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Developing Strategies for Climate Change:

The UNEP Country Studies on Climate Change Impacts and Adaptations Assessment

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Karen O´Brien, Editor

Universitetet i Oslo
University of Oslo

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CICERO
Center for International Climate
and Environmental Research
P.O. Box 1129 Blindern
N-0318 Oslo, Norway
Phone: +47 22 85 87 50
Fax: +47 22 85 87 51
E-mail: admin@cicero.uio.no
Web: www.cicero.uio.no

CICERO Senter for klimaforskning
P.B. 1129 Blindern, 0318 Oslo
Telefon: 22 85 87 50
Faks: 22 85 87 51
E-post: admin@cicero.uio.no
Nett: www.cicero.uio.no

Abstract

This report summarizes four country studies that were undertaken as part of the UNEP "Country Case Studies on Climate Change Impacts and Adaptations Assessment." These studies, carried out in Antigua and Barbuda, Cameroon, Estonia, and Pakistan, were funded by the Global Environmental Facility and managed as a project of the UNEP Atmosphere Unit in Nairobi, Kenya. These country studies illustrate the importance of adopting a flexible approach to the assessment of climate change impacts and adaptations. While the UNEP Handbook on Methods served as a common reference for the study teams, each team found it necessary to adapt these methods – sometimes to a considerable extent – to meet the specific needs of the country. Moreover, two of the country studies (Estonia and Pakistan) were able to build on previous work on climate impacts, while the other two (Antigua and Barbuda and Cameroon) broke new ground. The studies provide a basic foundation for understanding the potential impacts of climate change and the adaptation measures necessary to address them. They indicate the scope of the problems in each of the countries studied, as well as the direction adaptation studies should take. Most importantly, they demonstrate that while each country has a unique set of problems and strategies, all countries will benefit from long-term sustainable development.

Key words: Climate impacts, adaptation, vulnerability, Antigua and Barbuda, Cameroon, Estonia, Pakistan

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Executive Summary

This report summarizes four country studies that were undertaken as part of the UNEP "Country Case Studies on Climate Change Impacts and Adaptations Assessment." These studies, carried out in Antigua and Barbuda, Cameroon, Estonia, and Pakistan, were funded by the Global Environmental Facility and managed as a project of the UNEP Atmosphere Unit in Nairobi, Kenya.

The UNEP country studies program is aimed at improving the methods of assessing climate change impacts. Such methods have traditionally been formulated for countries with developed economies, often ignoring the needs and challenges of developing countries. Data constraints, a lack of resources, different scientific traditions, and other priorities can render many of the existing impact methodologies ineffectual, particularly when they are based on complex models that require an enormous amount of input data and technical expertise. The UNEP country studies program has sought to contribute to a better understanding of how assessment methods can be applied to country-specific circumstances.

The UNEP country studies were also designed to enhance technical capacity for addressing climate change within the institutional framework of each country. Technical assistance was made available to develop or increase analytical skills related to climate change impact and adaptation assessments. The process of producing country reports was also intended to improve national and regional policy coordination.

A final objective of the UNEP country studies program was to test and apply the Intergovernmental Panel on Climate Change (IPCC) technical guidelines for assessing climate change impacts and adaptations (Carter et al. 1994). These guidelines have been incorporated into a draft *Handbook on Methods for Climate Change Impact Assessment and Adaptation Strategies*, developed by UNEP in collaboration with the Institute for Environmental Studies at Vrije Universiteit in Amsterdam. This handbook translates the IPCC guidelines into a practical description of methods for impact and adaptation assessments. The handbook was especially designed to take into consideration the needs and requirements of developing countries.

The country studies summarized in this report represent integrative assessments that go beyond the traditional climate impact studies that are based on a doubling of atmospheric CO_2. They are innovative in that they consider adaptation strategies alongside an assessment of climate change impacts. The studies adopted a cross-sectoral approach aimed at identifying the interacting effects of climate change, with an emphasis on the socioeconomic consequences both within and among sectors. Baseline socioeconomic scenarios were developed, along with different trajectories for the future. By focusing on current and projected environmental and socioeconomic stresses, the studies exposed the context under which climate impacts must be considered, and laid out recommendations for climate change adaptations.

The results of the UNEP country studies illustrate a diversity of climate impacts in developing countries and countries with economies in transition. Taken together, the studies underscore the importance of considering impacts and adaptation strategies within the context of present-day realities and future trends. Confronting current socioeconomic and environmental problems emerges as an important means of addressing climate impacts and facilitating adaptation to long-term climate change.

The UNEP Country Studies emphasized the need to address climate change through policy and planning. This includes long-term physical planning in the case of Antigua and Barbuda, such as the establishment of appropriate setbacks along coastal areas. It also means the control of urban settlements in coastal areas of Cameroon. In Pakistan, addressing climate vulnerability through policies and planning was considered a key adaptation strategy. This involves, for example, improving and expanding Pakistan's infrastructure base, which has deteriorated as a result of budgetary constraints. The Estonian study emphasized the fact that climate change impacts are likely to be overshadowed by political and economic changes. The range of uncertainties associated with future socioeconomic scenarios thus adds to the uncertainties in adapting to climate change.

The four country studies presented in this report illustrate the importance of adopting a flexible approach to the assessment of climate change impacts and adaptations. While the UNEP Handbook on Methods served as a common reference for the study teams, each team found it necessary to adapt these methods – sometimes to a considerable extent – to meet the specific needs of the country. Moreover, two of the country studies (Estonia and Pakistan) were able to build on previous work on climate impacts, while the other two (Antigua and Barbuda and Cameroon) broke new ground.

In conclusion, the UNEP Country Studies provide a basic foundation for understanding the potential impacts of climate change and the adaptation measures necessary to address them. They indicate the scope of the problems in each of the countries studied, as well as the direction adaptation studies should take. Most importantly, they demonstrate that while each country has a unique set of problems and strategies, all countries will benefit from long-term sustainable development.

Acknowledgments

The UNEP Country Studies were carried out over a period of several years, beginning in 1996. The projects were sponsored by the Global Environment Facility (GEF). CICERO's participation in the project began with the first meeting on Country Case Studies on Climate Change Impacts and Adaptation Assessment, which was held in Oslo in July, 1997. Arne Dalfelt was in charge of coordinating technical assistance to the country study teams, and he played a vital role in getting the projects carried out. I replaced Arne Dalfelt as the Technical Assistance Coordinator for the project in January, 1998. Without the benefit of having participated in the full process of the country studies, I have tried to summarize the final reports that were submitted and presented at the Country Studies meeting in San Jose, Costa Rica in March 1998. The summaries presented in this report are based on my interpretation of the studies, and I am thus responsible for any errors or misinterpretations of the results presented in the final reports. Readers are encouraged to refer to the original reports for more detailed information. Copies of the full reports can be obtained from the addresses provided at the beginning of each chapter. The bibliographic references for the summarized country studies are included at the end of the report.

I extend great thanks to the country study teams for their effort and enthusiasm in carrying out this project. The members of each team who contributed to this report are presented in the Appendix. I would like to thank Arne Dalfelt of the World Bank for his continued advice and guidance, which helped see this project to completion. I would also like to thank Lars Otto Næss, formerly of CICERO and now at FAO, for his participation in the country studies and review of early drafts of this report. I am grateful to Linda Sygna, Bård Romstad, and Hans Kolshus for their critical role in producing tables and references for this report. I would also like to thank Lynn Nygaard for her careful help in editing the report, and Lene Borg and Marit Barosen for managing the accounts for the project. Special thanks go to the team of technical advisors for the UNEP Country Studies and the consultants that participated in the project. These include Asbjørn Aaheim, Beatrice Bulwa, Ian Burton, Mac Callaway, Rafael Rodriguez Capetillo, Timothy Carter, Stewart Cohen, Torbjørn Damhaug, Thomas Downing, Jan Feenstra, Mike Hulme, Stephen Leatherman, Sam Kanyamibwa, Richard Klein, Stephanie Lenhart, Pim Martens, William Kensett Nuttle, Robin Mahon, Martin Parry, Shannon Ragland, Atiq Rahman, Joel Smith, Youba Sokona, Morten Sørensen, and Claudio Volante. I am grateful to Paivi Kannisto and Edmundo Ortega at UNEP's Budget and Funds Management Service for facilitating the many financial transfers that made this project possible, and to Victor Ogbuneke for helping to complete out the project. I would like to thank Michael Short and Alex Alussa, the project coordinators at UNEP, for their patience in the delivery of this final report. Finally, I would like to acknowledge the GEF as the source of funds for this project.

Karen O'Brien
CICERO

1 The UNEP Country Studies

1.1 Introduction

Several studies indicate that climate change is already taking place, and that the climate system is likely to experience some amount of change, regardless of whether emissions reductions are successfully undertaken (Santer & et al, 1996; Watson, Zinyowera, Moss, & Dokken, 1996; Wigley, Smith, & Santer, 1998). In other words, it is no longer a question of "if," but rather "when" and "how." This means that each country must carefully assess how climate change may affect it, and how adaptations might be made. These national assessments are particularly important for countries that are vulnerable to current climate variability, environmental stresses, and growing socioeconomic pressures.

Within any country, the most vulnerable are considered those who are most exposed to perturbations, who possess a limited coping capacity, and who are least resilient to recovery (Bohle, Downing, & Watts, 1994). For this reason, climate change impacts in developing countries and countries with economies in transition are commonly considered to be more serious than similar impacts in countries with developed economies (IPCC, 1998). Vulnerability to climate change can be described in terms of marginality, susceptibility, adaptability, fragility, risk, or access to entitlements (Adger & Kelly, 1999; Liverman, 1994).

The set of studies presented in this report examines the situation in three countries representing different types of developing economies (Antigua and Barbuda, Cameroon, and Pakistan), as well as one country with an economy in transition (Estonia). Climate change impacts and adaptations were assessed using a wide range of methodologies. Vulnerability to climate change can be described in terms of marginality, susceptibility, adaptability, fragility, risk, or access to entitlements (Adger & Kelly, 1999; Liverman, 1994). Critical sectors and regions were selected by the study teams, and international experts were consulted to provide guidance and training. The results of these studies represent the outcome of national and international efforts to reach a better understanding of the impacts of climate change, as well as options for adaptation.

This report presents a summary of the four country studies based on the final reports submitted to UNEP. The conclusions that emerged from the country studies are considered within the context of long-term strategies for climate change in developing countries. The case studies show that climate change impacts and adaptation strategies cannot be isolated from current environmental problems and socioeconomic realities. Economic crises, socioeconomic changes, natural disasters, and environmental problems form the context within which climate change is taking place. In some cases, the severity of these factors or events make the impacts of long-term climate change appear less significant. Nevertheless, within the context of these ongoing changes, climate change is likely to be an added factor – one that could either exacerbate or mitigate existing or evolving conditions.

1.2 Background for the Country Studies Program

The four country studies were undertaken as part of the UNEP "Country Case Studies on Climate Change Impacts and Adaptations Assessment." These studies were initiated in response to the United Nations Framework Convention on Climate Change (UNFCCC), which requires all parties to formulate and implement national and regional programs to assess possible impacts of climate change, to mitigate impacts, and to take measures to facilitate adaptation to climate change. The studies, funded by the Global Environmental Facility, were managed as a project of the UNEP Atmosphere Unit in Nairobi, Kenya.

The UNEP country studies program is aimed at improving the methods of assessing climate change impacts. Such methods have traditionally been formulated for countries with developed economies, while often ignoring the needs and challenges of developing countries. Data constraints, a lack of resources, different scientific traditions, and other priorities can render many of the existing impact methodologies ineffectual, particularly when they are based on complex models that require an enormous amount of input data and technical expertise. The UNEP country studies program has sought to contribute to a better understanding of how assessment methods can be applied to country-specific circumstances.

The UNEP country studies were also designed to enhance technical capacity for addressing climate change in at least three institutions within each country. Technical assistance was made available to develop or increase analytical skills related to climate change impact and adaptation assessments. The process of producing country reports was also intended to improve national and regional policy coordination.

A final objective of the UNEP country studies program was to test and apply the Intergovernmental Panel on Climate Change (IPCC) technical guidelines for assessing climate change impacts and adaptations (Carter et al. 1994). These guidelines have been incorporated into a draft *Handbook on Methods for Climate Change Impact Assessment and Adaptation Strategies*, developed by UNEP in collaboration with the Institute for Environmental Studies at Vrije Universiteit in Amsterdam. This handbook translates the IPCC guidelines into a practical description of methods for impact and adaptation assessments. The handbook was especially designed to take into consideration the needs and requirements of developing countries.

