporating incentives and penalties in management.

304. Finally, developing strategies for institutional frameworks includes capacity-building in environmental public sector operations as well as within private-sector and community organizations, creating partnerships between all responsible parties (government, private sector, NGOs, individuals), and implementing various measures to allow low-income groups to buy, rent or build good quality housing on safe sites (Haughton 1999 and IPCC 2001).

305. Urban settlements have used such adaptation techniques as environmental impact assessments, capacity studies, environmental audit procedures, state-of-the-environment reports, statutory plan consultations, and participatory planning procedures. In some cases, urban settlements have also used a combination of these techniques to develop “Local Agenda 21s” (Haughton 1999 and IPCC 2001) which are being credited with increasing the progress of community-based planning and management. Ilo, Peru, and Manizales, Colombia, provide excellent examples of long-term community-based environmental plans, outlined in the Local Agenda 21 case study in chapter IX. All of these technologies for adaptation are discussed further in the following sections.

4. Monitoring and evaluation

306. Monitoring and evaluation has taken several forms in Manizales, Colombia, as a part of the city’s local environmental action plan, including a series of environmental observatories, discussed in the case study on Local Agenda 21s. Monitoring covered environmental conditions and trends and was important in assessing programmes and projects and the extent of citizen involvement (Valasquez 1998). These studies of the development of “Local Agenda 21s” for adaptation to environmental stress (including climate change), clearly demonstrate the importance of effective monitoring and evaluation of projects (the final stage of the adaptation process).

C. Role of technology in adaptation

307. The success of technologies for adaptation in the infrastructure sector appears to be directly related to their ability to consider cross-sectoral implications of climate change and improve cooperation among various actors in urban planning.

308. In reviewing technologies being used throughout these sectors, the importance of land-use planning and management in the adaptation of urban settlements is evident. Building codes and standards, zoning and clustering are all found in some form throughout the sectors and are all part of the new development principles (e.g. Smart Growth). Building and planning practices which take advantage of the projected increases in population (particularly important in urban areas as a result of urban migration) can be found throughout the literature and in all sectors linked to infrastructure. In addition, technologies for adaptation in this sector also focus on the reduction of dependence on natural resources (e.g. water and petroleum-based fuels) whose supply and/or cost may be altered as a result of climate change.

309. The **transportation sector** of human settlements has been labelled as the least flexible to change, as a result of primary dependence on petroleum-based fuels and well-established travel lifestyles throughout developed and developing countries alike (IPCC 2000). Appreciable research and effort is being expended in this sector in order to address the potential impacts of climate change. Mitigation technologies in the sector, such as vehicle technology improvement, fuel technology improvement and non-motorized systems, are complemented by the changes in infrastructure and transportation systems, widely employed as technologies for adaptation. Innovations in design, planning and implementation technologies include, among others, those listed in table 15. Several examples were taken from a case study of the city of Singapore, which has implemented a land transport policy to control transport growth, employing technical, regulatory and policy measures (IPCC 2000). The potential for physical changes in road characteristics as a result of changes in precipitation events and drier weather are also being studied. As they are not yet fully understood, however, no technologies for adaptation currently exist in the literature with which to address these potential impacts of climate change.

310. As the role of **industry** expands in developing countries, considerable potential for energy- and resource efficient-technologies exist in this sector. In developed and developing countries alike, efficiency in industry has greatly improved; however, considerable opportunities for adaptation to

climate change exist in the sector. Though the sensitivity of systems in the sector is considered low compared to natural systems, expected fluctuations in the systems' input and design conditions, as well as vulnerability as a result of siting, should be considered in adaptation processes (outlined in table 15) (IPCC 2000).

Table 15. Infrastructure technologies for adaptation

Building sector	
Hard	**Soft**
• Clustering of high density residential and commercial land use to improve the system efficiency of combined heat and power systems	• Limiting developments on flood plains or potential mud slide zones in order to adapt to both current and anticipated future flooding
• Laying out city streets and building lots to optimize the potential use of solar energy	• Building codes and standards to reduce energy consumption and also reduce the damage to buildings from destructive weather anomalies
• Minimization of paved surfaces and use of trees to reduce flooding, moderate urban heat-island effects and reduce the energy required for air conditioning	• Measures that provide low-income groups with access to property (e.g. regularizing property rights for informal settlements)
Transportation sector	
Hard	**Soft**
• Traffic and fleet management aimed at reducing road congestion • Vehicle quota system in Singapore • Electronic road pricing in Singapore • Designing clusters under the mixed land model (homes, jobs and stores are together) • Fiscal measures (e.g. import duties, registration fees, road taxes, etc.) • Urban rail systems	• Linking urban transport to land-use patterns • Comprehensive and integrated planning • Zoning • Increasing access to jobs and shops • Promoting mass public transportation • Well-developed communications systems
Industrial sector	
Hard	**Soft**
• Protecting industrial installations from flooding using physical barriers	• Reducing industrial dependence on scarce or variable resources • Siting industrial systems away from areas vulnerable to changes in weather conditions

Source: adapted from IPCC 2000 and IPCC 2001.

311. Employing hard technologies, such as physical barriers, serves to protect industrial installations against extreme climatic conditions expected as a result of climate change (e.g. flooding). Siting industrial systems away from vulnerable areas (e.g. coastlines expected to be inundated by sea-level rise) will also reduce their vulnerability to weather conditions. Industrial systems depend on the input of a number of resources for production, particularly on the provision of water supplies. Reducing the dependence of industry on such resources will, in turn, reduce industrial vulnerability to fluctuations in availability of these resources as a result of climate change.

312. The industrial sector must also be prepared to adapt to changes in government policies that might be made as a result of climate change. If, for instance, carbon taxes are instituted, input costs in the industrial sector would change (IPCC 2001). Technologies that reduce industrial dependence on vulnerable resources, as discussed above, would be one way of adaptation to be considered in this case. Much less predictable or conducive to adaptation are changes in consumer behaviour due to climate change, as well as industrial changes as a result of climate-sensitive natural resources (such as changes in the food industry as a result of changes in agricultural production) (IPCC 2001). Adaptation technologies for these areas of vulnerability have not been adequately researched.

D. Enhancing flows of technology for adaptation

313. In all sectors of urban settlement and infrastructure, government, private sector and community stakeholder groups play integral roles in the adaptation process. Although the methods of technology transfer vary in and among the various sectors, the importance of mainstreaming awareness-raising and considering the entire governance structure is clear.

314. **Governance structure.** In all sectors of urban settlement and infrastructure, government plays an integral role in environmental planning and management (Haughton 1999). Improving the government's institutional capacity in urban settlements is indispensable to the transfer of technologies for adaptation. Ensuring institutional capacity in other enterprises and organizations is also essential to managing change in the sector (IPCC 2001).

315. **Building sector.** Government-supported research, development and demonstration programmes have proven essential to technology transfer in the building sector. The pathways of technology transfer in this sector have included information and education programmes, the use of cost-based energy processes, energy and environmental labels, building energy codes, efficiency standards for appliances and equipment, leading by example in government buildings and purchases, and government support for research and development. The ability of local governments to provide effective land-use planning is central to technologies for adaptation in the buildings sector, therefore barriers resulting from the structure of government might also impede the transfer of technologies in this sector (IPCC 2000).

316. Barriers to technology transfer in the building sector of urban settlements include cultural boundaries encountered as a result of behavioural barriers in the information and education programmes previously mentioned, such as the short time horizon in planning and the inability of individuals to deal with life cycle cost minimization.

317. Strategies for overcoming these barriers must effectively include all aspects of the governance structure. Incorporation of the private sector, identified as an important source of funding, should be a major focus of efforts aimed at the transfer of technologies. Focus should be placed on identifying and removing barriers that discourage investment by the private sector in the building fields. Community groups and individuals must also play an important role in the design and implementation of urban planning and management, in order to transcend cultural barriers (IPCC, 2000). Effective incorporation of all of these actors will better address the behavioural barriers faced in information and education programmes.

318. **Transportation sector.** Pathways for the transfer of technology in the transportation sector are typically found in three categories; government driven, private sector driven and community driven. The participation of the private sector has been identified as essential to the transfer of technology in the transportation sector, as in the building sector.

319. While mitigation efforts in the vehicle and fuel technology fields must continue, the adaptation of current lifestyles and travel patterns will be central to reducing urban settlements' vulnerability in the transportation sector to climate change. As a result, strategies to overcoming barriers in the transfer of transportation technology require integrated study and coordination between the many stakeholders that design and depend upon transportation networks in an urban area. Necessarily, therefore, all social, cultural and institutional barriers to transfer must be appropriately considered when assessing the potential for such technologies for adaptation as management practices, fleet control, improved maintenance, better road signs and signalling (IPCC, 2000). These barriers can only be addressed through the inclusion of all stakeholders in the governance system as described above.

320. In reviewing the mechanisms of technology transfer in the transportation sector, the IPCC also refers to the importance of building endogenous technological capacities to increase the receptivity of a

country. Central to both of these strategies must be information sharing between those familiar with endogenous technologies and decision makers. Establishing partnerships between government and the private sector was also identified as a key strategy in the success of technology transfer, further suggesting the importance of strategies which endeavour to consider a wide range of individuals and groups in their governance structures (IPCC, 2000).

321. **Industry sector**. A need to develop capacity for selecting technologies in the industry sector was identified by the IPCC (2000), which suggested the need for a clearinghouse on climate abatement technologies. Though in this case the need is in the realm of mitigation, this may suggest a parallel need in developing countries and in countries with economies in transition (CEITs) for a database of information on technologies such as barriers for industrial installations located in vulnerable areas, as well as technologies employed for the reduction of industrial dependence on various resources.

E. Conclusions

322. A review of the various sectors in urban settlements suggests that the improvement of technologies through consideration of an integrated and exhaustive governance structure is central to the success of adaptation in infrastructure and urban environments.

323. Some researchers regard the adaptive capacity of infrastructure systems as the availability and access to resources by decision makers and populations in vulnerable sub-sectors of society (IPCC, 2001). Accepting this definition of adaptive capacity suggests that improvement in awareness-building and involvement throughout government, private and community groups would result in improved transfer of technologies for adaptation.