The country studies summarized in this report represent integrative assessments that go beyond the traditional climate impact studies that are based on a doubling of atmospheric CO_2. They are also innovative in that they consider adaptation strategies alongside an assessment of climate change impacts. The studies adopted a cross-sectoral approach aimed at identifying the interacting effects of climate change, with an emphasis on the socioeconomic consequences both within and among sectors. Baseline socioeconomic scenarios were developed, along with different trajectories for the future. By focusing on current and projected environmental and socioeconomic stresses, the studies exposed the context under which climate impacts must be considered, and laid out recommendations for climate change adaptations.

1.3 Methodology

Each country was encouraged to follow the approach to climate change impact and adaptation assessment recommended in the *Technical Guidelines of the Intergovernmental Panel on Climate Change* (Carter, Parry, Harasawa, & Nishioka, 1994; Parry & Carter, 1998; UNEP, 1996). This approach consists of seven steps, which are supposed to be followed in consecutive order, with the recognition that backtracking may at times be necessary. The steps can be summarized as follows:

1. Define the problem, including the goals of the assessment, the study area, the temporal and spatial bounds, and data needs.

2. Select the method. Four general methods are described: predictive modeling, empirical studies, expert judgment, and experimentation.
3. Test the method and sensitivity. This involves feasibility studies, data acquisition and compilation, and testing of models through validation and sensitivity analyses.
4. Formulate inputs and assumptions. This step includes establishing climatological, environmental, and socioeconomic baselines, determining the time frame of projections, projecting the reference case, creating climatic scenarios, and projecting socioeconomic trends with climate change.
5. Assess the impacts of climate change, and portray differences through maps or tables. This step also involves performing analyses of uncertainty and risk.
6. Assess autonomous adjustments, including inbuilt or physiological adjustments, routine adjustments, and tactical adjustments.
7. Evaluate adaptation strategies, based upon an additional seven-step process: 1) define objectives; 2) specify important climatic impacts; 3) identify adaptation options; 4) examine constraints; 5) quantify measures and formulate alternative strategies; 6) weigh objectives and evaluate tradeoffs, and 7) recommend adaptation measures.

The country study teams could pursue several methodological approaches to creating climate change scenarios as part of the fourth step. First, general circulation model (GCM) results could be used as the basis for regional scenarios. Scenarios corresponding to the geographic location of each country could be extracted from a collection of GCMs using SCENGEN software (Hulme, Jiang, & Wigley, 1995a). Second, analogue scenarios could be developed, using past climate conditions as a reference for studying future impacts. Third, synthetic scenarios could be created based on arbitrary increments of change. This last method provides a means to identify levels of sensitivity and vulnerability. The overall objective of any of the three methodologies is to provide a set of consistent scenarios that can be compared across regions and sectors.

Although all of the countries used the UNEP handbook and IPCC guidelines as a point of departure, the approaches that were pursued in the studies varied significantly among the four countries. Indeed, rather than serving as a mandatory prescription for carrying out assessments, the framework described above was designed to be flexible enough to meet the needs of different countries. Each country chose different methods, different ways to test methods and analyze sensitivity, and different ways to assess the impacts of climate change. Some countries emphasized baselines and reference cases, while others placed more emphasis on the two steps related to adaptation assessments.

The methods that were used in assessing impacts and adaptations to climate change in the country studies included a mix of biophysical models, economic models, empirical analogue studies, and expert judgments. The choice of method varied among countries and sectors, reflecting data quality and availability, as well as time constraints. In Antigua and Barbuda, the impacts of future climate change were analyzed largely in reference to past hurricanes and droughts. In Cameroon, a general lack of data made it necessary to rely heavily on the published literature on climate impacts. In Estonia, a rich historical record documenting past climate changes served as a baseline for considering future impacts and adaptations. New methods, such as the method of standard yields, were used to assess climate impacts. The focus in Pakistan was on contemporary environmental and socioeconomic issues, supplemented by an analysis of how they might be affected by climate change. For the socioeconomic baseline, Pakistan developed a "business as usual" scenario that considered long-term trends in light of recent structural reforms, along with a more optimistic scenario.

Some of the countries, particularly the small island state of Antigua and Barbuda, found the GCM-generated scenarios to be of limited use in the impact study. The land area of the small islands is not resolved within the ocean grid squares of the models covering the Eastern Caribbean, thus the climate results were not considered reliable. The use of a 100-year time frame was also criticized by some of the teams, as the uncertainties associated with projections give the scenarios little practical meaning.

Temperature increases and sea level rises were common to all of the scenarios used in the UNEP country studies. In addition, the study teams generally considered both positive and negative changes in precipitation. While most of the studies acknowledged that the magnitude and frequency of extreme events such as droughts, floods, and hurricanes might be affected by climate change, difficulties in modeling such changes limited the analysis to analogies with past or contemporary extreme events, or an analysis based on synthetic scenarios.

Each country performed a preliminary assessment of climate impacts, and then conducted more detailed analyses for selected sectors. The sectors, which were chosen at an early stage of the project, included those deemed important to the ecology or economy of the country, or in some cases sectors that were not included in earlier climate change impact studies. Although time and resource constraints limited the number of sectors that a country could reasonably undertake within the context of the UNEP country studies, the reports do identify key areas for future study.

Antigua and Barbuda carried out sectoral studies on human settlements and tourism, coastal zones, fisheries, the agricultural sector, water resources, and human health. Cameroon took a different approach and first selected two important regions of the country: the humid coastal zone around the Cameroon Estuary and the semi-arid Sudano-Sahelian zone in the northern part of the country. The sectors studied in the coastal zone included mangroves and infrastructure. Biodiversity and human health were the chosen sectors in the Sudano-Sahelian zone. Estonia concentrated its sectoral studies on agriculture, forestry, and water resources. The Estonian group also examined the impacts of climate change on the Baltic Sea region. Pakistan focused on agriculture, forestry and water resources, and placed a strong emphasis on developing and analyzing socioeconomic scenarios.

One of the principal constraints in the studies was the availability of data. Countries such as Antigua and Cameroon, lacking a strong history of data collection, found the methodologies included in the UNEP Handbook to be too presumptive regarding data availability. Some countries and sectoral groups felt that it was essential to develop innovative methods for assessing climate impacts in the absence of substantial data. Such innovations include the identification of basic indicators and emerging trends. Nevertheless, the UNEP Handbook did provide the country study teams with a wide array of possibilities to consider in assessing the impacts of climate change and adaptation strategies.

1.4 The Countries

Apart from all being non-Annex I parties to the United Nations Framework Convention on Climate Change (UNFCCC), the countries that were selected for the UNEP case studies represent very different regions, geographies, populations, and economies. In fact, the differences among the four countries are much greater than the similarities. In terms of regions and geographies, they are widely distributed across the globe and varied in their feature characteristics (Figure 1.1). Although each of the four countries lies along or within a body of water, the use of coastal resources varies, with some countries emphasizing fishing, and others tourism or trade.

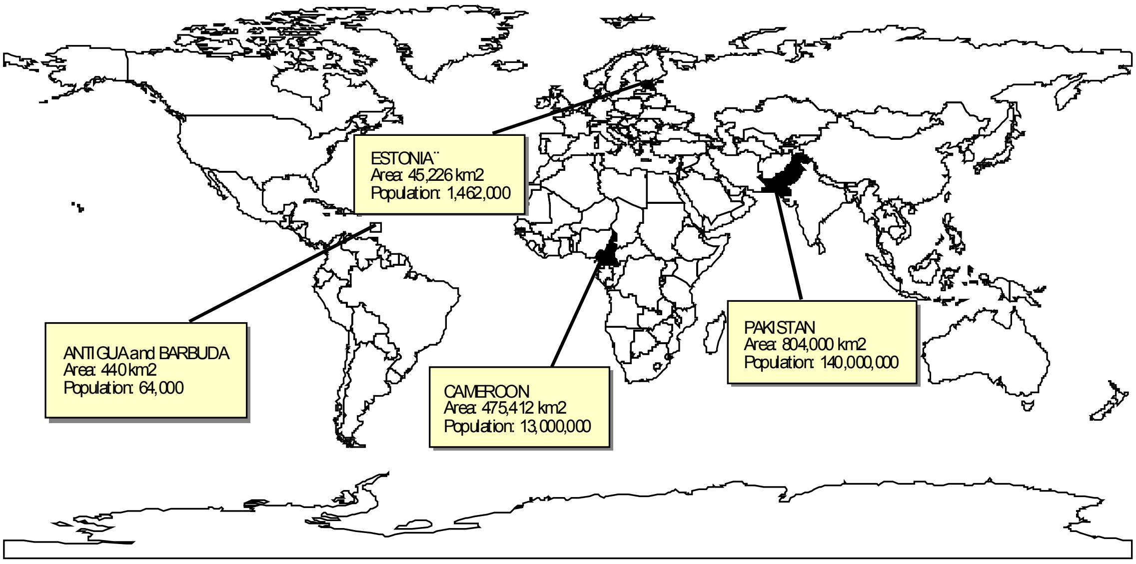

Figure 1.1 Countries included in the UNEP Country Studies on Climate Change Impacts and Adaptations Assessment

Antigua and Barbuda are two islands that form a small state in the eastern Caribbean. The total land area of the country is 440 km^2. The topography of the islands is relatively flat, and most developments are located near the coast. Tourism, focused on coastal areas, contributes at least 60% of Antigua and Barbuda's GDP. Consequently, sea level rise associated with climate change poses a significant threat to the ecology and economy of the islands. In spite of an abundance of surrounding seawater, water resources are relatively scarce on Antigua and Barbuda.

Abundant rainfall is generally related to extreme events, including tropical storms and hurricanes. Any climate-induced increase in the frequency or magnitude of droughts or hurricanes will have serious implications for the economy of Antigua and Barbuda.

Cameroon is a country in equatorial Africa that spans a diversity of ecosystems, including coastal zones, tropical forests, and semi-arid savannas. The area of Cameroon is 475,412 km^2. It is a country rich in natural resources, including petroleum, bauxite, timber, and many tropical crops. Most of the country's population and infrastructure is concentrated along the coast, therefore sea level rise and salt-water intrusion are serious concerns related to climate change. In the semi-arid Sudano-Sahel region, where rainfall is highly variable, climate change could threaten both humans and biodiversity. Human health is of particular concern in Cameroon, as it hosts many diseases and vectors associated with tropical climates. Climate change could facilitate the transmission of disease, increasing the social and economic costs of health care in Cameroon.

Estonia is located in Eastern Europe, between Latvia and Russia, bordering the Baltic Sea and the Gulf of Finland. Estonia has an area of 45,226 km^2, most of which is relatively flat terrain. The country has over 1,400 lakes and 3,794 km of coastline, of which two-thirds corresponds to the coastline of islands. Almost half of Estonia's land area is forested, and about one-quarter is under agricultural cultivation. Estonia has abundant supplies of shale oil, which is a major source for power generation and the main resource for the petrochemical industry. Estonia gained independence from the Soviet Union in 1991, and since then has undergone dramatic economic and political changes. The magnitude and speed of these changes are considered to eclipse the potential impacts of climate change. In any case, the changes have been and still are shifting the baseline for assessing climate impacts in Estonia.

Pakistan is a country of 803,940 km^2 located in southern Asia. It shares borders with India to the east and Iran and Afghanistan to the west. Pakistan's geography includes 1,046 km of coastline along the Arabian Sea. The terrain is varied, from the flat Indus plain in the east, to the high mountain ranges of the Himalayas, Karakorums, and Hindukush in the north. Over one-quarter of the land is considered arable, with at least 170,000 km^2 under irrigation. Almost one-half of the labor force is active in the agriculture sector. Pakistan faces problems with deteriorating infrastructure and low social development that pose challenges to economic development. Contemporary environmental problems include severe water pollution problems, soil erosion, and deforestation. Climate change could potentially affect Pakistan's water resources, with implications for agriculture, as well as urban and rural water use.

The population size of the four countries varies enormously, as do population growth rates. At one extreme is Antigua and Barbuda, with an estimated population of 63,986 inhabitants in 1991. The rate of population growth – now 0.44% – has been declining since the 1970s, largely due to migration and reductions in fertility rates. At the other extreme is Pakistan, with a population of about 140 million in 1997. Pakistan has an estimated overall population growth rate of 2.5%, and an urban growth rate of 5.6%. Between the two extremes lie Estonia and Cameroon. Estonia's population was estimated to be 1,462,130 in 1997. This number has been decreasing since independence was restored in 1990 as a result of the departure of non-Estonian workers and a decrease in birth rates. Cameroon's population was estimated at 13 million in 1995, with an annual growth rate of about 2.9% since 1987.

While the four countries can be characterized as having developing economies or economies in transition, such a generalization fails to capture the extreme diversity in both economic and human development. According to the World Bank Group (2000), both Antigua and Barbuda and Estonia are upper-middle income countries. Estimated real GNP per capita in 1998 was USD 8,890 for Antigua and Barbuda, and USD 7,563 for Estonia. Cameroon and Pakistan, with 1998 per capita GNPs of USD 1,395 and USD 1,652 respectively, are considered to be low-income countries. Of these, Cameroon is classified as severely indebted and Pakistan is classified as moderately indebted (World Bank Group, 2000).

Per capita GDP is not always a very revealing statistic as it says nothing about the distribution of income within a country or the population's well-being. A more informative indicator of a country's social situation may be the human development index (HDI). This index, introduced by the United Nations Development Programme (UNDP) in 1990, attempts to provide a more comprehensive measure of development. The index consists of three components of human development: longevity, knowledge, and standard of living (UNDP, 2000). According to this index, Antigua and Barbuda is characterized by high human development. With a life expectancy at birth of 75 years and an adult literacy rate of 95%, it ranks 29th out of 175 countries. Estonia, with a life expectancy at birth of 69.2 years and an adult literacy rate of 99%, is considered to be a country in the medium human development category. It ranked 77th out of 175 countries. Cameroon and Pakistan are characterized as countries with low human development, ranking 132rd and 138th, respectively, Cameroon has a life expectancy at birth of 55.3 years and a literacy rate of 63.4%, while Pakistan has a life expectancy of 62.8 years and a literacy rate of 37.8% (UNDP, 1998).

1.5 Overview of Results

The results of the UNEP country studies illustrate a diversity of climate impacts in developing countries and countries with economies in transition. Taken together, the studies underscore the importance of considering impacts and adaptation strategies within the context of present-day realities and future trends. Confronting current socioeconomic and environmental problems emerges as an important means of addressing climate impacts and facilitating adaptation to long-term climate change.

In the Sudano-Sahelian zone of Cameroon, high population pressure, inefficient management of soils, irrational exploitation of water resources, and inefficient management of protected areas were identified as current threats to the environment. Water scarcity is currently a serious issue in both Pakistan and Antigua and Barbuda. Scenarios of climate change superimposed on the current situation suggest that water scarcity may increase in the future, sometimes in spite of precipitation increases due to increased rates of potential evapotranspiration. Addressing contemporary water management issues thus can serve as an important strategy for dealing with climate change.

In Estonia, globalization, changes in technology, and the rapid development of information technology have had a strong influence on the economy. The share of the traditional industrial and agricultural sectors in the national economy is diminishing, while newer sectors such as financial services, transportation, and information technology, are growing rapidly. The economic transition and restructuring of the Estonian economy have resulted in a dramatic decrease in energy consumption in the industrial and agricultural sectors. Within the context of these changes, the impacts of climate change were considered to be manageable.

The UNEP country studies show that rather than promoting greater resiliency, many present-day activities are increasing vulnerability to climate change. For example, in Antigua and Barbuda, population increases and tourist-based developments are contributing to major stresses on coastal resources. In Cameroon, the rapid growth of the city of Douala has led to urbanization of low-lying areas that are threatened by inundation and erosion. In Pakistan, population growth is decreasing per capita water availability, and has transformed the country from a water-affluent one to a water-scarce one. A growing demand for fuelwood has led to increased deforestation, accompanied by environmental problems that increase vulnerability to climate change, such as soil erosion and reservoir silting. The current situation is thus considered to be exacerbating the impacts of future climate change.

Vulnerability is linked to weaknesses in policies and planning, or in some cases a lack of planning. In Antigua and Barbuda, the damage to infrastructure as a result of hurricanes can be traced to inappropriate standards and improper materials used in roof construction. In Pakistan, agricultural production has been constrained by problems that are of a technical, institutional, and policy nature. For example, the *warabandi* system of providing the discharge of a watercourse to one farm for a seven-day rotation does not contribute to maximum efficiency in irrigating cropland. In Estonia, forests are underutilized, in part due to the lack of a market, but also for institutional and legal reasons.

When the impacts of climate change are superimposed on contemporary environmental and social stresses, the options for sustainable growth are limited. The development of environmentally vulnerable areas, such as coastal zones, was singled out as a threat to a sustainable future in both Cameroon and Antigua and Barbuda. In Antigua and Barbuda, there are still a number of coastal sites that are considered ideal for tourism development. However, without policy intervention, present patterns of coastal development will continue, increasing the likelihood that climate change will have negative consequences for coastal zones, the tourism sector, and the national economy. The country studies suggest that a focus on economic growth without consideration of the long-term implications for sustainability can result in increased vulnerability to climate change.

The country studies brought out the cross-sectoral and interdisciplinary nature of climate impacts. There was a considerable degree of overlap among the impacts and adaptation strategies considered by the various sectoral teams. The links between tourism and coastal resources in Antigua and Barbuda, for example, demonstrate that climate change policies must be integrative rather than sectoral, particularly when it comes to plans for economic development. In Cameroon, where the impacts of climate change on mangroves and infrastructure in the coastal zone were studied, linkages between the two sectors also became evident. Development pressures account for the greatest threat to mangroves in the Cameroon Estuary, yet mangrove destruction in turn threatens the stability of infrastructure by increasing vulnerability to erosion. Superimposing climate change on these sectors magnifies the current pressures.

The country studies suggest that change in climate variability and extreme events are in some cases of greater concern than a change in average temperature or precipitation. One single extreme event, such as a strong hurricane, can cause more coastal erosion and landwards retreat of beaches than a decade of sea-level rise. An increase in the frequency and intensity of hurricanes could thus have a much greater impact on the coastal zone than a gradual change in climate. The mangroves of Antigua and Barbuda and Cameroon will not be affected by temperature change as much as by a positive or negative change in the intensity of precipitation, which could alter the ratio of seawater to freshwater and thus damage the ecosystem. On the other hand, coral reefs are currently growing close to their maximum temperature tolerance, and even small increases in temperature could have negative impacts on Antigua and Barbuda's reef system. In Pakistan, a combination of increased river flows and increased pressures on flood plains means that flood hazards may be one of the most serious problems associated with climate change.

Not all impacts discussed in the studies were considered negative. In Estonia, the impacts of climate change on agriculture and forestry were considered beneficial. In particular, agriculture could become more competitive in the future, and it is likely that most crops of southern origin, such as maize, summer wheat and buckwheat, will become more productive. Furthermore, the capital city of Tallinn will be out of the freezing zone of the Baltic Sea in the second half of the 21st century. In Antigua and Barbuda, climate change could intensify the seasonal cycle of winds and lead to fewer days at sea for the country's fishing fleet. Although this would lead to a short-term reduction in catch per vessel, over the long run it might lead to stock recovery for resources that are already over-exploited, and eventually to an increased catch. In Cameroon, the shrimp catch is expected to increase under scenarios of increased rainfall. Nevertheless, overexploitation of the fishery could cancel out this beneficial effect of climate change. Although model simulations suggest that temperature increases alone may result in minor reductions in grain yields in Pakistan, increased levels of atmospheric CO_2 could lead to significant increases, including increased production of straw.

1.6 Adaptation Strategies

The UNEP country studies placed a heavy emphasis on the analysis of adaptation strategies for climate change. Until recently, adaptation has not been given much attention, as attention has focused primarily on mitigation. According to the UNEP Handbook (1996, p. 2-1), "adaptation refers to all those responses and adjustments to climate change that may be used to reduce vulnerability, and strengthen resilience." It also relates to actions that exploit new opportunities resulting from climate change.

The UNEP Country Studies emphasized the need to address climate change through policy and planning. This includes long-term physical planning in the case of Antigua and Barbuda, such as the establishment of appropriate setbacks along coastal areas. It also means the control of urban settlements in coastal areas of Cameroon. In Pakistan, addressing climate vulnerability through policies and planning was considered a key adaptation strategy. This involves, for example, improving and expanding Pakistan's infrastructure base, which has deteriorated as a result of budgetary constraints. The Estonian study emphasized the fact that climate change impacts are likely to be overshadowed by political and economic changes. The range of uncertainties associated with future socioeconomic scenarios thus adds to the uncertainties in adapting to climate change.

In some cases, cross-sectoral contradictions became evident with respect to adaptation strategies. For example, to address water scarcity in Antigua and Barbuda, it was recommended that the government consider an incentive system to encourage the public to construct larger water storage tanks to collect rainwater. However, the health sector identified cisterns or above-groundwater storage tanks as breeding habitat for the mosquito that transmits dengue, and recommended that piped water be used in new housing developments to reduce dependence on stored water and reduce the health risks associated with climate change. Integrated country studies enable the identification of such contradictory strategies.

The studies examined some of the actions or adjustments that are already being used to address climate variability. For example, investments in drip irrigation technology to address water scarcity in Antigua and Barbuda could represent an effective adaptation strategy to long-term climate change. Responses to climate variability were seen as one way of adapting to future climate change.

Several of the country studies expressed some degree of confidence regarding the potential for adaptation, especially if climate change is considered a gradual phenomenon. In Estonia, it was emphasized that the projected positive trends of climate change, both for temperature and precipitation, will occur on the background of the natural change experienced over past centuries. Comparing scenarios of climate change with the observational record, it was found that the changes are within the limits of historical air temperature fluctuations.

The recognition that the climate has changed or varied in the historical past has served as a means for contextualizing adaptation strategies for future climate change. Resiliency emerged as an important factor in adapting to long-term climate change. The importance of resiliency is captured in the Pakistan report:

> Over the centuries, the Pakistani farmer has learnt to live with change and adversity. In his humble style, with simplicity and often in ignorance he moves on with his life, adapting imperceptibly to the changes around him. He bounces back to normalcy after every cataclysmic event like a drought, a mega-

> flood, even war. This inherent resilience provides him with adequate capacity to meet the growing threat of climate change. The fact that global warming is a slow process extending over decades makes him adequately competent to adapt to it. (p. 162)

It was concluded that increases in average temperatures would not result in catastrophic changes for Pakistan's farmers, or for countries like Estonia. However, if climate change is characterized by changes in the frequency and intensity of extreme events, then such complacency may be misplaced. Exposure to extreme events may increase or intensify under climatic change. In addition, there may be significant changes in the timing and duration of seasons. Changes in the onset and timing of rainfall were considered to be critical for agriculture. The magnitude of any change in climate is also important. In the case of Antigua and Barbuda, a sea-level rise of 0.3 meters will not have a major impact on human settlements. However, if sea level rises by one meter, then the entire island of Barbuda, with its relatively flat topography, is likely to be inundated.

Addressing current problems is often seen as one way to increase overall resilience to climate change. An assessment of climate adaptation strategies reveals that economic reforms, policy changes, improved management and increased monitoring are important means of addressing long-term climate change. In fact, most of the adaptation measures identified in the studies could be considered necessary or beneficial, even in the absence of climate change. These measures are often referred to as "win-win" strategies. Nevertheless, most of the adaptation measures identified in the studies require strategic actions, and few will occur autonomously.

Much of the discussion regarding greenhouse gas mitigation in a South-North perspective focuses on the transfer of technology and the need to help developing countries adapt to climate change (e.g. UNFCCC Articles 4.8 and 4.9). Nevertheless, adaptation measures based on technological or engineering solutions were seldom identified as priorities over management improvements based on the precautionary principle. For example, in Antigua and Barbuda the effects of climate change on marine ecosystems cannot be easily mitigated by engineering methods. Instead, the study recognized that the better the quantity and quality of important coastal habitats, the less likely it will be that climate change will affect them and the fisheries that depend on them. Although desalination was considered a potential adaptation to address water scarcity, the high cost of the desalinated water rendered this an unlikely option for agriculture.

The UNEP country studies suggest that much can be accomplished without technology transfers. In fact, the knowledge, technology, and human resources necessary to undertake adaptation strategies to climate change are in most cases presently available. In the cases where technological adaptations were recommended, they could be targeted at specific measures identified in the country study reports.