324. Experience in the infrastructure sector has also highlighted the importance of coordinated financial support for the implementation of technologies. Smart Growth development, for instance, involves significantly more risk than conventional development, therefore, ensuring financial viability is key to these technologies. Experience in Colombia with local environmental action plans has also highlighted this need for financial support of technologies as being central to their success.

325. In addition, experience with technologies for adaptation has clearly shown that the more successful strategies and means of transferring technologies are those that meet a number of human needs in addition to their provision of environmental benefits (IPCC 2000). Focus should, therefore, be placed on technologies that serve a variety of purposes above and beyond environmental improvement, a quality central to Smart Growth development initiatives (as outlined in chapter X).

X. Case studies for technologies for adaptation

326. This section contains case studies for each of the sectors described in the previous chapters (table 16). Each case study reviews (a) the need for the technology, (b) the mechanism used in transferring the technology, (c) barriers for further implementation, (d) the degree of stakeholder engagement, and (e) results and lessons learned.

Table 16. Summary of case studies reviewed

Sector	Case study name	Type of technology	Technology classification
Coastal zones	• Storm-surge early warning • Factoring future climate change in today's decisions: The case of Boston harbour • Biorock	• Soft • Soft • Hard	• Traditional/modern • Modern • Future
Water resources	• Water harvesting in North Darfur state, Sudan • The SWMnet regional network, Eastern and Central Africa • Seasonal forecasting in adaptation to long-term climate change, Burkina Faso	• Hard • Soft • Soft	• Traditional • Traditional/modern • Traditional/modern
Agriculture	• Floating agriculture in the flood-prone areas of Bangladesh • Mexican farmers learn new irrigation methods • New rice for Africa (NERICA)	• Hard • Soft • Hard	• Traditional • Modern • Modern
Public health	• Heat event early warning systems • Information planning for small island states • SMARTNET: a public/private partnership to prevent malaria	• Hard • Soft • Soft	• Modern • Modern • Modern
Infrastructure	• Smart Growth planning methods • "Local Agenda 21s" and urban environmental management • Urban transport in Surabaya, Indonesia	• Soft • Soft/hard • Hard/soft	• Modern • Modern • Modern

A. Coastal zones

327. The three case studies in coastal zones described below provide examples of an information technology that could be more widely harnessed (early warning system), a soft technology that focuses on the planning process around infrastructure in coastal areas, and a high technology (biorock) that is still in the testing stage that protects coral reefs.

1. Coastal zone early warning systems in Bangladesh

328. Need. Every year millions of people in Bangladesh are exposed to catastrophic flooding in coastal areas. These floods can result in thousands of deaths and can lead to epidemics, as well as seriously damage habitats, agricultural production, fisheries, and pastoral systems. In rural areas of Bangladesh, disaster preparedness and early warning systems are very limited. Moreover, millions of people living in coastal communities have little possibility for evacuation from flood prone areas and are highly vulnerable to flood related diseases.

329. Transfer mechanism. The technology was transferred as part of a project called Vulnerability and Risk Reduction through a community-based system for flood monitoring and forecasting - Community Flood Information System (CFIS) designed to enhance the capacity of Bangladeshi communities to adapt to the risks of floods and cyclones. Experience throughout the world has shown that local people are best placed to prepare for and respond to disasters, including floods. The CFIS project worked in several coastal districts in partnership with local organizations and communities. Its goal was to build an interactive process of collecting and disseminating information on monsoon floods to community stakeholders to increase the capacity of local communities to adapt to adverse climate phenomena.

330. Barriers to further implementation. Prior to the project, most people in the project region obtained flood forecast information from a combination of sources: word-of-mouth (neighbours,

relatives, friends), traditional knowledge (wind, cloud, rain patterns), and local media (radio, television, newspapers). The first two are notoriously "hit-or-miss" and prone to inefficiencies. And information from local media is ineffective as most people are unable to understand media reports easily and as a result cannot take full advantage of warnings provided.

331. Stakeholder engagement. Individuals in coastal communities were consulted during the planning stages of the project, as well as once the project was completed to assess its value in improving the preparedness of local communities to flood surges.

332. Results and lessons learned. The CFIS project generated useful information during the devastating floods of 2004. The timely and widespread delivery of flood warnings in the project region was widely acknowledged to be helpful in prompting communities to take steps to protect crops, habitats, livestock and other support systems. Initial findings of the project were shared in a national workshop just after the flood in September 2004. The Honourable Prime Minister of Bangladesh appreciated the experience of the CFIS project and recommended that the concerned agencies, including the Disaster Management Bureau, replicate the model in other flood prone areas of the country.

2. Factoring future climate change in today's decisions: The case of Boston harbour

333. Need. Even before the arrival of English and European settlers, Boston harbour was an important natural resource for local Native Americans who fished and planted crops along the coasts of the 30 or so islands that dot the harbour. In the early 1600s the Massachusetts Bay Company landed and began settling the area, clearing land for livestock and firewood. Boston harbour quickly became a busy trading port and by 1660 almost all English imports to New England came through these waters. However, as Boston grew and flourished over the next 300 years, the city's waste began to exert a heavy pollution toll on the harbour. Those treatment plants that were installed only performed primary sewage treatment, and the facilities were often overloaded. By the early 1980s the media were calling Boston harbour the filthiest harbour in the United States. The Massachusetts Water Resource Authority (MWRA) realized that a sewage treatment plant was needed for the greater Boston metropolitan area, but one that could withstand climate change – and in particular accelerated sea-level rise.

334. Transfer mechanism. This case study is a good example of technology flows that need to happen within countries. The technology was readily available but it was implemented as a result of litigation initiated by a private citizen that led to the courts ordering the city of Boston to build a new secondary treatment plant, and carry out a subsequent cleanup of the harbour. Deer Island, located within the harbour, was selected as the site for the sewage treatment plant. The design called for raw sewage collected from communities on shore to be pumped under Boston harbour and then up to the Deer Island treatment plant. After waste treatment, the effluent would be discharged into the harbour through a downhill pipe. In order to reduce the costs of pumping untreated sewage from the shore up to the Deer Island treatment plant, the MWRA originally planned to lower the level of the Deer Island plant about half a metre to be closer to sea level. However, design engineers were concerned that sea-level rise would necessitate construction of a wall around the treatment plant to keep the sea out. The effluent would then need to be pumped up over the wall and into the harbour. Such a pump would cost several hundred million dollars. To avoid such a cost, even though it might be decades before it would need to be installed, the designers decided to leave the island at its higher elevation. In 1998 the Deer Island treatment plant was completed.

335. Three points deserve special mention concerning the proactive adaptation planning by the MWRA. First, the decision by the MWRA to account for climate change will also enhance the resilience of the harbour treatment system under current climate variability from storm surges (Weiner (1993) found the 10-year surge elevation in Boston harbour to be 2.8 metres, the 100-year surge elevation to be 3.16 metres and the 500-year surge elevation to be 3.41 metres). Second, while the planning involved

was proactive and innovative, the pump technology involved was conventional and readily accessible. Finally, Boston harbour has become progressively cleaner. Native fish species, such as smelt, herring, striped bass and bluefish have returned to the harbour, as have porpoises and seals.

336. Barriers to further implementation. The potential for more widespread planning to address the effects of climate change exists through municipal and state governments, but there is currently a lack of government commitment at the federal level to address climate change effectively.

337. Stakeholder engagement. The process of implementing the design change was a public process that was open to citizen participation. Indeed, the process was initiated due to the intervention of an individual citizen.

338. Results and lessons learned. The planning for climate change exemplified by this case study has rendered the coastal infrastructure more resilient to future sea-level rise.

3. Biorock: Coral reef restoration technology

339. This case study is different from the coastal case studies previously discussed in the sense that it is a high technology that is still in the testing stage. As such, the issues relating to transfer mechanisms, barriers to further implementation, stakeholder engagement and lessons learned do not apply. The discussion is limited to a description of the technology and its potential to reduce some of the adverse impacts associated with a rise in sea-water temperature.

340. Biorock is a technology for adaptation that shows high potential for reducing the harmful effects of seawater temperature rise and other global-warming-related impacts on coral reefs.

341. The technology works by applying a low-voltage electrical current through seawater, causing dissolved minerals to precipitate on to surfaces that eventually grow into white limestone structures similar to those materials that make up coral reefs and nourish tropical white sand beaches. Various field tests show evidence that these methods have been successful in the acceleration of coral growth in areas subjected to environmental stresses (e.g. temperature rise, pollution, sedimentation) and have produced structures that have been populated by a range of coral reef organisms, such as fish, crabs, clams, octopus, lobster, sea urchins and barnacles. More information on this technology is available at <http://www.globalcoral.org/>.

B. Water resources

342. The three case studies below provide examples of a traditional technology that could be more widely harnessed (water harvesting), a soft technology that focuses on building a knowledge network around small-scale, effective solutions, and a high technology that provides weather forecasting support to small farmers.

1. Water harvesting in North Darfur state, Sudan

343. Need. With most people dependent on rain-fed agriculture, livelihoods in North Darfur are often threatened by drought. Declining rainfall and soil degradation over recent years have led to lower crop yields, making households vulnerable to food crises. Traditionally, farmers have practiced rain-fed cultivation in sandy soils called qoz, but, more recently, have begun to shift to water harvesting cultivation in the alluvial soils along Wadi El Ku as a means to mitigate some of the risks inherent in rain-fed cultivation.

344. The water harvesting technique being adopted, trus (terrace), captures and conveys rainwater to the arable land. With this technique, cultivated land is bounded on three sides, and a rainwater collection area is positioned at the open side upslope of the cultivated land. This collection area impounds

rainwater, allowing it to infiltrate into the soil. An outer collection arm is constructed at a right angle to the base to direct surface run-off to the cultivated land. The dimensions vary with slope and amount of run-off expected in the area. Base bund lengths are between 50 and 300 metres, with arms usually 20–100 metres.