1.7 Conclusions

Considering the results of the four studies together, what can be said about developing strategies for climate change? All of the UNEP country studies stressed the primacy of contemporary socioeconomic challenges and environmental policies. The country studies suggest that climate impacts in developing countries may differ significantly from impacts in countries with economies in transition. The reasons for this include different ecological conditions, different levels of industrialization, and different degrees of dependency on the natural resource base.

Nevertheless, it is also evident that climate impacts vary significantly among developing countries. Each country faces a particular set of contemporary challenges that must be addressed when considering the impacts of climate change. These challenges also form the basis for evaluating potential adaptation strategies.

All of the studies stress the need to address current problems in order to face a future with climate change. In some cases this means increasing institutional capacity to administer and regulate environmental issues, and in other cases it means a greater commitment of resources to support existing measures. Some contradictions emerged in the UNEP country studies that need to be addressed at the policy and operational levels, if the results of the impact assessments are to lead to adaptations and reduced vulnerability to climate change. These contradictions include an emphasis on economic growth at any cost within sectors that are likely to be affected by climate change.

The studies show that vulnerability to climate change cannot be addressed outside of the social and economic realities prevalent in each country, and without recognizing the changes that are occurring in response to national and global economic and political processes. Economic changes, along with political, social, and demographic changes and increasing pressure on environmental resources, mean that some regions or sectors may become more vulnerable to climate change in the future, while others may become more resilient. The dynamic aspects of climate vulnerability that emerged in the UNEP country studies can be used to develop and direct strategies for addressing climate impact and adaptations.

2 Antigua and Barbuda

The climate change impact and adaptation assessment for Antigua and Barbuda began in September 1996, and was conducted by a team of national experts under the coordination of Daven Joseph of the Ministry of Planning in Antigua and Barbuda. A copy of the full report, including a list of participants and authors, can be obtained from the Ministry of Planning, Cross Street, St. John's, Antigua.

Source: CIA World Factbook (1999)

2.1 Introduction

Antigua and Barbuda form an archipelagic island state located in the Eastern Caribbean, between latitudes 17ºN and 18ºN and longitudes 61ºW and 62ºW. Antigua is the larger of the two islands, with an area of 280 km^2 square miles. Barbuda, which lies 42 km to the north of Antigua, has an area of 160 km^2. The topography of the two islands is relatively flat. Antigua is characterized by gently rolling hills and a mountainous area with peaks of up to 400 meters, whereas Barbuda is low-lying, with most elevations between 15 to 30 meters.

Although the islands contain a variety of soil types, most of the original vegetation was removed or degraded as a result of land clearing and intensive agricultural use, particularly sugar cultivation. Currently, only about 15% of the land area is covered with forest. There is a high degree of avian and marine biodiversity in Antigua and Barbuda, and the islands are fringed with some of the most extensive coral reefs in the Caribbean.

The climate of Antigua and Barbuda can be described as tropical maritime, characterized by relatively high temperatures, a small diurnal temperature range, high relative humidity, steady easterly trade winds, and a marked seasonal rainfall. The rainy season typically extends from July to November, whereas the dry season occurs between December and June. The annual average rainfall in Antigua is 1039 mm. Dry conditions and droughts occur fairly frequently in Antigua and Barbuda, at an interval of approximately every four to seven years. Tropical depressions, storms, and hurricanes influence the climate of Antigua and Barbuda, and contribute significantly to annual rainfall totals.

The 1991 national census estimated the population of Antigua and Barbuda to be 63,896. However, since 1970 the population of the two islands has been characterized by declining growth. Between 1970 and 1980, the annual growth rate for Antigua and Barbuda was 0.37, declining to -0.28% in the period between 1981 and 1991 and to -0.24% between 1991 and 1996. The declining population growth is a result of reductions in fertility rates as well as the effects of migration. These demographic changes have been accompanied by significant changes in the age structure of the population, with reductions in the percentage of young people (0-14 years) and a rise in the percentage of population aged 65 years and over.

From an administrative perspective, Antigua and Barbuda is divided into six parishes. The largest of these is St. John's Parish, which contains the capital city of St. Johns. Approximately 60% of the total population live within St. John's Parish, in contrast to only 2% on the island of Barbuda. The population density of St. John's Parish is 1250 persons per square mile, whereas the population density of Barbuda is only 20 persons per square mile. Although external migration overshadows internal migration, there has been a notable population shift from rural to urban areas.

Early settlement in Antigua and Barbuda developed within a plantation economy based on the export of sugar. The island's flat terrain facilitated a dispersed settlement pattern throughout most of the island. Areas of major population concentration included the large plantations and sugar estates that were scattered primarily along the Central Plain. As sugar and agriculture declined in the 1940s and 1950s, the town of St. Johns became the only viable source of employment on the islands. As a result, considerable rural-urban migration ensued. New migrants settled in specific locales around the central business district, and the periphery of St. Johns became densely populated. By 1946, St. Johns accounted for 54% of the island's population.

Key Point: A high dependency on tourism leaves Antigua and Barbuda vulnerable to fluctuations in demand, including any changes in demand driven by climate change impacts in other parts of the world.

Antigua and Barbuda is considered to be an upper-middle income country. The economy is predominantly dependent on tourism, which directly and indirectly contributes to approximately 60% of the gross domestic product (GDP). Steady growth in government expenditures since the 1980s have resulted in a current accounts deficit of 0.63% of the GDP between 1991 and 1993, which was financed in part by commercial loans. In 1994, the total external debt of Antigua and Barbuda was XCD 849.4 million (1 Eastern Caribbean Dollar equals approx. USD 0.37), amounting to a debt to GDP ratio of 68.9%. Approximately 7.2% of Antigua and Barbuda's GDP is directed towards servicing this debt.

Tourism forms an important part of the national economy of Antigua and Barbuda. Tourism resources include natural resources such as beaches, historical sites, and people; superstructures such as hotels, guesthouses, and airports; and infrastructure such as water, electricity, transportation, and hospitals. A high dependency on tourism leaves the country vulnerable to fluctuations in demand, particularly from the tourism-generating countries of the United States, Canada, and many parts of Europe. Although it is recognized that the economy should diversify, tourism is still perceived as the key to long-term economic prosperity.

The development of the tourism sector has not affected the primacy of St. John's in terms of human settlements. However, tourism developments on the periphery of the island have helped to slow the pace of migration into the urban area of Antigua. More important, these developments have sustained and even expanded some settlements that were in rapid decline during the middle of the century.

Key Point: Extreme events have a devastating impact on the economy of Antigua and Barbuda. An increase in the frequency or magnitude of hurricanes or droughts will have severe consequences for long-term economic growth.

Economic growth, particularly in the tourism sector, has resulted in an increased demand for imported goods in Antigua and Barbuda. Consequently, imports increased from XCD 707.94 million in 1990 (or 79% of GDP) to XCD 909.99 million (or 87% of GDP) in 1993. At the same time, exports increased from XDC 51.25 million in 1990 to XCD 180.67 million in 1993. Overall, Antigua and Barbuda's balance of trade remains in deficit.

Climate change poses a potential threat to small island states such as Antigua and Barbuda. Sea level rise and changes in the frequency and intensity of extreme events could have important impacts on both the economy and ecology of the two islands. The potential for long-term changes in temperature and precipitation demands a better understanding of how different sectors would respond. Moreover, it demands an integrated perspective that takes into account the simultaneous impacts of climate change on different sectors.

2.2 Climate Change Scenarios

Synthetic scenarios of climate change were developed for Antigua and Barbuda. The use of large-scale global circulation models (GCMs) was considered inappropriate for an island state the size of Antigua and Barbuda. The lack of data and the limited time frame for the study precluded the use of mathematical and biophysical climate models. It was also considered important to use relatively simple and easily understood scenarios that policy- makers and the wider public could comprehend.

The synthetic scenarios consisted of increased hurricane/tropical storm activity and more intensified drought conditions. The scenarios, presented in Table 2.1 and Table 2.2. assume a linear increase in the number of storms. In addition, a projected sea level rise was calculated for use in the coastal zone and human settlements sectors. These synthetic scenarios are in accordance with IPCC and other projections of the likely impacts of anthropogenic climate change on the islands of the Caribbean.

Much of the assessment was also based on an approach known as forecasting by analogy. According to this method, Antigua and Barbuda's past experiences with hurricanes and droughts are used as the basis for understanding and predicting the future effects of climate change. Hurricanes are by far the most frequently occurring natural disaster in the Caribbean. Over the past decade, two major hurricanes have hit the islands, resulting in a significant amount of damage. Their dangers arise from a combination of factors, including high winds, heavy rains, and storm surges.

Droughts have also occurred on the islands with some frequency. The most recent serious drought occurred in 1983. Periods of prolonged dry spells or droughts have resulted in water shortages in all settlements, particularly those in drier parts of the island. Water supply is therefore a critical issue, and the situation is expected to become worse with population growth and the expansion of tourism, both of which are expected to increase the demand for water. Such extreme events can be used to provide insights into the potential impacts of climate change.

Table 2.1 Hurricane Scenarios for Antigua and Barbuda

Year	Average No. of Storms	Intensity Increase + Decrease -	Storm Surge (Heights)	Surface Winds
1995	9.30			
2001	10.23	1096	Increase	Increase
2011	11.16	2096	Increase	Increase
2021	12.09	3096	Increase	Increase
2025	13.02	4096	Increase	Increase
2050	13.95	5096	Increase	Increase

No. of storms: Linear increase based on 35 year mean (1960-1995)
Intensity: Linear increase; based on Emanuel, 1987 who suggested a 40% increase in hurricane intensity resulting from a 4°C increase in global temperature.
Storm Surge: Qualitative; depends on category of hurricane.
Surface Winds: Qualitative; depends on category of hurricane.

Table 2.2 Drought Scenarios for Antigua and Barbuda

Year	Rainfall Reduction	Type of Drought	Total Projected Rainfall
1995 (Baseline year)	0% (40.98″)	Normal	40.98″
2006	5%	Slight Drought	38.93″
2016	10%	Mild Drought	36.88″
2030	15%	Moderate Drought	34.83″
2040	20%	Moderate to Severe Drought	32.78″

Occurrences of extreme climatic events, such as hurricanes and droughts, can have a devastating impact on the economy of small island communities, destroying infrastructure and productive capacity, interrupting economic and social activities, and changing the natural resource base. With their small ecological space, sensitive ecosystems, narrow economic structures, and generally high population densities, the impacts amount to a severe economic shock that tends to retard growth and redirect economies away from their long-term growth path. In practice, the damage caused by natural disasters has been measured in terms of the cost of replacement for infrastructure, crops, hotels, etc. However, these short-term measures rarely capture the full economic effects of natural disasters, as they ignore the long-term benefits, such as improved housing and infrastructure, and greater environmental protection and enhancement. These benefits can accrue if there are sufficient domestic or international resources channeled to them in the aftermath of the natural disaster.

Hurricane Hugo struck Antigua and Barbuda in September 1989, causing extensive damage to agriculture, fisheries, housing, tourist accommodations, and the infrastructure that serves all sectors of the economy. Damage assessments carried out by the United Nations Development Programme (UNDP), the Food and Agricultural Organization (FAO), and others estimated the total cost to be XCD 154.1 million, which represented 17.6% of the GDP at factor cost. In terms of damages, the building and housing stock accounted for the largest single element. Infrastructure damage was the second most important, and natural resources and the productive sectors such as agriculture and fisheries were third. The southern part of the island was more affected than the north. Prior to Hurricane Hugo, during the period 1980-1988, the economy had experienced a high rate of real growth, averaging 6.8%. In the aftermath of Hurricane Hugo, the average rate of growth declined to an average of 2.2% in the period 1989-1991.

Key Point: Population growth and urbanization are contributing to a scarcity of hazard-free or low-hazard development sites. Climate change could further reduce the area of land considered suitable for growth and expansion.

In September 1995, Hurricane Luis devastated Antigua and Barbuda. Virtually all major tourism facilities located along the coast were damaged by Hurricane Luis, resulting in closures and lost revenue. Antigua and Barbuda experienced a 17% decrease in the number of tourists following the hurricane. Approximately 7000 persons were left unemployed. Data indicate that the total cost of damages amounted to XCD 346.54 million, or 30.49% of the GDP at factor cost in 1994. In other words, the magnitude of the impact was over twice that of Hurricane Hugo in 1989. Prior to Hurricane Luis in 1995, the risks associated with natural disasters were perceived by most to be low or non-existent. As a result, little attention was paid to design standards or the development of known hazardous areas.

In 1983–1984, Antigua experienced a severe drought, when less than 1000 mm of rain occurred over 21 consecutive months. All surface reservoirs dried up, and the supply from groundwater produced only one-sixth of the constrained national demand. As a result of this drought, water had to be imported to the island. More recent droughts have been nearly as severe, but the availability of desalinized water has made their impacts less visible. However, desalinized water is expensive, and usually aimed at the domestic and tourism sectors rather than agriculture.

2.3 Baseline Socioeconomic Scenarios

Climate change will not be the only factor influencing the future of Antigua and Barbuda. Social and economic conditions are expected to change, affecting both the country's vulnerability and resiliency to climate change. It is therefore an important step in any assessment to consider the trends that are likely to occur *in the absence* of climate change. Scenarios of climate change can then be superimposed on these baseline scenarios to suggest more probable impacts of climate change. Projections of socioeconomic scenarios for Antigua and Barbuda were made for a 30-year time frame, using 1991 as a baseline year. Longer forecasts were deemed unrealistic, given the lack of data necessary for reliable projections.

The population of Antigua and Barbuda is projected to grow from a base of 64,000 in 1991 to between 78,000 and 99,000 by the year 2021. The low-growth scenario represents an increase of 27% from the base, whereas the high-growth scenario represents an increase of 60%. The projected population growth can be attributed to a tightening of immigration laws in receiving countries, particularly the United States, as well as an influx of immigrants from neighboring islands in the CARICOM bloc. In addition, life expectancy and fertility rates are expected to rise after 2001.

Population growth and urbanization are contributing to a scarcity of hazard-free or low-hazard development sites. They are also creating a scarcity of affordable sites for low-income development schemes. Developments in high vulnerability, hazard-prone areas carry a high risk, which can only partially be mitigated by expensive structural measures.

Future domestic water demands in Antigua and Barbuda are projected to increase in proportion to population growth. It is assumed that domestic per capita water consumption will remain constant over the next 20-25 years. Although per capita consumption should typically increase with an improved standard of living, the assumption considers that such increases will be compensated for by the anticipated positive effects of water conservation measures. It is assumed that future demands for tourism and agriculture will increase in proportion to anticipated economic growth of these sectors, based on the medium economic growth scenario.

The economy of Antigua and Barbuda is expected to grow from between 1.8% and 6% per annum by 2021, with a middle scenario of 4% growth per annum. These growth rates are consistent with economic projections made by the World Bank for Antigua and Barbuda.

It is projected that tourist arrivals will increase from 484,700 in 1991 to 680,000 by 2000. Depending on future investments made in this sector, the number of tourists could increase to as much as 930,000 by 2021. Such growth would necessitate an expansion and improvement in infrastructure such as roads, sea ports, airports, telecommunications, and other facilities. Both population growth and a growth in tourism are anticipated to have multiplier effects that will result in increases in construction, transportation, communication, and financial service sectors. Such growth is also likely to increase imports, from a base of XCD 774.89 million in 1991 to XCD 2,219 million by 2021. Exports are expected to increase from XCD 95.65 million in 1991 to XCD 396 million in 2021.

These growth scenarios imply that even as soon as 25 years from now the society will have changed significantly, thus climate change will have its greatest impact on an economy and society that is quite different from the present one. Tourism is likely to play a larger role in the economy, and government revenues will be directed towards a growing population. As a small island nation, Antigua and Barbuda are constrained by the land area that can be used to accommodate future expansion. Antigua and Barbuda run the risk that environmentally-vulnerable areas will be developed or utilized in ways that do not contribute to a sustainable future. If climate change is superimposed on the baseline scenarios, then the areas that are deemed suitable for growth and expansion are even more limited. The sectoral studies on human settlements, tourism, and coastal zones identified a number of areas for concern.

2.4 Human Settlements and Tourism

A major difficulty in determining the impact of climate change on human settlements and tourism is the fact that many other factors are also important, independent of climate change. In many cases, these factors may be far more important in terms of the risk that they pose for human settlements and tourism. The most important of these include population growth, urbanization and industrialization, technology choices, and government policies and programs.

In the Caribbean, an urban area is usually defined by the size and function of the settlement, and sometimes by the available facilities. For the purposes of the study, the capital city of St. Johns in Antigua was classified as urban, as was Codrington in Barbuda. All other settlements were described as rural. A distinction between coastal and inland settlements was made in order to assess their level of vulnerability.

The high population density in the parish of St John's has resulted in problems such as overcrowding, inadequate waste disposal, and insufficient provision of water. A substantial number of housing units in the urban area are in derelict condition and cannot be reasonably renovated. Access to land and credit for housing has been limited to a small segment of the population. Squatting is often the only alternative.

Most of Antigua and Barbuda's tourist developments are located in coastal areas. In fact, thirty-nine of the fifty-five hotels have beachfront locations. Physical planning concepts and controls have only recently been introduced in Antigua and Barbuda, with the passage of the 1977 Land Development and Control Act. As a result, the spatial distribution of settlements has, for the most part, evolved through natural trends rather than through policy and planning. To achieve an efficient form of development, there is a need to place greater emphasis on long-range physical planning and control of urban development.

The importance of locational factors was evident during the 1995 hurricane season, when the country was hit by two hurricanes within the space of one week. Heavy rains and storm surges produced localized flooding and landslides. Much of the damage inflicted on housing and public buildings by Hurricane Luis can be traced to inappropriate standards for methods and materials used in roof construction. The hurricane exposed some major weaknesses in building codes and legislation. The majority of the homes that were damaged were built to specifications without the capacity to withstand hurricanes. In addition, a number of the houses were not insured.

To determine the role of locational factors in contributing to the vulnerability of settlements, forty-seven settlements were selected according to population size, function, physiographic characteristics, and income. This allowed the study team to capture a wide spectrum of settlements, including most of the traditional villages. A vulnerability index was then constructed, and each settlement was evaluated based on the presence or absence of the following six physiographic factors:

- Location on a coastal plain, flood plain or watershed;
- Valley settlement;
- Partially submerged during high tide;
- Deficient rainfall (less than 40 inches) or groundwater dependent sites;
- Exposure to gales (sites located on hillsides, hilltops and bases of cliffs);
- Exposure to storm surge.

A score of one was assigned to each factor present, and a score of zero was assigned if the factor had no relevance to the settlement. The total score for each settlement was used to classify its vulnerability, ranging from low (2 points and under) to medium (3 points), to high (4 points) and very high (5-6 points).

Thirty-four percent of the major settlements were classified as low vulnerability, 28% were classified as medium vulnerability, 19% were classified as high vulnerability, and another 19% were evaluated as very high vulnerability. Inland settlements tended to have a lower vulnerability ranking than coastal or flood plain-oriented settlements. This is not surprising, given that they are located a sufficient distance from the impact zone of storm surges and rising sea level. Nevertheless, some inland settlements, particularly those located upon slopes facing or exposed to the coast, may be susceptible to strong winds, including prolonged and higher intensity hurricane winds. Combined with high extreme rainfall events, the sloping aspect could initiate landslides, erosion, and slippage.

Design factors and development standards contribute to an increase in vulnerability when inappropriate standards are applied. Building shortcuts in residential construction, improper grading of road-cuts, the use of design parameters inconsistent with the hazard susceptibility of sites, and insufficient attention to the environmental impacts of the development are some examples of factors that increase vulnerability. During the building boom of the 1970s and 1980s, very little attention was paid to the integrity of the building to withstand strong storms and hurricanes. There were no building codes at the time, and cost cutting was a driving factor within the construction industry.

Key Point: Improper design factors and inappropriate development standards associated with the building boom of the 1970s and 1980s have increased the vulnerability of human settlements in Antigua and Barbuda to climate change.

The current policy measures and legislation regulating and monitoring developments include building codes and the Land Development Control Act and Regulations. However, the implementation and monitoring of these policy measures are extremely ineffective due to a weak institutional capacity to administer and regulate environmental issues. There are also inadequate resources (both financial and human) to support the measures. Finally, there is a lack of commitment and political will to support a program for Environmental Planning and Management.

A vulnerability analysis of sea level rise examined both the physical and human susceptibility of the coastal zone to sea level rise, and the ability of society to cope with those changes. Most studies have used a one-meter sea level rise as the standard (Carter et al., 1994). In this study, sea level rise scenarios of 0.3 m and 1.0 m by the year 2100 were used to examine the potential impacts on coastal areas.

A sea level rise of 0.3 m will have no major impact on human settlements, since this represents a relatively small change over a 100-year time span. To assess the effects of a one-meter sea level rise, topographical maps with contour intervals of 10 feet were used, along with hydrographic maps. The projected sea level rise will lead to an increase in the risk of floods produced by storm surges. Settlements on the southwestern coast were found to be most vulnerable, and most of Barbuda is likely to be inundated under a one-meter sea level rise scenario. The location of tourism facilities on or near beaches makes the tourism sector particularly vulnerable to the threat of sea level rise.

To examine the vulnerability of human settlements and the tourism sector to climate change within the context of baseline trends, a matrix was developed to portray current conditions and baseline trends in the absence of climate change (see Table 2.3). Baseline scenarios indicate that population will increase by between 26% (low scenario) and 60% (high scenario) by the year 2021, with a corresponding increase in the number of households. The direct contribution of tourism (i.e. the hotel and restaurant sector) to the GDP is projected to increase to about 14%. This growth necessitates an expansion in infrastructure, construction and other economic and service-oriented activities.

Based on the baseline conditions of the human settlements and tourism sector, a vulnerability matrix of the different climate drivers was constructed (see Table 2.4). Each variable or climate driver in the matrix was assessed and given a ranking, from low to very high. The more important the driver is in contributing to the vulnerability of the sector, the greater level assigned to that particular cell. From this table, it can be seen that without climate change, the vulnerability of human settlements and tourism is moderate. Exceptions occur in years with hurricanes or droughts.

With a 1ºC increase over baseline temperatures, a 30-cm rise in sea level by the year 2100, and a 10% increase in the frequency of extreme events, the sector is projected to have a moderate to high vulnerability. Under a scenario of extreme global warming, characterized by a 2ºC increase in baseline temperatures, a sea level rise of 1 meter by 2100, and a 30% increase in extreme events, the human settlements and tourism sector of Antigua and Barbuda would be very highly vulnerable.

The successful implementation of adaptation options will depend upon the country's human and financial resources capability, cultural and social acceptability, and integration with other programs and projects. There are still a number of coastal sites that are considered ideal for tourism development. However, if no intervention measures are taken, it is likely that the present pattern of constructing tourism facilities directly on the coast will continue.

Experiences from past hurricanes demonstrates the need to take measures to reduce the vulnerability of these facilities to extreme climate events, considering that the frequency and intensity is likely to increase in the future.

The following adaptation measures are recommended to reduce settlement vulnerability in Antigua and Barbuda:

- Hazard mapping to identify those areas that are most vulnerable to the effects of climate change.
- Flood control, including the cleaning of watercourses and drains.
- Land use controls and enforcement, including zoning regulations, building codes, and planning and infrastructure standards, and setback requirements for the coastal zone.
- Retrofitting of existing structures to strengthen their resilience against the hazards of climate change and hurricanes.
- Capacity building, particularly the strengthening of institutions responsible for environmental management.
- Improvement in the forecasting and early warning system to increase preparedness.
- Public education and information to raise public awareness about climate change.

Most of the recommended adaptation measures require strategic actions, and few will occur autonomously.

Table 2.3 Overview of baseline scenarios by 2021, with no change in climate.

Issue	Baseline Scenarios	Impact on Human Settlements and Tourism
Population trend	Increase from 61,689 (1991) to 98,946 (2021). Percentage increase for: Low scenario: 26.4 High scenario: 60.4	Expansion and creation of new housing, subdivisions and tourism facilities
Tourism trend	Increase to 14.4% of GDP	Expansion in tourism infrastructure and tertiary sector
Other domestic economic activities	Increase	Expansion in construction, transportation, communication and financial services.
Imports	Increase	Increased food imports, building materials and waste. Investments in waste disposal facilities and supplies.
Exports	Remain constant over the period	Increase in tourism receipts

Table 2.4 Vulnerability assessment of different climate drivers for 2100

Climate Driver	Effect on Human Settlements and Tourism
WITHOUT CLIMATE CHANGE	
Base T_{wet}	L
Base T_{dry}	L
Base P_{wet}	M
Base P_{dry}	L
Year(s) with hurricane	VH
Year(s) with drought	H
WITH CLIMATE CHANGE	
SLR-low (30 cm by 2100)	L-M
ENSO	H
Warming: + 1°C, SLR-low (30 cm by 2100), Extremes + 10%	M-H
Warming: + 2 °C, SLR-high (100cm by 2100), Extremes + 30%	VH

L = low, M = moderate, H = high, VH = very high, T = temperature, P = precipitation, SLR = sea level rise. ENSO = El Niño Southern Oscillation

2.5 Coastal Zones

The sectoral study on coastal zones examined the sensitivity of coastal resources of Antigua and Barbuda to climate variability and change, and identified the possible impacts of sea level rise on the coastal zone. The most vulnerable regions of Antigua and Barbuda were highlighted, and adaptation strategies were developed to reduce risk in those and other areas.