345. Transfer mechanism. The trus is a locally developed, endogenous technology that has been further developed by the Intermediate Technology Development Group (ITDG). Since 1998, as part of its food security programme in North Darfur, ITDG has helped local communities to improve water harvesting techniques and has provided training in trus building. The construction methods are simple and easy to master, with only hand tools required. The cost is low, as labour and the renewal of worn-out hand tools are the main expense for the farmers. The work is carried out in the dry season, when it does not conflict with food production.

346. Barriers to further implementation. Potential for more widespread dissemination exists through the Ministry of Agriculture, which is responsible for providing agricultural extension services to rural farmers. Ten pilot projects were established as demonstration plots to diffuse technical know-how concerning the different aspects of water technologies. In these project areas, land was distributed to the poor and landless farmers according to a list provided by the tribal leaders. Unfortunately, the pilot projects suffered from under-funding and limited infrastructure; the result being that the pilot projects did not demonstrate substantially improved productivity and reduced costs. Moreover, the ministry has not been able to develop the scientific and the institutional capacity to design location-specific agricultural technologies concerning water harvesting, with the result that perceptions of the technology have suffered, and even where positive results have been obtained, there are insufficient channels through which to spread the innovation.

347. There is also a lack of government commitment to provide assistance in years of exceptional torrents and floods that destroy the trus. The lack of commitment leads to bureaucratic delays in approving funding, poor coordination and poor logistics. There is also a lack of regional planning and policy initiatives to support the farmers in maximizing the use of their limited resources and farming investment. For example, even where water harvesting cultivation has been shown to increase agricultural production and income, there is still limited accessibility to credit and delays in delivering loans to farmers, due to restrictive lending conditions formulated by the Agricultural Bank authorities.

348. Political and social instability in this region is also a severe challenge to the effective implementation of this technology. Civil war has caused displacement of civilian populations from rural areas, leading to disrupted and unsystematic farming practices.

349. Stakeholder engagement. In Sudan, farmers are organized into unions at the village level, through which farmers voice their opinions and elect representatives at the state level. Tribal leadership is also involved in management of the natural resources. However, the Sudanese government often frames policies and programmes without consulting these local constituencies; and this top-down approach fosters reluctance to support even programmes that may provide benefits to local farmers.

350. Results and lessons learned. Water harvesting cultivation in alluvial soils has diversified the crop varieties and extended the agricultural season for another four months. Farmers have reported substantial productivity growth for vegetables and cash crops, leading to increased employment opportunities, secured family food supplies, and increased affordability for children's education. Moreover, higher agricultural production has opened new opportunities for trading in agricultural products.

351. Lessons learned from the case study include the recognition that (1) developmental interventions that are flexible and agile are needed to respond to the changing environmental, social and demographic

conditions of the study area, (2) pastoral and farming production systems are dynamically interrelated; these links must be considered in any future interventions to reduce resource-based conflicts, (3) women play an important role in cultivation activities and need to be a key target of interventions, (4) climate change technologies for adaptation require policy reform and incorporation into national development plans, and (5) the implementation of adaptation measures and national strategies needs to involve the rural communities impacted by these measures and strategies. Effective community development should be built on grass-roots participation and involvement.

2. The SWMnet regional network, Eastern and Central Africa

352. Need. In Eastern and Central Africa (ECA), smallholders produce more than 95 per cent of crops using low-input systems, which have degraded soil quality (capacity of soil to maintain productivity in terms of plant growth and environmental health). Although farmers' skills, local knowledge and ingenuity had helped to improve and maintain soil quality over long periods, changing demands have made endogenous techniques inadequate. In addition, ECA experiences alternating floods and droughts, both leading to severe land degradation and frequent famines.

353. To address these constraints, the Soil and Water Research Network (SWMnet) (www.asareca.org/swmnet/home.htm) was created to enhance investments in, and the role of the management of, soil and water to improve productivity, and to add value and increase the competitiveness of, agricultural enterprises in the ECA subregion. A particular focus is the development of effective strategies to enable farmers, communities and countries to adapt and cope with climate variability.

354. Transfer mechanism. SWMnet provides demand-driven knowledge and technologies for integrated management of soil and water for agriculture and the environment, and promotes improved strategies for adaptation and coping with climate-induced crises and shocks. SWMnet promotes effective participation of stakeholders, who take part in implementing the technologies. One of the main problems for soil and water management technologies is the inadequate understanding of their performance in locations other than where they were originally developed. Consequently, many proven technologies and practices have not been widely spread, and only small islands of success have been achieved. Limited understanding of best-bet options for different eco-regions, and opportunities and circumstances facing the local people increase the risk to investments and highly reduce overall productivity and profitability of soil and water management interventions. SWMnet facilitates and supports research to establish the spatial and temporal applicability of proven options and verify their suitability under different conditions.

355. Barriers to further implementation. There are critical constraints and barriers to collaboration in ECA, which hinder networking at the subregional level. These constraints include financial, political, social and cultural constraints. Currently, the agro-meteorological capacity within this region is weak; therefore, climate variability is normally not fully considered in decision-making at the farm and policymaking levels.

356. There is also low implementation of proven strategies that reduce vulnerability to climate variability and provide options for stakeholders to predict climate situations. Moreover, possibilities for positive exploitation of the temporal and spatial variability of climate, through trade and commodity exchange across zones and countries, have not been realized in national and regional planning.

357. Stakeholder engagement. There is extensive endogenous knowledge in the region; therefore, in every strategic theme, SWMnet directs efforts towards an intensive, systematic and detailed stock-taking of knowledge and experience at local, national and international levels. Stakeholders consulted in this process include:

(a) Individual farmers and farmers' organizations

(b) NGOs implementing relevant development work

(c) Public organizations involved in research, extension and training in integrated management of soil and water;

(d) University departments with programmes in soil and water management and related subjects

(e) Public and private organizations involved in managing data on climate, land and water resources

(f) Private sector providers of relevant services

(g) Policy and planning organizations with a mandate in land and water resources and environmental conservation

(h) Regional organizations, international agricultural research institutes and other international organizations with relevant programmes and activities in ECA.

358. Results and lessons learned. SWMnet has fostered an active dialogue between practitioners, supporting the further development of the members' institutional practices.

3. Seasonal forecasting in adaptation to long-term climate change, Burkina Faso

359. Need. Rural households in the Sudan–Sahel region that depend largely on rain-fed agriculture for food and income could substantially benefit from climate forecast information to improve agricultural productivity. In 1997 the Climate Forecasting for Agricultural Resources (CFAR) Project, funded by the United States National Oceanic and Atmospheric Administration, was initiated to assess how farmers (both agriculturists and pastoralists) in Burkina Faso could use climate forecasts to enhance agricultural sustainability and food security. This two-phase initiative included a study of local forecasting knowledge, adaptive strategies to climate variability, and farmers' information networks through fieldwork, surveys, interviews and participatory exercises (1997–2001). The second phase (2001–2004) involved the experimental dissemination of seasonal rainfall forecasts based on sea surface temperature in selected communities, monitoring of farmers' and pastoralists' responses, and the circulation of information among and beyond the communities. The forecasts were presented as the probability of rainfall being in the higher, middle, or lower percentile of total historic seasonal rainfall for the region.

360. Transfer mechanism. Radio broadcasts and workshops were used to disseminate forecasts to farmers and herders. These workshops were held at the village level at three project sites at the Sahel, Central Plateau, and southwest. Participants were selected jointly by facilitators with village chiefs, administrative leaders (délégué), and key farmers whom CFAR had been working with for some time, and included women and immigrants. The workshops included presentation of the forecast, discussion of response strategies, the plan for dissemination at the village level, clarification by the project teams and discussion of issues with the farmers, and distribution of a leaflet summarizing the forecast in local languages. Key farmers explained to everyone what they learned when they got back to their villages.

361. Barriers to further implementation. The forecasts were often late, were for three months and three zones only, and were not specific to individual farm locations. They provided only total seasonal rainfall, not rainfall distribution. Institutional barriers, such as village politics, ethnic identity and gender roles, contributed to exclusion of certain groups. Social norms for appropriate social interaction occasionally hindered outreach. There were also obstacles in village dissemination as some participants downplayed the probability aspect of the forecast to reinforce their own credibility. Farmers' perceptions and priorities affected how they understood and what they remembered of the information received from the forecast dissemination team or from radio broadcasts. Finally, there were resource barriers as

forecast dissemination ceased after completion of the CFAR project because the Burkina Faso government lacked the financial resources to continue or extend the project and feared the potential political liabilities stemming from the risk of forecast failure and subsequent economic losses and popular discontent.

362. Stakeholder engagement. The project engaged farmers, including agriculturists and pastoralists, in collaboration with major institutional stakeholders, including the Direction de la Météorologie Nationale (forecast development and presentation), the National Agricultural Research Service (to determine the farming implications of the forecasts through crop modelling components), and Plan International, one of the largest development NGOs operating in Burkina Faso (to provide logistics and communication support). Provincial level representatives of technical services (ministries of agriculture, livestock, environment) and other local level stakeholders (representatives of NGOs, farmers' organizations, agribusiness, etc.) participated in the forecast dissemination workshops as well.

363. Results and lessons learned. Most rural producers, even those with limited resources, can use and benefit from climate forecasts by making small adjustments in their livelihood and production strategies. However, seasonal forecasts require enhancements and supporting resources, such as risk-based decision-making tools, before they can be implemented widely in support of adaptation to long-term climate change.

C. Agriculture

364. The three agriculture case studies below provide examples of a traditional technology that could be more widely harnessed (floating agriculture), and two modern technologies (high efficiency irrigation schemes and new rice varieties).

1. Floating agriculture in the flood-prone areas of Bangladesh

365. Need. The southern, south-western and coastal areas of Bangladesh remain inundated for long periods every year, especially during the monsoon season. People dependent on agriculture have been using a method of cultivation locally referred to as *vasoman chash*, meaning floating agriculture, since the time of their forefathers. This system is similar to hydroponics, which is a method whereby plants are grown in the water and derive their nutrients from the water instead of from soil. A bio-land or floating bed, is prepared with biomass using water-hyacinth, aquatic algae, waterwort and the other water-borne creepers, straws and herbs or plant residues. The people have adopted and modified the method for different locations according to their needs. The modifications include adjustments in the size, shape and materials used for preparing the floating beds, and are made to enhance the system's ability to cope with monsoon and tidal flood. After harvesting the Aman paddy (cultivated in the monsoon season), people collect and preserve the stubble in the winter for the preparation of floating beds, together with the water hyacinth, collected in May and July from the rivers, channels and other water bodies.

366. Beds can be of any shape or size (perhaps 50 metres long by 15 metres wide and about three quarters of a metre high), and can easily be floated into location. The size depends on the body of water available and farmer's needs, preferences and resources. Though the bed has no definite size, small size beds are easier to manage and better for crop production. The most durable and stable beds are made of base layer and water hyacinth. The upper layer, which is laid about a week after the first layer, is comprised of small and quick-rotting waterworts (or small duck weed type of plant), which make good manure. It takes 15–20 days from the collection of the materials to the start of cultivation.

367. There are two main systems of floating beds: floating island type and stabilized floating island type. The first system is used widely in the Pirojpur and Barisal districts. The second system was introduced about two and the half years ago in Atghar-Kurian union in Shawrupkathi in the Pirojpur

district. Now the latter system is used widely throughout the district. The floating beds, which are used mostly to cultivate vegetables, are more fertile and productive than traditional garden beds on land.

368. Transfer mechanism. A number of projects have promoted this technology in recent years. The noteworthy are the Sustainable Environment Management Programme (SEMP) and Reducing Vulnerability to Climate Change (RVCC). The RVCC project has provided technical training and motivational activities to promote the technology as a way to diversify livelihoods at the community level, while the SEMP project has provided financial support along with technical training and motivational activities.

369. Barriers to further implementation. This technology faces few barriers. However, small amounts of financial capital for marginalized farmers can help a lot in promoting this type of technology. In some cases, lack of water hyacinth and other aquatic vegetation has been a barrier.

370. Stakeholder engagement. Communities are involved in floating agriculture. Community members themselves decide on the size of the beds and type of vegetables that will be grown. They are involved fully from preparation of the bed to sale of the product in the market.

371. Results and lessons learned. An assessment of vulnerability to climate change and sea-level rise for Bangladesh revealed that the southwestern and coastal areas of Bangladesh will become more vulnerable to inundation and more areas will suffer water logging. To adapt with coastal inundation and water logging problems, floating agriculture will help diversify livelihoods and help coastal communities to adapt to these effects of climate change.

2. Mexican farmers learn new irrigation methods

372. Need. Groundwater became depleted in Sosa Oaxaca Valley, Mexico, due to over-extraction, drought and inefficient water-use. Farmers wanted to build new wells and expand their fields and took their request to Mexico’s National Water Commission, but they were turned down. So the farmers turned for help to a bilateral donor agency, which helped to facilitate the creation of a local Groundwater Technical Committee (GTC).

373. Transfer mechanism. Through the group, farmers learned new methods of irrigation. They also learned how to produce organic vegetables and other crops, and how to use water and energy resources efficiently. Farmers were also taught about the causes and effects of watershed problems and how to adopt new technologies. The National Water Commission contributed half the cost of constructing new irrigation systems, while local governments picked up 25 per cent and the farmers pitched in the rest. The key is the new irrigation system housed inside a 1.5-hectare greenhouse. Its automated system has sprinklers and drip lines to supply water and nutrients to the soil inside and outside the complex. Producers are planning to increase the size of the greenhouse so they can expand the irrigation system. Meanwhile, the National Water Commission reports that the groundwater level in Oaxaca Valley is returning to healthy levels.

374. Barriers to further implementation. Unknown.

375. Stakeholder engagement. Farmers, the National Water Commission and the bilateral agency were involved. Farmers received training and were involved in the creation of the GTC. Eighty of the 88 families in Sosa now use the new systems, complete with walking sprayers, sprinklers, and drip lines.

376. Results and lessons learned. Since drought intensity and scale are expected to increase, the promotion of improved irrigation technology will help to address drought problems in many areas.

3. New rice for Africa (NERICA)

377. Need. After much effort, breeders at the Africa Rice Center in Côte d'Ivoire were able to cross varieties of African rice (*Oryza glaberrima*, adapted to African conditions but prone to lodging and grain shattering) with varieties of Asian rice (*Oryza sativa*, high yielding, but susceptible to stresses) to produce early maturing, higher yielding, drought tolerant, pest resistant varieties able to thrive in saline soils. Known by the acronym NERICA, which stands for New Rice for Africa, these varieties could revolutionize rice farming in Sub-Saharan Africa because they produce a crop with minimal inputs even under stress, yet respond well, with bountiful crops, when farmers are able to apply additional inputs. Varieties of NERICA are being planted on 100,000 hectares (including 60,000 hectares in Guinea and about 10,000 hectares in Uganda) and are helping countries cut crippling rice import bills.

378. Transfer mechanism. The West African Rice Development Association (the former name of the Africa Rice Center, which retains WARDA as its acronym) used participatory varietal selection (PVS), an impact-oriented and demand-driven technology generation and dissemination approach. In the first year of the typical three-year programme, WARDA and extension agents established a 'rice garden' in a target village, often in the field of a leading or innovative farmer. The rice garden contained NERICA varieties; modern, improved Asian rice; popular local and regional varieties; and a few glaberrimas (African Rice). Farmers from the host community and surrounding villages were encouraged to visit the garden as often as they liked to monitor progress. WARDA also spread the news among its other 17 member countries, and workshops were held in 1998 and 1999 at which two-person teams from each country were trained in the PVS methodology. The PVS approach has since been applied in all 17 countries, and a regional network was established whose participants meet annually to discuss progress.

379. Barriers to further implementation. Once the new varieties gained a level of acceptance among farmers, seed supply was identified as a bottleneck to wider distribution. To overcome this problem, WARDA imported and adapted a community-based seed system (CBSS) developed in Senegal. The system builds on farmers' own seed-saving practices, with some training input on selecting panicles for seed harvest and methods of preparation, storage and maintenance. With the adoption of CBSS, new varieties can be made available to farmers in four years, as opposed to the seven normally required with formal seed systems. With initial success in Côte d'Ivoire, the system was adapted further and adopted in Guinea, and it is expected to spread elsewhere soon.

380. Stakeholder engagement. Farmers, seed breeders, trainers.

381. Results and lessons learned. New varieties able to cope with stresses relating to climate change are necessary to meet the food demands of growing populations. Cross-breeding of varieties with different stress tolerances would be helpful, and therefore further research into development and dissemination is necessary.

D. Public health

382. The three case studies described below provide examples of a modern technology that provides an early warning system for extreme heat events, and two soft technological interventions, one focusing on building information resources for small island States, and the other a public–private partnership to take action against malaria.

1. Early warning systems for heat events

383. Early warning systems for heat events are designed to alert the population and relevant authorities in advance about developing adverse meteorological conditions, and then to implement effective measures designed to reduce adverse health outcomes during and after the event. The principal components of an early warning system include identification and forecasting of the event (including

consistent, standardized weather criteria for when warnings are activated and deactivated), prediction of possible health outcomes, an effective and timely response plan that targets high-risk populations, and an ongoing evaluation and revision of the system and its components. Heat event early warning systems have been shown to save lives (Ebi et al. 2004). What is considered a heat event varies considerably by latitude and across the summer season, requiring local determination of risk. A variety of population-specific factors determine whether oppressive weather represents a risk, including cultural and economic factors and the status of the public health infrastructure.

384. Need. Severe and sustained periods of high ambient temperature during the summer season are associated with marked increases in morbidity and mortality, particularly in mid-continental areas with high seasonal and diurnal temperature ranges. For example, the heat event that occurred in Europe in August 2003 was unprecedented (Schar et al. 2004) and caused excess mortality in France, Switzerland, Germany, Italy, Spain, Portugal and the United Kingdom of Great Britain and Northern Ireland. The greatest mortality impact was in France, where it was estimated that during the first three weeks of August 2003 more than 14,000 excess deaths occurred, compared to what would have been expected for the time of year (Insitut de Veille Sanitaire 2003).

385. Transfer mechanism. An example of a response plan is the Philadelphia Hot Weather Health Watch/Warning System (PWWS) (Kalkstein et al. 1996). Television and radio stations and newspapers are asked to publicize the heat event, along with information on how to avoid heat-related illnesses. These media announcements also encourage friends, relatives, neighbours and others to make daily visits to elderly persons during the hot weather. A 'Heatline' is operated in conjunction with the Philadelphia Corporation for Aging to provide information and counselling to the general public on avoidance of heat stress. The Department of Health contacts nursing homes and other facilities boarding persons requiring extra care to inform them of the high-risk heat situation and to offer advice on the protection of residents. The local utility company and water department halt service suspensions during warning periods. The Fire Department Emergency Medical Service increases staffing during warnings in anticipation of increased service demand. The agency for the homeless conducts increased daytime outreach activities to assist those on the streets. Senior citizen centres extend their hours of operation of air-conditioned facilities during warning periods.

386. Barriers to further implementation. A major barrier to the implementation of effective early warning systems for heat events has been limited understanding on the part of the public and the responsible agencies of the dangers associated with heat events, and of the appropriate responses thereto. For example, a review of written response plans in cities in the United States vulnerable to heat events found that one third of the cities contacted lacked any written heat event planning, and that of the 10 cities with written response plans, a third of them were no more than cursory (Bernard and McGeehin 2004). Further, five plans reported fan distribution programmes despite evidence that fans do not reduce mortality risk during heat events and may increase heat stress if used improperly.

387. Stakeholder engagement. The extent of stakeholder involvement in planning and implementation of heat event early warning systems has varied based on institutional, cultural, and other factors.

388. Results and lessons learned. Three trends are likely to increase heat-related morbidity and mortality in the next few decades: increasing urbanization, increases in the number of elderly people, and projections that heat events in the future will be more intense, more frequent and will last longer (Meehl and Tebaldi 2004). If these projections are accurate, mid-latitude regions need to be prepared for heat events, irrespective of whether or not they have occurred frequently over the past century. Early warning systems for heat events are a key technology for reducing impacts thereof.