More than 60% of the population of Antigua and Barbuda live within the coastal zone. Population increases and tourist-based developments are already putting considerable pressure on coastal resources. In addition, reclamation of land, sand mining, and the lack of a comprehensive system to control flooding and sedimentation has increased the country's vulnerability to erosion, coastal flooding, and storm damage.

To see how climate change would affect the coastal areas of Antigua and Barbuda, a scenario approach was taken. The scenario assumed a temperature increase of 1.25°C by 2075 and a sea level rise of 3 to 4 mm per decade (with a high scenario of 10 mm per decade). It was assumed that the increase in temperature would also lead to an increase in the number and intensity of storms, as well as more extreme variations in wet and dry periods. It was further assumed that the sea level rise would be absolute and not relative (i.e. there is no vertical movement of the land), and that over time the relationship between sea level rise and socioeconomic impacts is linear.

A comprehensive inventory of coastal areas of Antigua and Barbuda was undertaken to identify current coastal resources. Once identified, baseline conditions were set and related to climate and sea level. Measures were designed to test possible impacts of climate change and sea level rise on the various coastal resources. Where appropriate, the IPCC Common Methodology was followed.

Antigua and Barbuda's coastal resources include mangroves and wetlands, coral reefs and sea grass beds, and beaches. The dominant species of mangrove on both islands is red mangrove (*Rhizophora*), mixed with black mangrove (*Avincenia*), white mangrove (*Laguncularia*), and occasionally button mangrove (*Conorcarpus*). Mangrove systems are important habitats for fisheries in the eastern Caribbean islands (Alleng, 1993; Appeldoorn, Dennis, & Monterrosa Lopez, 1987; Boulon, 1992; Dennis, 1992).

It was estimated that there were 4901 ha of mangroves in Antigua and Barbuda in 1991 of which only about 60% remain today. Most of the mangrove sites around Antigua have been destroyed or are severely damaged. The major cause of the damage is due to coastal development. Mangroves are being cleared to make way for the construction of new hotels, which requires extensive dredging of the mangroves and near shore areas. The dredging of coastal waters has altered the current, tide and wave regime, thus disrupting the ecology of the entire area.

Key Point: Sea level rise will have a negative impact on mangrove ecosystems, the profiles of extensive beaches, and the quantity and quality of groundwater supplies in Antigua and Barbuda.

It is expected that climate change will significantly disrupt the mangrove ecosystems around Antigua and Barbuda, particularly since many of these areas are presently under stress from natural and anthropogenic sources. Temperature change itself is expected to have a minimal effect on mangrove ecosystems. However, changes in precipitation patterns, such as increases in flooding or droughts, would alter the seawater to freshwater balance and thus significantly affect mangrove ecosystems. A decrease in precipitation would reduce productivity, as well as increase exposure to seawater, leading to salt stress.

Sea level rise will result in the greatest impact on mangrove systems. A rise in sea level could cause mangroves to retreat shorewards (Senedakar, 1993). However, if sedimentation does not keep pace with the rising sea level, then erosion of the substrate could be expected. Increased sedimentation from anthropogenic sources could result in stable or slowly retreating mangrove areas in larger systems. Fringing mangroves, on the other hand, would be significantly reduced, as they have slow rates of sediment accumulation.

It is estimated that Antigua and Barbuda is currently losing its mangrove systems at an average annual rate of about 1.5-2.0%. With a sea level rise of 3-4 mm per year, there would be little or no mangroves on Antigua by 2075, since the coastal slopes of most areas do not allow for landward retreat. With a sea level rise of 10 mm per year, this condition would be reached as early as 2030 or 2035. The condition is different for Barbuda, where extensive lowlands could theoretically accommodate retreat for a longer period.

Antigua and Barbuda sit on a shallow rock-floored platform or "shelf," which in turn is covered by sediment (sand and mud) and a wide variety of coral reefs. Coral reefs provide the habitat for a wide variety of reef fishes that make up the catch from fisheries along the Antigua and Barbuda shelf. It has been estimated that approximately 25.45 km^2 of reefs can be found around Antigua alone. The reefs are better developed on the windward east coasts of the islands, and poorly developed or non-existent on the leeward west coasts. Like mangroves, coral reefs can be damaged by sedimentation from road construction or buildings. Reefs on the west and southeast coasts show a high degree of environmental damage.

Sea grasses located on Antigua's shelf and intertidal zones are also important resources. Seagrass beds are of considerable importance to fisheries; they serve as nursery areas for many species of fishes, lobsters, and conch (Appeldoorn et al., 1987). The distribution of seagrass beds is generally controlled by water depth and salinity.

Climate change will affect both coral reefs and sea grass beds. The impacts are related to sea level changes and fluctuations in temperature that affect critical habitats, intense storms that cause direct physical damage, and the indirect effects of increased precipitation, which leads to an increase in sediment supplied to coral reefs, seagrass beds, and mangrove areas.

Coral reefs are currently growing precariously close to their maximum temperature tolerance of 30ºC, therefore even small increases in temperature are expected to have detrimental effects. In fact, an increase of 1-2ºC for several weeks may cause bleaching, as a result of the loss of zooxanthellae. If the stress is temporary, the coral will recover, but with a reduced growth rate and reproductive capacity. If the stress is prolonged, the bleached coral will eventually die (Glynn, 1996). The predicted rise in sea temperature is not expected to affect the physiological functioning of seagrasses (Vincente, Singh, & Botello, 1993).

Tropical storms are considered important to the diversity of coral reefs, as long as the reefs have adequate time to recover between storms. However, under a scenario of increases in intensity and frequency of tropical storms, the reef system would not have the necessary time to recover, and corals could eventually die. Hurricanes, on the other hand, reduce the physical complexity of coral reefs and the abundance of living corals. These effects are greatest at shallow depths, where wave action is greatest. However, shallow corals are adapted to wave action, thus hurricanes can cause considerably greater damage in deeper water, where corals seldom experience wave action under normal conditions (Harmelin-Vivien & Laboute, 1986).

Some of Antigua and Barbuda's most important resources, especially in terms of tourism, are its extensive beaches. Sandy beaches form the dominant coastal landscape of Antigua and Barbuda. The major use of beaches on these islands include recreation, fish landing sites, a source of fine aggregates used in building construction, and habitats for nesting turtles and other animals and plants. Anthropogenic factors affecting beaches include sand-mining activities, dredging, and building of hard structures too close to the shoreline.

The dominant impact on the beach system will arise from any change in sea level, combined with the cumulative effects of hurricanes. Hendry (1993) contends that sea level rise alone will subject higher levels of coastal zones to wave and current action, resulting in a net migration of the sediment - water interface landward as the shore profile adjusts itself. Using a rate of sea level rise of 3.0 mm/year over the next three decades, and then 4.0 mm/year until 2100, the shoreline of Antigua and Barbuda is anticipated to retreat nearly 40 meters. This corresponds to a retreat of 1 meter for every 10 mm of sea level rise. Beaches on undeveloped coastlines, such as most of Barbuda, will continue to retreat inland as they erode. On developed coastlines, where the beach cannot move inland because of concrete and hard structures, the beach will get narrower and may eventually disappear.

It must be noted that the average change in coastal areas would be difficult to discern, since the width of many beaches in Antigua and Barbuda varies by more than 9 meters as a result of normal seasonal changes. Furthermore, one single event, such as Hurricane Luis, could cause more coastal erosion and landward retreat than a decade of sea level rise. What may be of far greater impact to Antigua and Barbuda's coastal zone is any change in the frequency and intensity of hurricanes as a result of climate change.

The impacts of hurricanes on Caribbean coastlines include erosion, retreat of the land edge or sand dune along the beach, and accretion (Cambers, 1996). In Antigua and Barbuda, it is anticipated that erosion will dominate along most of the coast, despite some accretion in a few areas. The amount of beach erosion depends on the characteristics of the particular hurricane, coastline shape, width of the offshore shelf and the presence of local features such as coral reefs. Along with sea level rise, the net effect of erosion will be a reduction in the land area of Antigua and Barbuda.

Coastal aquifers contribute substantially to the water resources of Antigua and Barbuda. Whereas Antigua is heavily dependent upon desalinated water for domestic and other purposes, Barbuda depends greatly on its groundwater resources. Rising sea level will threaten the viability of fresh water aquifers and other sources of groundwater. Most of the main aquifers, wells, sinkholes, and water bodies in Barbuda are located relatively close to the coast. The depth of the water table is generally less than 1.5 meters in the lowlands (Stewart Environmental Systems Inc., 1980). Any slight increase in sea level can affect the level and salinity of the groundwater supplies. With the projected future sea level rise, the main aquifers and wells may be fully or partially inundated and the groundwater supplies could become permanently lost. This will threaten the entire economy of the island of Barbuda.

After the general impacts of climate change on coastal zones were considered, a comparative geographic analysis was carried out. The purpose of this exercise was to assess which areas of the island are most vulnerable to climate change, as well as to identify the characteristics that influence this vulnerability. Five coastal areas that characterize the critical features of the coastal zone of Antigua and Barbuda were chosen as the focus of the study. The first four areas are located on the larger island of Antigua, and the fifth is the entire island of Barbuda. Variations within and between areas were deemed useful for a comparative analysis.

I. Dickenson Bay to St. John's

This represents the most developed area in socioeconomic terms, and it consists of major tourism and urban centers. Coastal roads are present in most parts, and the area is serviced with piped water and electricity supplies. There are a number of tourist structures along or bordering sandy shores. Anthropogenic factors have contributed to the destruction of most mangrove sites in this area, including the deposition of dredge spoil and wastewater from a nearby power plant. The coastline from Dickinson Bay to St. John is gradually eroding, at a rate of 0.9 m/year. This is a cause for concern, given the high density of tourism development. Hurricane Luis caused severe erosion in 1995, decreasing the mean profile by 41.5%, or about 7 m.

II. Five Islands to Old Road

This area has a major coastal road, along which the majority of the population resides. Tourist activities, including several hotels and a marina, dominate the coastal zone. Other economic activities include fishing, agriculture, and sand mining. Steep slopes and volcanic rocks are abundant, and there is an average rate of coastal accretion of 0.4 m/year. At the same time, the three beaches showing the most severe erosion in Antigua are located in this area. Several pure stands of mangrove and sea grass can be found in this coastal region, and the dominant reef system is in good condition. The six major tourist resorts are located in relatively low-lying areas, making them vulnerable to sea level rise and climate change.

III. Falmouth to Bethesda

This coastal area is characterized by sheltered coves surrounded by moderate to steep slopes. Although one of the most rapidly eroding beaches is located in this area, there is an average rate of accretion of 0.2m/year for the area as a whole. Tourism, agriculture, and fishing are the main economic activities. The area is also rich in archaeological and historical resources, and it includes a national park. Significant areas of sea grass and patches of mangrove remain, and there is a loose assemblage of corals in the coastal waters.

IV. Coolidge to Willikies

This region is characterized by a number of small offshore islands that provide natural habitats for some of the few rare animal species found in Antigua and Barbuda. Some of the sheltered bays provide hurricane anchorages, and the area is generally good for coastal navigation and yachting. There are extensive areas of coral reefs, sea grass beds, mangroves and wetlands. In terms of development, the area includes an airport, six major hotels, a desalination plant, a brewery, a cement factory, and a marina.

V. Barbuda

Barbuda is a low-lying island composed largely of coralline limestone rocks, with sandy beaches fringed by coral reefs. Sea grass beds and mangroves dominate some areas, and there is an extensive lagoon and wetland habitat. Hotel development is limited to the southern shores, and service industries are associated with the several areas of settlement. Fishing, agriculture and sand mining form the primary economic activities. More than 95% of Barbuda is public land. The mangroves in the lagoon were significantly damaged by Hurricane Luis in 1995.