2. Information planning for small island developing States

389. The fact that climate change related health impacts can be direct, indirect, multiple, simultaneous and substantial poses major challenges to governments, policy makers, decision makers, and resource managers in small island developing states (SIDS). The capacity to undertake vulnerability assessments and develop adaptation policies and measures requires information on the health impacts of climate variability and change at the local and regional level; however, this information is currently very limited. To better understand the potential human health consequences of projected climate change for small island States, a series of workshops and a conference were conducted.

390. Need. Many SIDS currently suffer high health burdens, including morbidity and mortality, from extreme weather events, certain vector-borne diseases, and food- and water-borne diseases. The major concerns for many SIDS include the fact that climate change could change the frequency and severity of extreme weather and climate events, such as cyclones, floods and droughts; and change the range and prevalence of climate-sensitive diseases, particularly vector-borne diseases. High priority diseases identified in workshops (see paragraph 173) include malaria, dengue fever, diarrhoeal diseases, heat stress, skin diseases, acute respiratory infections and asthma (Ebi et al. 2005). Small island States also face health related problems due to sea-level rise, including coastal flooding; exacerbated storm surges; damaged coastal infrastructure; salination of island fresh water; damage to coastal ecosystems, coral reefs and coastal fisheries; and population displacement.

391. Transfer mechanism. The World Health Organization, in partnership with the World Meteorological Organization and the United Nations Environment Programme, conducted three workshops (Samoa, July 2000; Barbados, May 2002; and the Maldives, December 2003) and a conference (following the Barbados workshop) (WHO 2000; Aron et al. 2003; WHO 2003). Key recommendations were identified for improving the capacity of the health sector to anticipate and prepare for climate variability and change.

392. Barriers to further implementation. Key barriers to effective adaptation planning in many small island States include limited understanding that climate change is already affecting human health in some countries, few studies have been conducted of the potential health impacts of climate change under different scenarios, and current burdens of climate-sensitive health determinants and outcomes are high, so the limited human and financial resources available must be directed to their control.

393. Stakeholder engagement. The workshops and conference were well attended by staff from ministries of health.

394. Results and lessons learned. Workshop recommendations for improving the capacity of the health sector to anticipate and prepare for climate variability and change in small island States focused on high priority research gaps, capacity-building (including institutional needs), advocacy and community awareness of health impacts relating to climate change, adaptation strategies, policies and measures to reduce projected impacts, data needs, climate forecasts, and resource needs (Ebi et al. 2005).

3. SMARTNET: A public–private partnership to prevent malaria

395. Insecticide treated bed nets (ITN), which kill adult mosquitoes, are one of the four main strategies of the Roll Back Malaria (RBM) global partnership to reduce illness and death associated with malaria. Although most malaria-endemic countries have adopted the RBM strategy, achieving sustainable universal coverage requires intensified financial and technical commitments to bed net distribution.

396. Need. In Africa in 2000 there were as many as 213.5 million clinical episodes of P. falciparum malaria among 557 million people exposed to any risk of infection; children less than 5 years old experienced over 48 per cent of these episodes (Snow et al. 2003). Approximately 1.14 million people died as a result; 68 per cent of these were children less than 5 years old. In the United Republic of Tanzania, in a population of about 34 million, there are over 16 million cases of malaria annually, killing one person every five minutes and causing the death of 80,000 children under the age of five. The country's annual malaria burden is 3.4 per cent (USD 1.2 million) of GDP.

397. Transfer mechanism. SMARTNET is a public–private partnership between the Ministry of Health, Population Services International (Tanzania office), net manufacturers, insecticide suppliers, distributors, wholesalers, retailers, NGOs, research organizations, advertising and promotion companies, the United Kingdom of Great Britain and Northern Ireland Department for International Development, and the Royal Netherlands Embassy. In the United Republic of Tanzania, SMARTNET has provided support to manufacturers, distribution agents and retailers through transport subsidies, guaranteed payments for shipments, and support for marketing.

398. Barriers to further implementation. Malaria's highest toll is in the rural areas of the country where accessing ITNs is more difficult and the ability to pay is reduced. SMARTNET and other partners implemented strategies to reduce these barriers. For example, traders at weekly mixed goods and produce markets now sell ITNs along with other goods. A voucher programme was created that targets subsidies to the most vulnerable groups, pregnant women and children under the age of five. Pregnant women receive a voucher at antenatal visits and can use the voucher as part payment of an ITN at a nearby retail outlet or shifting market.

399. Stakeholder engagement. There was a high level of stakeholder engagement. ITN coverage among households in malaria risk areas of the United Republic of Tanzania has increased from 37 per cent in 2001 to over 50 per cent in 2004, and household surveys show that children under five years of age are given priority to sleep under the nets. The country should achieve the Abuja target of covering 60 per cent of children under five and pregnant women with an ITN by the end of 2005.

400. Results and lessons learned. This programme was not designed and implemented in response to, or anticipation of, climate change. However, climate change is projected to increase the range and intensity of malaria transmission in some regions of Africa (e.g. Patz et al. 2005). Therefore, programmes such as this may need to be revised, reoriented and/or expanded just to maintain current levels of disease control.

E. Infrastructure

401. The three case studies described below provide examples of land use planning approaches that are showing promise in building adaptive capacity in urban settlements. Each of these would be classified as soft technology insofar as they are information based, and high technology insofar as they rely heavily on information technology. The first case study reviews the Smart Growth urban planning approach, the second reviews the impact of some local Agenda 21 programmes, and the third reviews a change study for a large urban area in North America.

1. Smart Growth planning methods

402. Smart Growth development is a decision-making framework which provides communities with guidance as to how and where they should allow for and plan development. Over the past 50 years, the trend has been towards highly dispersed development patterns, and the effects of such growth (including dependence on vehicles, abandonment of city infrastructure, etc.) are now being questioned. As a result, a number of communities, policy makers, planners and developers at all levels, joined to develop Smart Growth projects, and a network of over 32 such organizations now exists.

403. Need. The technologies promoted under Smart Growth vary from planning and development to management and institutional strategies. Guided by 10 principles (below), Smart Growth development incorporates such aspects as compact development, reduced impervious surfaces and improved water detention, safeguarding of environmentally sensitive areas, mixing of land uses (e.g. residential, office and retail), transit accessibility, and support for pedestrian and bicycle activity and other micro-scale urban design features (EPA 2001). Countless examples of development technologies in keeping with these principles have now been documented (by partners in the Smart Growth Network and elsewhere) (ICMA 2002 and 2004).

Box 2. Smart Growth principles

1. Mixed land use
2. Take advantage of compact building design
3. Create a range of housing opportunities and choices
4. Create walkable neighbourhoods
5. Foster distinctive, attractive communities with a strong sense of identity
6. Preserve open space, farmland, natural beauty and critical environmental areas
7. Strengthen and direct development towards existing communities
8. Provide a variety of transport choices
9. Make development decisions predictable, fair and cost effective
10. Encourage community and stakeholder collaboration in development decisions.

404. Creating a range of housing opportunities and choices (principle 3) is essential in building capacity to adapt to climate change. This principle is also central to the institutional framework outlined by the IPCC in its Third Assessment Report (IPCC 2001). Past experience clearly has shown the tendency for those living in overpopulated areas with insufficient infrastructure to suffer significantly more during extreme climatic events, making the need for safe housing opportunities accessible to all extremely clear. Predictable, fair and cost effective development decisions (Principle 9) are essential to building capacity equitably in and among the system of possible actors in urban planning and is, hence, essential in adaptation (ICMA 2002 and 2004).

405. Transfer mechanism. A wide variety of technologies are currently being implemented in keeping with the principles presented in box 2. Table 17 illustrates some of these technologies being implemented in keeping with principles 3 and 9 (by those in the Smart Growth Network and elsewhere).

406. Barriers to further implementation. While Smart Growth development efforts continue to succeed and their prevalence grows, several barriers remain that must be addressed in future projects. Developers are faced with a significant amount of added risk in developing Smart Growth projects, with respect to conventional development. Additional work is required by local governments that have been required to enact new laws, agreements and incentive packages. In addition, on many occasions stakeholders have clashed over project implementation.

Table 17. Some techniques and technologies applied in the Smart Growth Network

Create a range of housing opportunities and choices	Make development decisions predictable, fair and cost effective
• Establishment of employer-assisted housing • Streamlining the development review process when units include affordable housing • Creating a regional programme to encourage all communities to include a fair share of affordable and moderate-range housing • Using transport funds as an incentive to create housing near mass transit networks • Using housing to engender 24-hour cities in revitalization plans • Adopting property tax exemptions for mixed-income developments and low-income homeowners • Using different builders on contiguous blocks of land to ensure a diversity of housing styles.	• Educating elected leaders and public officials about smart growth • Directing development along corridors to create stronger districts • Creating pattern books to streamline construction and enhance project marketability • Making zoning codes and other land development regulations simple to use and easy to read • Establishing state- or regional-level "smart growth" cabinets • Creating an "incentives expert" for developers and businesses when an area has been designated for development/redevelopment • Implementing geographic-based planning into the development process.

407. Stakeholder engagement. The benefit of a clear, open and predictable development process to the community and to stakeholders is clear in experiences generated so far with Smart Growth (which under principle 10 encourages stakeholder collaboration in development). Experience with Smart Growth development points to the importance of:

(a) Bringing stakeholders into the decision-making process early on;

(b) Incorporating new tools to help stakeholders better envision the projects' impacts;

(c) Providing community members with user-friendly information;

(d) Involving the full range of stakeholders (ICMA 2002 and 2004).

408. Smart Growth technologies in ensuring stakeholder engagement included, among others:

(a) Using a "kick the tires" trip to take local government officials and residents to visit Smart Growth communities;

(b) Establishing context-sensitive design training courses that focus on community-involvement strategies for traffic engineers;

(c) Illustrating complex concepts with photographs and imagery;

(d) Creating and distributing free videos to illustrate local planning goals.

409. Lessons learned. The profitability of Smart Growth projects has been identified as a key factor in their success, enabling them to continue to receive attention from investors, lenders, developers and entrepreneurs. The additional risk associated with these projects will require creative solutions to ensure their financing. Experience with Smart Growth projects suggests that local governments must act "uniformly and consistently" in order to convey a stable and predictable development process associated with Smart Growth (ICMA 2002 and 2004).