For each area described above, indices were derived to show the degree of vulnerability to climate change and sea level rise. Using the inventory of coastal resources, each individual category was checked and assigned a value for each area (see Table 2.5). The categories were valued relatively, as high, medium or low. High values were assigned a score of 3, medium values a score of 2, and low values a score of 1. The sum of values for each area gives a vulnerability index relative to the other areas. In general, the more resources found in an area, the higher its vulnerability to the impacts of climate change and sea level rise. The five areas show variations in vulnerability among the different categories, but generally there is little difference when total vulnerability is considered.

For Antigua and Barbuda's coastal zone, short-term adaptation strategies include protective measures to restore beach and/or protect property (COLSALC, 1996). Although rather expensive to implement, this strategy is often favored on islands such as Antigua and Barbuda (Cambers, 1993). The construction of hard structures such as walls, revetments, groynes, bulkheads, dikes, levees, and detached breakwaters are temporary solutions to increased erosion and other effects of sea level. Semi-hard types of protection such as sandbags can also be a temporary option. In some vulnerable areas of Antigua, property owners have applied beach restoration measures to reduce the risk of excessive coastal erosion. These include periodic beach nourishing, dune restoration, and in some cases littoral drift replenishment. The study team noted, however, that such activities are usually implemented without any appropriate studies or research. Long-term strategies for Antigua and Barbuda's coastal zone include retreat and accommodation options, which can be expensive to implement. The retreat option involves the general control of coastal development, including the phasing out of development in vulnerable coastal areas. Long-term planning for coastal areas requires careful management strategies, which have always been problematic given the many agencies involved in Antigua and Barbuda's coastal zone management.

Table 2.5 Summary of the vulnerability of the different areas

	Vulnerability Score				
Category	Area 1	Area II	Area III	Area IV	Area V
Coastal structures/ Marina facilities	13	9	8	8	6
Heritage Resources	4	6	7	6	7
Housing	4	3	2	2	3
Natural Environment	13	20	18	20	20
Primary Industry	4	8	7	7	11
Recreation	15	18	14	16	16
Secondary Industry	6	0	0	10	5
Services	9	9	9	9	9
Tourism	17	15	12	6	6
Waste Disposal	11	8	8	9	6
Total	96	96	85	93	89

Note: Vulnerability as used here refers to the area's ability to cope with the consequences of climate change and accelerated sea level rise.

An important adaptation strategy for Antigua and Barbuda would be the establishment of suitable setbacks along the coastal zone. Currently, in accordance with the Land Development Control Act of 1977, there is a setback of 15 m from the high water mark. Appropriate setbacks for sandy beaches must be based on factors that include the following:

- Historical and recent changes in the coastline position
- Changes in coastline directly related to recent hurricanes
- Changes in coastline position likely to occur as a result of predicted sea level rise
- Coastal geomorphology and anthropogenic factors
- Planning consideration parameters

It was considered extremely important to implement serious coastal conservation measures in Antigua and Barbuda as a safeguard against possible climate change and sea level rise. The recommendations of the study team included increasing the research capacity in order to ensure a continued flow of scientific information and relevant data, harmonization of the agencies involved in coastal zone management, and establishment of a national policy for coastal development.

2.6 Fisheries Sector

While the impacts of climate change on coastal areas is of prime concern to Antigua and Barbuda, there is also concern that climate change will affect fishery resources and fishing activity in the waters surrounding the islands. The fishery sector comprises the biophysical production system for all types of fishery resources located within the Exclusive Economic Zone (EEZ), the harvesting subsector, and consumers of fishery products, including exporters and the tourism sector.

An assessment of the climatic impacts on Antigua and Barbuda's fisheries was made largely through inference, as there was no time-series data available for a quantitative assessment. There was, however, some empirical data relating to the effects of storms on the harvesting sector, but it relies to a large extent on expert opinion. Given the general lack of data, a precautionary approach to managing the various components of the fishery sector was considered most advisable, until better information is available.

Key Point: It is difficult to distinguish climate-induced impacts on the fishery sector from changes resulting from exploitation. Given the lack of data, a precautionary approach to fisheries management is recommended.

The most difficult aspect of detecting climate-induced impacts on the fishery sector of Antigua and Barbuda lies in distinguishing climate related changes from changes resulting from exploitation. All significant fishery resources found in the waters of Antigua and Barbuda are exploited, and in several cases overexploited. Thus, there are likely to be visible declining trends in the abundance of some stocks.

Antigua and Barbuda's EEZ covers an area of 110,071 km^2. However, the majority of fishing takes place on the Antigua and Barbuda Shelf, which encompasses an area of 3,400 km^2. The fisheries of Antigua and Barbuda are based on a wide variety of demersal and pelagic resources. Demersal resources are found primarily in association with the Antigua and Barbuda Shelf. They include spiny lobster, conch, shallow reef fishes, and deep reef fishes. Pelagic resources are found on the shelf, at the shelf edge, and in the oceanic regions of the EEZ.

Aside from estimates of potential yield, there are no good estimates of the current status of the fishery resources of Antigua and Barbuda. Uncertainty regarding trends and the current status of fishery resources in Antigua and Barbuda makes it difficult to establish a baseline against which to evaluate possible impacts due to climate change, even with future monitoring. The status of many pelagic fishes, on the other hand, is assessed by the International Commission for the Conservation of Atlantic Tunas (ICCAT). ICCAT studies indicate that most major species are at or near full exploitation. An assessment of the impact of climate change on those resources would require the input of ICCAT data.

The planned development of institutionalized fisheries began in Antigua and Barbuda during the 1950s. Prior to this time, fisheries were administered on an *ad hoc* basis, as fishing was not considered an activity important to economic development. Nevertheless, the relative importance of the fishing industry increased as Antigua and Barbuda experienced a contraction in its agricultural sector during the late 1950s and a growth in tourism.

There are currently about 650 fishermen in Antigua and Barbuda, operating about 355 vessels. Most fishing efforts target the demersal resources located on the shelf areas, whereas very few pursue the pelagic resources that are available seasonally in the EEZ. The fishing industry provides employment for fish purchasers and vendors who sell to consumers and distribute to restaurants, most of which serve the tourism industry. There are also several exporters of fish, lobster, and conch. The gross total revenue from the fishery sector was estimated at USD 27,320,717 in 1995. Of this, 66.4% was value added by export, local sales by middlemen, and restaurant sales.

Recreational fishing, particularly from charter boats, contributes to the value of Antigua and Barbuda's fishery sector. There are about 20 charter cruisers available to visitors for deep-sea fishing, and they could potentially contribute about USD 960,000 to the economy every year.

The only wharf and landing facility in Antigua and Barbuda is located in the St. John’s area. As a result, land-based activities for the fishing industry are centered in St. John’s. However, the shallow waters adjacent to the wharf and the inadequate market facilities impede further fisheries development, forcing fishermen and marketers to operate their businesses under extremely inadequate conditions. The government of Antigua and Barbuda intends to develop fisheries, largely through the construction of a new fish landing facility to provide better conditions for the landing and marketing of fishery products. It also plans to explore the potential development of pelagic fisheries in the EEZ to the northeast of the island shelf.

Under the climate change scenarios used in the fisheries sectoral study, atmospheric and sea surface temperatures are expected to rise by about 1.5ºC by the year 2075, with an accompanying sea level rise of about 20 cm. Some sources suggest that there will also be an amplification of the seasonal cycle of surface winds. This is likely to result in changes in sea surface currents at various scales, and in sea surface conditions. Finally, the frequency of hurricanes, tropical storms, and their progenitors (tropical waves and depressions) is likely to increase. There may also be an increase in hurricane intensity.

Many large pelagic species, which migrate throughout the Caribbean region and beyond, are likely to compensate for climate change by adjusting their migratory routes and distribution patterns. The issue of concern to Antigua and Barbuda lies in the availability of these species in local waters under climate change conditions.

Most fishery resources of importance to Antigua and Barbuda have early life history (ELH) stages (egg and larvae) that drift in the plankton. Once the young leave the plankton, some use coastal habitats such as mangrove ponds and seagrass beds as juveniles, before moving on to their adult habitats. Consequently, any impacts on the habitats in which they spend their early life may affect the numbers and sizes of recruits that survive to enter the fishery. The implications of climate change for coastal zones were discussed above. In addition, any changes in coastal circulation, either wind-driven or due to changes in large-scale ocean currents impacting on shelf topography, may affect recruitment.

Temperature increases are likely to result in increased growth and mortality of most fishery resources. The extent of these changes could be explored by comparing growth and mortality data for the major species at locations within their ranges with different mean temperatures. The data for such a comparison, however, is limited to species such as spiny lobster, conch, and a few common reef fishes such as red hind or coney.

In addition to potential impacts on biomass and production of fisheries, the availability of fish stock may be affected by climatic change. Availability can be defined as the proportion of the resource that is vulnerable to the fishing gear or method. Availability may change independently of the abundance of the resource. Climate change and variability may affect the availability of fish by altering the distribution of the resource, or by changing the way that they interact with the fishing gear. Evidence shows that weather has considerable influence on the availability of the major demersal resources of the island shelf. Changes in the weather, particularly in the seasonal cycle, are likely to affect availability of these resources to fishermen (Gallegos, Czitrom, Zavala, & Fernandez, 1993).

The impacts of climate change on the harvesting sector can be considered from two perspectives: those that affect revenues, and those that affect fishing costs. If climate change affects the amount of effort that can be expended each year, then the total annual revenue per vessel will change accordingly, as will revenue for the industry overall. Fishing activity is typically curtailed in the first two to three months of the year, when high winds prevail, or during the passage of storms in hurricane season, from July to October. If climate change results in an intensification of the seasonal cycle of winds, then there would be an increase in the number of days during which vessels would be forced to stay in port. This would result in a short-term reduction in catch per vessel. However, in the longer term, a reduction in fishing effort may lead to stock recovery for those resources that may be overexploited, and consequently to increased catch per unit effort and increased total landings, even from a reduced effort.

Inputs and costs related to fishing could also be affected by an intensification of the seasonal cycle, and by any increase in the frequency of storms. Harsher weather conditions in the windy season increase traveling times to fishing grounds, increase fuel costs because of rough seas, increase labor costs because of the working conditions, and increase maintenance costs because of damage of the vessel, equipment, and fishing gear. In fact, destruction of fish traps during the windy season is one of the main costs attributable to weather.

Storm and hurricane damage has a major impact on the fishing industry. About 16% of the total fleet was either destroyed or lost as a result of Hurricane Luis, and another 18% was damaged. In addition to the cost of replacement and repair to fishing vessels and gear caused by a hurricane, there is a loss of revenue due to disruption of the fishing industry. The Fisheries Division and FAO together estimated a recovery period of about 6 months for Hurricane Luis. After this hurricane, many individuals who were unemployed due to the closure of hotels and businesses sought short-term employment in fishing. Most of this short-term effort was probably directed at already overexploited nearshore areas. Thus the immediate response to hurricanes may lead to further overexploitation of nearshore resources.

To address the expectation of increased winds, and thus of generally worse sea conditions for fishing, a program to increase the sea worthiness of fishing vessels is recommended. It was also deemed advisable to encourage the high proportion of fishermen with small vessels to invest in larger vessels with the fullest range of safety equipment feasible for the size of boat. This latter adaptation can be considered autonomous, but might require support from government agencies.

To adapt to the effects of increased tropical storms, mooring sites should be provided for large vessels, particularly in the protected areas afforded by mangroves. Provisions should also be made for facilities for removal of vessels of all sizes from the sea to sites above the reach of the storm surge, including the means to secure them against wind damage. Trap loss can be minimized if vessels are sufficiently large and safe to retrieve traps when storm conditions are imminent. The impact of trap loss on fish and lobster resources through ghost fishing can be reduced by introducing biodegradable escape panels that open after about a week, allowing the animals to escape.

The effects of climate change on marine ecosystems cannot easily be mitigated by engineering measures. The better the quantity and quality of important coastal habitats, the less likely it will be that climate change will affect them and the fisheries that depend upon them. Nevertheless, given the vulnerability of coastal habitats to both anthropogenic actions and climate change, it may be useful to consider the development of pelagic fisheries in Antigua and Barbuda. Due to the seasonal nature of pelagic resources, it would be necessary to use multipurpose vessels that could be used to catch demersal fishes in the off-season. The strategy should aim for the replacement of existing smaller vessels with larger vessels, rather than to add to the fleet and exert additional pressure on demersal resources.