2. Local Agenda 21s and urban environmental management

410. Need. The city of Manizales, Colombia, has been afflicted with a number of environmental problems throughout its history, including inappropriate transformations in its ecosystem, as well as river and catchment pollution, and high seismic and geological risks. These resulted in a number of impacts within the urban settlement areas, reducing the city's adaptation capacity. These impacts include:

(a) Transport and road infrastructure systems that are inappropriate to the settlement's topography (could be damaged by landslides or flooding with climate change);

(a) Dwellings that are located in high-risk locations for floods, landslides, air and water pollution or disease (vulnerable to flood or landslides; disease vectors more likely);

(b) Industrial contamination of rivers, lakes, wetlands or coastal zones (vulnerable to flooding);

(c) Degradation of landscape (interacts with climate change to produce flash floods or desertification);

(d) Shortage of green spaces and public recreation areas (enhanced heat island effects);

(e) Lack of education, training or effective institutional cooperation in environmental management (lack of adaptive capacity) (IPCC 2001 and Velasquez, 1998).

411. Though the stages involved in the environmental action plan in Ilo, Peru, differed from those in Manizales, the case of Ilo also provides valuable insight into the use of "Local Agenda 21s" in urban capacity-building and adaptation. When facing environmental problems as a result of copper mining, the fishmeal industry and a lack of basic infrastructure in Ilo, a local council worked to develop a long-range environmental plan

412. Transfer mechanism. In response to existing pressures in urban areas, a local environmental action plan was developed as a means of implementing Agenda 21 in Manizales. The process began in 1990–1992 with a focus on social welfare and disaster prevention in the city. Studies on the areas' physical vulnerability showed that approximately 4,240 dwellings (housing approximately 7 per cent of the population) were located in areas with significant overcrowding and insufficient urban infrastructure. In response to these studies, disaster prevention and readiness work was done, including reducing the number of dwellings in high-risk zones (by 63 per cent) and reforesting more than 300 hectares to further protect the hillsides.

413. In 1993–1995, studies on the economic growth of the city showed a period of significant growth. During this period, as a result of national decentralization policies, the municipality was obliged to transform public enterprises into mixed ownership entities. This period of consolidation in the environmental management of the city allowed for cooperation between the local university, which sought to make Manizales a pilot project for all of Colombia and the municipality. This public–private environmental cooperation provided a technical base for environmental management and the development of environmental education initiatives at community level. During this stage of the local environmental action plan, the first community environmental committees were established.

414. The period between 1996 and 1998 was focused on the advancement of participative methodologies for strengthening the management capacity of local entities and communities. International participation in the environmental action plan during this time also helped to increase investment in environmental work from within the country and abroad. During this time, a 1.2 per cent extra environmental surcharge was placed on urban and rural properties and municipal governments were required to invest this tax in environmental problems, further increasing investment in environmental

work. Throughout these processes, a range of data were continuously collected which formed the bases for monitoring conditions and trends in the municipality (Velasquez, 1998).

415. In Ilo, Peru, the local authorities and population worked together in developing a long-range plan to reduce industrial pollution and improve housing conditions and the living environment. The focus was on support for community organization and self-help in established and new low-income settlements (Diaz et al. 1996). Because in Ilo 70 per cent of land is controlled by the industrial sector, the environmental plan focused on preparing the city for sustainable future growth with the arrival of new migrants. The municipality provided 10,000 serviced plots over seven years of work, in addition to increasing freshwater supply, building new roads and, overall, reducing the problem of spatial segregation among inhabitants. With work completed in providing a safer environment for the citizens in Ilo's growing urban population, the plan then also focused on enforced modernization of copper production to reduce emissions and waste (e.g. wastewater treatment, improved systems of solid waste collection, etc.) (Diaz et al. 1996).

416. Barriers to further implementation. The plan was to be extended and designed for the 11 smaller areas into which Manizales is divided (communas). These plans have been lacking in commitment and participation on the part of the institutions and residents. Velazquez suggests the need for more effective preparation for coordination and decision-making phases in these smaller regions. Problems have also arisen around the issues of land use, specifically individual economic or political group interests, which have limited the participation of community leaders.

417. Difficulties arose in covering the entire area of study, in processing, verifying, and analyzing all of the data collected, as well as in the commitment of human resources to collating, centralizing and distributing the information. In response to this barrier, the Autonomous University of Manizales designed a system of urban environmental observatories, physical locations where the community could have access to the environmental information and where programmes of environmental education could be held (Velasquez, 1998).

418. Stakeholder engagement. In the case of the Manizales environmental action plan, community groups were set up and community environmental agendas and environmental priorities were established within these groups. Community participation in the Manizales environmental plan also included the establishment of three mixed-economy enterprises (with public and private members): solid waste dumps, a recycling plant and a centre for supplies.

419. In Ilo, Peru, management committees were formed to address various locally contentious issues and many decisions regarding urban development are made by these committees, which provide a cross-sectoral forum. In Peru, only issues that cannot be resolved in this manner are sent to the mayor for final decision-making. A permanent multisectoral commission on the environment was established, responsible for the monitoring and implementation of all projects carried out under the rehabilitation plans in Ilo. The commission includes representatives from all affected municipalities, representatives from squatters settlements, farmers, and from valley and regional government. As in Manizales, micro-enterprises were also established in Ilo (two), responsible for waste collection and final disposal (Diaz et al, 1996).

420. Lessons learned. The Manizales example of a "Local Agenda 21" plan shows the importance of joint action between various groups. In this case, cooperation between the municipality and the university gradually strengthened the links between research and management. In one case, when no modifications were to be made to the development plan, the university, residents, and ecological and environmental NGO groups joined in a citizens' forum and were able to formalize an agreement for a local environmental action plan: Bioplan 1997–2000 (Velasquez, 1998). Results from the Manizales projects have been positive in resolving concrete environmental problems in the poorest communities.

421. "Local Agenda 21" projects in Ilo, Peru, have exhibited the importance of stable leadership and widespread consultation in policymaking. The same leaders remained in power for the five terms leading up to 1996 and although the mayor changed once, there were no notable changes in policy. The formation of the permanent multisecotral commission on the environment as well as the various management committees incorporating stakeholders has strengthened local democracy and consensus surrounding the environmental action plan, improving policymaking through the involvement of all actors in the governance structure.

3. Urban transport in Surabaya, Indonesia

422. Need. Like many large cities in developing countries, Surabaya, the second largest city in Indonesia, faces a number of transport challenges, including increasing motor vehicle use and resulting air quality reduction and increased urban congestion. Already in Surabaya, motor vehicle ownership in 1990 was higher than in Singapore and Jakarta and twice as high as in Manila, Seoul and Hong Kong and growth has continued, faster than population growth (Silaban 2002 and GTZ-SUTP 2001). As a result, Surabaya is now one of the most dangerous cities in the world by health and traffic safety indicators. Such congestion problems are directly linked to the adaptation potential of individuals in communities, such as Surabaya, therefore transport problems must be addressed to prevent further congestion and the various risks associated with congestion, which stand to increase with increased, unchecked urbanization.

423. Transfer mechanism. Mechanisms to adapt Surabaya's transport system included proposed projects to reform the public transport sector and employ economic instruments for adaptation, among several others. Suggested efforts to reform the public transport sector included:

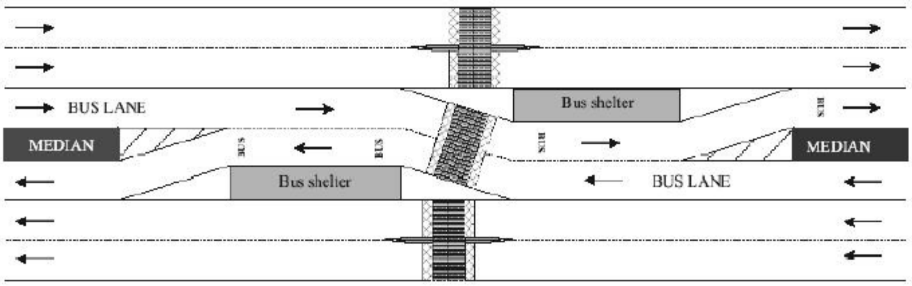
(a) Establishing a programme for the use of less-polluting urban buses (running on compressed natural gas)

(b) Improving driver behaviour by controlling licensing

(c) Introducing obligations for taxi operators relating to the level of pollution from their vehicles

(d) Physical improvements, including bus stops, pedestrian facilities, terminals and bus priority lanes in congested areas (Silaban 2002).

Figure 3: Traffic lines reorganized to avoid congestions



424. Economic measures proposed in the adaptation process included the development of parking management schemes, taking into consideration tools such as:

(a) New parking policies and fees

(b) Reform of the annual vehicle taxation system, to reverse the current approach to high taxes on new vehicles, low taxes on old, heavily polluting vehicles

(c) Area licensing scheme

(d) Congestion road pricing mechanisms.

425. Implementation of the public awareness campaign was to include all sectors, including relevant government agencies, consultants and community groups. In addition, as part of the plan for institutional reform, a pilot project was suggested on the proposed transport plan using appropriate guidelines for environmental impact assessment (Silban 2002 and GTZ-SUTP, 2001).

426. A lack of functioning traffic lights, the poor condition or lack of footpaths and many measures taken to increase motorized traffic speed have made Surabaya one of the most dangerous cities in the world. Therefore a case study on improving non-motorized transportation in Surabaya was carried out by the Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ).

427. Barriers to further implementation. The proposed projects have not yet been carried out, so it is difficult to speak about the barriers encountered. It should, however, be noted that the Institute for Transportation and Development Policy reported plans on the part of the Indonesian government to go ahead with a proposal to build a six-lane elevated toll highway through the centre of the city, despite objections by city officials, planners and individuals. The Mayor and other elected officials came up against political pressure to refrain from public criticism of the project.

428. Stakeholder engagement. Working groups in each area of concentration were formed in order to assemble stakeholdes to meet on a regular basis. The working groups were responsible for developing and refining project proposals and implementation schedules, and assisting in their implementation and monitoring. In instances where working groups were not formed, stakeholders were brought into decision-making discussions (Silaban 2002).

429. A national seminar/workshop for the Involvement of Stakeholders in the Improvement of Urban Air Quality in Surabaya was held in Surabaya in August 2003, organized by UN/ESCAP, the City of Surabaya, the Ministry of the Environment of Indonesia, and IGES (Kirakyushu Initiative for a Clean Environment, 2004).

430. Results and lessons learned. Developers of the project point to the importance of winning the political support of the Mayor and Governor and the affected communities as important to the project’s success and to securing support for the project. Political pressure, as previously mentioned, however, appears to be a substantial barrier in the development of adaptation technologies in the transport sector. While it appears that traffic in the region continues to worsen, it is imperative that developments in the transport sector incorporate the adaptation process.

XI. Synthesis of major findings

A. Technology and adaptation

431. This section describes some of the major conclusions associated with the fundamental premises for promoting the flow of technology for adaptation. In preparing these conclusions the secretariat took into account suggestions from members of the EGTT.

432. At the broadest level of classification, technologies for adaptation can comprise “hard” technologies, such as drought-resistant seeds, seawalls and irrigation technology, and “soft” technologies, such as crop rotation patterns, as well as information and knowledge. Within these two broad categories, technologies for adaptation to climate change can be further classified into four major categories: traditional, modern, high technology and future technology. Each may have an important role to play in meeting the challenge of adaptation to climate change.

433. Successfully identifying the role of technology in adaptation to climate change (i.e. actions that reduce vulnerability to the impacts of climate change) may well include actions that are directed at improving prevailing social, economic and environmental conditions and management practices in a system or sector. The role of technology fits within a four-stage adaptation process consisting of (i) information development and awareness-raising, (ii) planning and design, (iii) implementation, and (iv) monitoring and evaluation.

434. To understand the actual process for the effective transfer of technology, one needs to focus on "flows of technology" in sectors. This term implies and is generally understood to mean that there is more, different and better technology in some places than others, and that part of the task in applying technology therefore involves the movement, "transfer", of that technology from where it is found to where it is needed. Understanding how technology flows apply to the unique circumstances posed by the challenge of adapting to climate change is as critical as the process of identifying the range of suitable technologies.

435. The IPCC defines mitigation as an anthropogenic intervention to reduce the sources or enhance the sinks of GHGs. It defines adaptation as an adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects. These are two fundamentally different processes that pose very different entry points and implications for technology transfer. The approach to transferring most technologies for adaptation may therefore differ from the approach to mitigation, largely because the issues involved are different and the technology needs of countries are different.

436. Until very recently, technology transfer to address climate change has focused almost exclusively on mitigation issues. And, given that the overwhelming majority of global GHG emissions are from the energy sector, clean energy supply alternatives have emerged as the dominant focus for technology transfer. Since the technologies are mostly unavailable in developing countries, it has been a priority on the part of developing country decision makers to gain access as a means of promoting infrastructure development, modernizing energy delivery and stimulating private sector investment. Hence, technology transfer in the climate context has come to focus squarely on flows of experience, know-how and equipment between countries (i.e. from developed to developing country Parties) and less on deployment and dissemination within countries.

437. As the Convention process has taken up the question of technology for adaptation, some of the ideas about technology transfer for mitigation have been carried forward into the adaptation domain. In so doing there is a danger that some important distinctions between the processes of mitigation and adaptation may be overlooked. First, adaptation is not new in the way that mitigation is new. Second, the sectors that need technology for adaptation are ubiquitous – not mostly focused in one dominant sector like energy. Third, many technologies for adaptation are already readily available in developing countries. And fourth, the most needed technologies for adaptation are probably not likely to be as capital intensive as those for mitigation.

438. There are several differences that can be observed by treating technology transfer as equivalent for mitigation and adaptation. First, in addition to the flows of experience, know-how and equipment between countries (North–South and South–South), it may be necessary for these flows to take place more efficiently within countries. Second, in many cases technologies for adaptation need not to be new or somehow on the cutting edge of technological innovation, as the most effective technologies may be those that may be already available elsewhere in the country.

439. The selection of technologies for adaptation is important due to the fact that caution needs to be exercised in the introduction of modern technology to avoid possible unintended side effects. The development and application of suitable criteria, motivated by the exigencies of the adaptation challenge, will help to avoid some of these types of problems. There are three essential criteria. First, any chosen

technology should be subject to some efficiency criterion. Before adopting any specific adaptation measure or set of measures it is important to be satisfied that the benefits of doing so exceed the costs. Second, it is important that the choice of technology for adaptation is equitable in its distributional effects. In choosing among alternatives for adaptation to climate change, governments may wish to consider which segments of the population will particularly benefit, and where and upon whom the adverse effects may fall. Third, some adaptation options, although efficient (favourable benefit–cost ratio) and reasonably equitable, may be politically, socially or legally unacceptable. In some instances a 'simple' change in law may be sufficient. Often changes in cultural values and attitudes are involved, and these can be much harder to change.

B. Sectors and adaptation

440. This section describes some of the major conclusions associated with the flows of technologies for adaptation to each of the five sectors considered in this paper.

441. In many **coastal** locations technology has been instrumental in reducing society's vulnerability to ever-present weather related hazards. Many existing technologies that have proven to be effective in reducing vulnerability to weather related hazards will also be important as technologies for adaptation to climate change. Technologies may have to be adjusted to meet local needs, and technological development and innovation will continue to increase the effectiveness and efficiency of existing technologies, but given current projections of climate change, successful adaptation is possible without having to rely on the development of new technologies specifically for adaptation.

442. Climate change is but one of many interacting stresses in coastal zones. The importance of controlling non-climatic stresses in the quest to reduce vulnerability to climate change must not be underestimated. Vulnerability to climate change is not only determined by the degree of climate change but also by prevailing social, economic and environmental conditions and by the existing management practices in a system or sector. Therefore, successful adaptation to climate change (i.e. actions that reduce vulnerability to the impacts of climate change) may well include actions that are directed at improving such conditions and management practices. Finally, technology by itself is not a panacea for coastal areas, but it can make an important contribution towards the sustainable development of coastal zones, provided it is implemented within an enabling economic, institutional, legal and socio-cultural environment. Technologies for adaptation are therefore most effective as part of a broader, integrated coastal zone management framework that regognizes immediate as well as longer-term sectoral needs. A successful adaptation strategy will comprise a mix of various adaptation approaches, tailored to the particular needs of the area at risk and aimed at reducing implementation constraints.

443. For **water resources**, climate change induced variability in the hydrologic cycle superimposes additional challenges on planning and management of water resources. The development of appropriate adaptation strategies to cope with this added uncertainty requires a broad, integrative approach given the multidimensional roles that water plays in sustaining human life, society and the ecosystems on which they depend. The intrinsic characteristics of integrated water resource management (IWRM) make it an ideal overarching framework in which to evaluate, design, implement and monitor adaptation strategies for climate impacts to water resources.

444. Building communities of practice around IWRM can facilitate the mainstreaming of climate adaptation strategies into sustainable development efforts, providing synergy in awareness-raising, capacity-building, and in the creation of social, political and institutional environments receptive to technological innovation. These communities of practice aid in the transfer of technologies for adaptation that meet key needs, such as information technologies (remote sensing, forecasting) that enhance understanding of natural (e.g. hydrologic) and engineered (e.g. demand) system components and

tools that support decision-making (e.g. scenario-driven processes and multicriteria assessment technologies).

445. For **agriculture**, because there are a number of uncertainties regarding the range of impacts associated with climate variability and climate change, it is important to consider a diverse portfolio of potential technologies for adaptation. This is essential to retain the flexibility to transfer and adopt needed technology. Barriers, such as lack of information, lack of financial and human capital and unreliable equipment and supplies can rarely be surmounted unless the transferred technology has high probability of directly addressing climate related impacts in a cost-effective manner.

446. The effectiveness of technology transfer in the agricultural sector in the context of climate change response strategies also depends to a great extent on the suitability of transferred technologies to the socio-economic and cultural context of the recipients, considering development, equity and sustainability issues. Constraints on the supply of new technologies, a shortage of technological information and a shortage of capital are also important aspects of technology transfer. It is evident that integration of both hard and soft technologies and building working partnerships between government and non-governmental organizations is necessary to increase the effectiveness of different technologies for adaptation to adverse climatic effects. Governments can facilitate the flows of technologies within countries with incentives, regulation and by institutional strengthening.

447. Regarding **public health**, there is a long history of dealing, with varying degrees of effectiveness, with the impacts of climate variability. Incorporating consideration of where, when and how extensively climate change could affect future disease burdens is important for increasing resilience. Many of the climate-sensitive health outcomes do not need to be addressed individually; health outcomes with common risk factors, such as malnutrition and diarrhoeal diseases associated with the dry season, may be reduced together by the implementation of appropriate interventions. Such interventions include effective health education programmes, improvement of health care infrastructure, disaster preparedness plans, vector monitoring and control, and appropriate sewage and solid-waste management practices. The ability to predict climate variations on a seasonal or inter-annual scale presents communities with the opportunity to develop the capacity and expertise to deal with climate variability, which will also help communities prepare for the effects of climate change.

448. Priorities for further research and development include expanding current knowledge of the associations between weather/climate and human health. It would be helpful to identify and map locations, hazards and communities that are especially vulnerable. It is important to improve understanding of the complex relationships between the risks posed by climate variability and change, and other factors that influence the range and incidence of climate-sensitive health determinants and outcomes. Underlying this is the need to collect more valid and comprehensive health, meteorological, environmental and socio-economic data at appropriate scales. Institutional arrangements are needed to share knowledge at national and international levels, including improving education and training. All of these activities require funding for capacity-building, interdisciplinary research and regional/national assessments. Technology is fundamental to the effectiveness of the interventions being developed and implemented.

449. Finally, with regard to **infrastructure**, an integrated and exhaustive governance structure is central to the success of adaptation in infrastructure and urban environments. Awareness-building and involvement of government, private and community groups is likely to greatly improve the likelihood of the successful transfer of technologies for adaptation for infrastructure. Also important is coordinated financial support for the implementation of technologies. Smart Growth[13] development is a good

[13] See the case study on page 88.

example, as are local environmental action plans. Finally, the more successful strategies and means of transferring technologies are those that meet a number of human needs in addition to their provision of environmental benefits. Focus should, therefore, be placed on technologies that serve a variety of purposes above and beyond environmental improvement.

C. Broad policy questions

450. This section outlines some of the major policy related questions that have emerged from the discussion of the flows of technologies for adaptation and the sector-specific issues.

451. The case studies presented in this technical paper highlight the important role of existing (i.e. traditional and modern) technologies in addressing the adaptation challenge. It is a reflection of effective adaptation activities that, except for the case study on biorock, chapter X focuses on technologies that are currently widely available and used in several developing countries. What would be the specific policy implications for technology needs assessment and the emphasis on the deployment and diffusion of technology within countries?

452. The discussion in the sectoral sections also indicates that there is a potential role for high and future technologies. What policy implications does this pose for technology transfer between countries? This process would involve international technology transfer following the pattern set by technology transfer for mitigation.

453. Are there new institutional arrangements needed for information, planning, implementation and monitoring for adaptation? That is, rather than only uni-directional transfers of technologies from North to South, would efforts towards the creation of a global coalition or network for sharing technology and know-how information for adaptation and related capacity-building be more useful in meeting the needs of vulnerable communities and countries?

454. Are there additional criteria that need to be applied in the selection of technologies for adaptation? It should be recalled that the three proposed in this paper are (i) benefits, including economic/financial and costs, (ii) equity, and (iii) social/legal acceptability.

455. The discussion in each of the five sectors argues – though in different ways – that existing technologies that have proven to be effective in reducing vulnerability to weather related hazards will also be important as technologies for adaptation to climate change. Hence, successful adaptation is possible, to some extent, by relying on existing technologies for coping with climate variability and on the development of new such technologies. What policy implications does this finding have for national and international mechanisms to facilitate the flow of such technologies for adaptation?

456. Answering these questions should take into account that technologies for adaptation are locally applied. This does not preclude the existence of technologies for adaptation that may be broadly used at the international, regional and country levels.

Annex I

Decisions of the Conference of the Parties of the UNFCCC relating to technology transfer

Decision	Key features
13/CP.1: transfer of technology	Decides to provide continuous advice to improve the operational modalities for the effective transfer of technology (paragraph 4(b)); and to support and promote the development of endogenous capacities and appropriate technology relevant to the objective of the Convention in developing countries which are Parties to the Convention (paragraph 4(c)).
7/CP.2: development and transfer of technologies	Requests the Convention secretariat to give high priority to the development and completion of a survey of the initial technology needs, as well as technology information needs, of Parties not included in Annex I to the Convention (non-Annex I Parties), with a view to providing a progress report to the Subsidiary Body for Scientific and Technological Advice (SBSTA) at its fourth session; Paragraph 3 of the decision requests the Subsidiary Body for Implementation to evaluate and report on the transfer of technologies being undertaken between Parties included in Annex II to the Convention (Annex II Parties) and other Parties, and to do so by drawing on a roster of experts as referred to by the decision, and to take into account the planned technical report of the Intergovernmental Panel on Climate Change on methodological and technical aspects of technology transfer.
9/CP.3: development and transfer of technologies	Requests the Convention secretariat to continue its work on the synthesis and dissemination of information on environmentally sound technologies and know-how conducive to mitigating, and adapting to, climate change; for example, by accelerating the development of methodologies for adaptation technologies, in particular decision tools to evaluate alternative adaptation strategies, bearing in mind the work programme on methodological issues approved by the Subsidiary Body for Scientific and Technological Advice at its sixth session, which was that priority should also be given to methods for evaluating and monitoring the effectiveness and effects of specific policies and measures and for assessing adaptation strategies and technologies.
4/CP.4: development and transfer of technologies	Recognizes the need for continued efforts by Parties to promote and cooperate in the development, application, diffusion and transfer of technologies. It also recognizes that the private sector plays, in some countries, an important role in the development, transfer and financing of technologies, and that the creation of enabling environments at all levels provides a platform to support the development, use and transfer of environmentally sound technologies and know-how. Paragraph 3 of the decision requests Annex II Parties (a) to take all practicable steps to promote, facilitate and finance, as appropriate, the transfer of environmentally sound technologies and know-how to developing country Parties and their access thereto; (b) to support capacity-building and the strengthening of appropriate institutions in developing countries to enable the transfer of environmentally sound technologies and know-how; Paragraph 4 of the decision requests Parties included in Annex I to the Convention and in particular Annex II Parties: (a) to assist developing country Parties in their efforts to build capacity and institutional frameworks to improve energy efficiency and utilization of renewable energies through multilateral and bilateral cooperative efforts; (b) to provide assistance to developing country Parties to build capacity for sustainable management, conservation and enhancement, as appropriate, of sinks and reservoirs of all greenhouse gases not controlled by the Montreal Protocol on Substances that Deplete the Ozone Layer, including biomass, forests and oceans as well as other terrestrial, coastal and marine ecosystems; (c) to assist developing country Parties to build capacity to adapt to the adverse effects of climate change; (d) to assist developing country Parties to strengthen their endogenous capacities and capabilities in the areas of technological and socio-economic research and systematic observation relevant to climate change and its associated adverse effects; (e) taking into account Article 6 of the Convention, to cooperate in and promote capacity-building of developing country Parties at the international, regional, subregional and national levels through cooperation programmes supported by United Nations and other multilateral agencies, as well as bilateral agencies.
5/CP.4: implementation of Article 4.8 and 4.9 of the Convention. (decision 3/CP.3 and Articles 2.3 and 3.14 of the Kyoto Protocol)	Decides that the basic elements for further analysis should include the following: (a) Identification of the adverse effects of climate change (b) Identification of the impacts of the implementation of response measures under the Convention (c) Identification of the specific needs and concerns of developing country Parties arising from such adverse effects and impacts defined through, inter alia, the national communications from non-Annex I Parties (d) Identification and consideration of actions, including actions related to funding, insurance and the transfer of technology, to meet the specific needs and concerns referred to in (c) above.

9/CP.5: development and transfer of technologies: status of the consultative process	Invites non-Annex I Parties that have not already done so to report their technology needs, in their national communications, to the extent possible; Urges Annex II Parties to give particular attention to reporting on technology transfer activities, as specified in part II of the revised guidelines for reporting by Annex I Parties (FCCC/CP/1999/6/Add.1).
4/CP.7: development and transfer of technologies (decisions 4/CP.4 and 9/CP.5)	Decides to establish an expert group on technology transfer to be nominated by Parties, with the objective of enhancing the implementation of Article 4, paragraph 5, of the Convention, including, inter alia, by analysing and identifying ways to facilitate and advance technology transfer activities and making recommendations to the SBSTA. See annex of decision for details of the framework for meaningful and effective actions to enhance the implementation of Article 4, paragraph 5, of the Convention.
5/CP.7: implementation of Article 4, paragraphs 8 and 9, of the Convention (decision 3/CP.3 and Article 2, paragraph 3, and Article 3, paragraph 14, of the Kyoto Protocol)	Decides to support, through the Global Environment Facility the following: Under information and methodologies the strengthening of existing and, where needed, establishing national and regional systematic observation and monitoring networks (sea-level rise, climate and hydrological monitoring stations, fire hazards, land degradation, floods, cyclones and droughts); Strengthening existing and, where needed, establishing national and regional centres and institutions for the provision of research, training, education and scientific and technical support in specialized fields relevant to climate change, utilizing information technology as much as possible. Under vulnerability and adaptation: • Enhancing capacity, including institutional capacity, to integrate adaptation into sustainable development programmes; • Promoting the transfer of adaptation technologies; • Establishing pilot or demonstration projects to show how adaptation planning and assessment can be practically translated into projects that will provide real benefits, and may be integrated into national policy and sustainable development planning, on the basis of information provided in the national communications from non-Annex I Parties; and/or other relevant sources, and of the staged approach endorsed by the Conference of the Parties in its decision 11/CP.1; • Supporting capacity-building, including institutional capacity, for preventive measures, planning, preparedness for disasters relating to climate change, including contingency planning, in particular, for droughts and floods in areas prone to extreme weather events; • Strengthening existing and, where needed, establishing early warning systems for extreme weather events in an integrated and interdisciplinary manner to assist developing country Parties, in particular those most vulnerable to climate change.
10/CP.8: development and transfer of technologies	Requests the Chair of the SBSTA to conduct consultations and facilitate collaboration among expert groups established under the Convention, to the extent practicable, on their work programmes on cross-cutting issues, including those relating to technology transfer and capacity-building activities.
1/CP.10: Buenos Aires programme of work on adaptation and response measures	In paragraph 5(b) decides to further the implementation of actions under decision 5/CP.7, paragraph 7, including through the following: Under the heading vulnerability and adaptation: (i) carrying out pilot and demonstration projects under decision 5/CP.7, paragraph 7 (b) (v), in particular to take forward adaptation projects identified in national communications and other relevant sources, including activities that strengthen adaptive capacity; (ii) Enhancing technical training for integrated climate change impact and vulnerability assessment across all relevant sectors, and for environmental management relating to climate change under decision 5/CP.7, paragraph 7 (b) (ii); (iii) Promoting the transfer of technologies for adaptation under decision 5/CP.7, paragraph 7 (b) (iv), on an urgent basis in priority sectors, including agriculture and water resources, for example through the exchange of experiences and lessons learned in enhancing resilience to the adverse effects of climate change in key sectors; (iv) Building capacity, including institutional capacity, for preventive measures, planning, preparedness and management of disasters relating to climate change, including contingency planning, in particular for droughts and floods and extreme weather events, in accordance with decision 5/CP.7, paragraphs 7 (b) (vi) and 8 (c).
6/CP.10: development and transfer of technologies	Decides to encourage Parties to explore the opportunity for further joint research and development programmes/projects between Annex II Parties and non-Annex I Parties for the development of environmentally sound technologies to respond to the requirements of Article 4, paragraph 5, of the Convention.

Annex II

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