2.7 Agricultural Sector

The population of Antigua and Barbuda depends greatly on fresh fruit and vegetables for proper nutrition. Although agriculture presently contributes a small percentage (4%) to the gross domestic product (GDP), the government is seeking to increase this percentage in the future. As a net importer of food, Antigua and Barbuda's food supply patterns may be affected both in terms of price and availability if climate change affects global food production. There is also the possibility that climate change could have direct effects on the agricultural sector. To assess the potential impacts, a vulnerability matrix was constructed for the crop, forestry, and livestock sub-sectors.

Key Point: Antigua and Barbuda is a net importer of food, thus changes in the global food supply and prices will have a relatively greater impact than the direct effects of climate change on agriculture.

Antigua has seven broad categories of land classes, ranging from land that can be easily cultivated to bare rock and flooded land. Antigua's main crops include eggplant, carrot, cabbage, onion, sweet pepper, pumpkin, yams, sweet potato, tomato, and squash. Most of the produce is consumed locally, although sea island cotton is grown for export to Japan and elsewhere. Some of the vegetables and tree crops are sold to hotels.

National forests dominate the forestry sector, but contribute very little to the island's economy. Forestry in Antigua and Barbuda is, however, considered important from a watershed protection standpoint. The competing fuelwood industry must also be considered, as should the growing interest in ecotourism. Increases in temperature are expected to result in a high "drying-out" rate of the potential fuel of grassland and forested areas. Over the last decade, it is estimated that an average of 346 ha was consumed annually by wild fires. Whenever forested areas are severely damaged by wild fires, species of a lesser quality often invade to take the place of valuable tree species. In the case of Wallings and the greater Body Ponds Watershed, citronella grass has been taking over wooded areas at a rapid rate, thereby reducing the actual area under forest cover.

Livestock include cattle, small ruminants, poultry, and pigs. Livestock production in Antigua is characterized as a low-input and low-output system in which growth of the herd represents the main priority. As a result, livestock numbers have increased significantly, to the point where overgrazing has become a problem. Many of the cattle and small ruminants graze on rough pasture that is communal land, often on former sugar estates. All livestock production is consumed locally.

Increased concentrations of atmospheric CO_2 may benefit all crops and pasture, to some extent. However, increased temperatures and higher potential evapotranspiration rates can be expected to adversely affect tree crops and corn. A sea level rise would have little direct effect on agriculture, livestock, and forestry. Exceptions are the tree crops whose roots extend into water tables that could become saline. Wetter conditions would be beneficial to most crops and trees, although some water logging could also be expected. Drier conditions, on the other hand, would be detrimental, unless irrigation water is made available.

For the livestock sector, climate change is likely to result in a shortage of forage and feeds, water shortages, increased effects of pests and diseases, damage to sheltered animals, damage to or loss of housing, stress conditions, loss of productivity and production, loss of income, and loss of investment. Nevertheless, most of Antigua and Barbuda’s livestock are hardy tropical breeds and crosses that can withstand high temperatures and dry conditions, thus cattle, sheep, and goats are expected to fare well under climate change conditions.

To analyze the impacts of climate change on crop yields, a simple water balance and crop-climate model was run, superimposing incremental changes in temperature and precipitation on crop growth. The model, CropWat version 5.7, was developed by the Food and Agricultural Organization (FAO). It was used to run sensitivity analyses on several crops that show potential for future development within the agricultural sector, including cotton, onion, vegetables and pasture. Data input requirements included monthly average minimum and maximum temperatures, relative humidity, wind, solar radiation and precipitation, as well as future temperature and precipitation values. Complete climate data were only available for the airport meteorological station, but that is considered broadly representative for the whole island.

The climatic data were used to calculate potential evapotranspiration (PE) based on the FAO’s modified Penman-Monteith formula. Crop coefficients reflect different water requirements for different stages of crop growth. The simulation was set with an initial planting date that determined the start of the growing season. The monthly balance between crop water requirements and available water was then calculated. The difference between the plant's water requirements and the amount that it actually uses, limited by rainfall and soil water storage, was used to calculate the percentage reduction in optimal yield associated with water stress.

Scenarios of climate change were based on average temperature increases of 1.25ºC by 2075, along with +/- 10% and 20% precipitation. These changes were then scaled down to the year 2050. Temperature and precipitation parameters were varied accordingly in the models, and the resulting effects on crop yields were analyzed. Planting dates and soil types were also altered to examine the effects of various adaptations on crop yields. The scenarios focus on mean changes and do not reflect changes in extremes, including the frequency of droughts or hurricanes.

All simulations were for rainfed agriculture. Output from the model included the actual water used by the crop, the amount of water the crop could have used if it had been available, the amount of irrigation water that could have been beneficially used, and the reduction in yield due to water stress. The resulting simulations (see Table 2.6) indicate that crops are not significantly affected by a change in temperature alone. However, if temperature increases and precipitation decreases, then there is a corresponding decrease in seasonal yields for all crops. Changing the planting dates did provide an effective means to cope with water stress. For example, when the planting date for onion was moved forward to the second week in August, there was a notable improvement in yields.

The modeling study described above did not consider changes in temperature and precipitation extremes. Yet climatic extremes are likely to have a significant impact on the agricultural sector of Antigua and Barbuda. The effects of drought are extremely harsh on crops. When drought occurs, plant growth virtually comes to a halt and the country appears parched. Only a few deep-rooted and salt-tolerant species such as mango (*Mangifera indica*), coconut (*Cocos nucifera*) and acacias (*Acacia sp.*) are not affected by drought. The most widespread damage to croplands from drought usually takes the form of soil erosion and leaching. Lack of rain and overgrazing of pastures result in the erosion of large bare areas by wind.

Droughts also have a large impact on the livestock sector. Impacts from the 1983/1984 and 1993/1994 droughts included loss of body weight, a high percentage increase in both external and internal parasites, an increase in diseases, low fertility and reproductive rates for males and females, late maturation of offspring, and an increase in calf mortality. At the other extreme, heavy rainfall can also be very damaging to agriculture. The large amount of rainfall (280 mm or more) that may accompany thunderstorms can result in waterlogged soils, a decrease in aerobic activity, and a loss of soil microbia. High-intensity rainfall also saturates the soil and causes drainage and waterways to erode the banks and floors. Silting along waterways impedes drainage after the storm has passed, thereby increasing the possibility of future flooding. The effective storage potential of surface reservoirs and ponds is also reduced.

Hurricane force winds and rains prove to be destructive to most species of vegetables. In addition to the loss of actual crops, infrastructure such as farm buildings are often damaged. In the absence of crop insurance, which presently does not exist for the agricultural sector, complete or heavy crop losses make infrastructure replacement very difficult or impossible. The livestock sector can also be devastated by a severe storm. Poultry and small ruminants are often victims of the high winds and intense wetting. They may die, or be severely stressed and go into prolonged molt. In the latter case, poultry will either stop producing eggs, or reduce output significantly. In the aftermath of Hurricane Luis, the most affected livestock farmers were small and resource poor. Farm losses of XCD 43.00 per bird were incurred, and a significant amount of stored feed and medication was lost. Investment capital was also eroded, which adversely affected the farmer's ability to support family and meet other financial obligations.

Several actions are routinely taken by farmers to cope with present effects of droughts and hurricanes. Some farmers have switched to higher yielding varieties, or used hot season varieties during hot and dry periods. Others have invested in drip irrigation, greenhouse technology, or water storage devices, such as mini dams and ponds. Finally, some farmers have prepared land earlier, in order to avoid having fallow land in the hurricane season that is vulnerable to soil erosion.

From the perspective of adaptation, the study identified an urgent need to develop a comprehensive cross-sectoral water policy, which would include the use of water for agriculture. At the same time, the introduction of drought tolerant varieties in Antigua and Barbuda should be investigated, along with the possibilities for mulching irrigation. For the livestock sector, a reduction in the number of animals per hectare can be considered a possible adaptation to long-term climate change. Development of high-protein fodder as well as additional storage for fodder was also identified as a potential adaptation to drought.

2.8 Water Resources

Irrigation was mentioned as an adaptation strategy for Antigua and Barbuda's agricultural sector to cope with decreased precipitation and an increased frequency of drought. Yet water is not an abundant resource on the two islands, and agriculture is not considered a priority in the allotment of water. In fact, the quality and quantity of water supplies in Antigua and Barbuda is already an important environmental issue. Overall freshwater availability in Antigua and Barbuda is currently in the order of 380 m^3 per person per year. This is significantly below the threshold for water stress and scarcity. Furthermore, water is an expensive commodity in Antigua and Barbuda, compared to most other countries.

The provision of a safe and sufficient water supply already represents an important challenge for the country. Consequently, the quantity and quality of water supplies in Antigua and Barbuda are particularly vulnerable to any reduction in availability. The water resources sector examined the impacts of climate change on the national hydrological cycle and water resource availability, as well as impacts on the economics of water supply and demand. It also considered adaptation measures to increase the country's preparedness to meet future scenarios of water availability.

The national water distribution system forms a major input into vital sectors of the economy, including tourism and agriculture. It also contributes to public health and the general welfare of the population. The expansion of tourism and an increase in construction activities has led to more intensive land use and pollution, which in turn have affected watersheds, largely through increased erosion and siltation. The contemporary water resource issues that apply to Antigua and Barbuda include the following:

- Water resource scarcity
- High seasonal and interannual rainfall variability
- High exposure of watersheds to stress and pollution
- Inadequate reservoir design and catchment management
- High risk and vulnerability to floods and droughts
- Sharing of water between sectors

Lack of a legal and institutional framework for water resource management provides a summary of the current water resources and water supply and demand situation in Antigua and Barbuda. It should be noted that the tourism sector is the largest industrial consumer of water, at 0.8 million m^3 per year, while the desalination units account for approximately 62% of the total water supply.

Water demand projections can only be carried out with some degree of certainty for ten-year intervals up to the year 2020, because of the lack of socioeconomic projections beyond that year. Two scenarios for future water development can be considered: Under Scenario 1, there is no development of additional surface and groundwater resources in the future. The increase in water demand will be covered exclusively by desalinated water. Under Scenario 2, a doubling of surface and groundwater supplies is expected toward the year 2020. Desalinated water will be used only to cover any shortfalls in demand. The estimated water production costs under the two scenarios are indicated in Table 2.9.

The water resource situation in Antigua and Barbuda is already dominated by the supply of desalinated water, and unless substantial investments are made in new reservoir and treatment capacity for surface and groundwater resources, then Scenario 1 is more likely to prevail. If Scenario 2 were to be pursued, surface and groundwater would account for more than 50% of the total water supply.

Based on forecasts of water production costs and revenues generated from water sales, it is considered economically advantageous to try and gain added supply from deep wells and surface storage. Scenario 2 would provide annual savings of USD 2.6 million in comparison to Scenario 1. However, given that the frequency of droughts may increase in Antigua and Barbuda, it is considered imperative to maintain some functional desalination units to effectively manage future risks.

Water demand projections are driven primarily by population and economic growth rates. The highest increase is related to the development of the tourist sector. Water demand is forecasted to reach 5,800,000 m^3 by 2020. The combined inputs of groundwater, surface water, and desalinated water are expected to meet this demand. The challenge facing the Antigua Public Utilities Authority (APUA) will be to reduce overhead production costs, without sacrificing water quality and quantity.

The assessment of climate change impacts considered the three major sources of water in Antigua and Barbuda: surface water, groundwater; and desalinated water. These three sources supply the national water distribution system and contribute to the vital economic sectors of the economy. In addition, rainwater harvesting at the household level is an important source of drinking water for the majority of the population.

Table 2.6 Yield reduction under rainfed conditions at Coolidge (clay soil conditions).

Crop	Planting date	Output	Base	2050 (T = +1.03 °C)				
				-13.75%P	-6.875%P	Temp +1.03°C	+6.875%P	+13.75%P
Onion	Sep-23	Actual water use (mm)	445	429	440	452	462	471
		Potential water use (mm)	526	550	550	550	550	550
		Actual irrigation reqt (mm)	132	171	160	150	138	145
		Cumulative reduction in yield (%)	24.4	35.1	31.7	28.2	25.3	22.5
	08-Oct	Actual water use (mm)	555	560	566	567	567	567
		Potential water use (mm)	561	574	574	574	574	574
		Actual irrigation reqt (mm)	31	56	45	38	31	44
		Cumulative reduction in yield (%)	2.8	5	3.1	2.8	2.8	2.8
Vegetable	Sep-23	Actual water use (mm)	364	366	373	376	376	376
		Potential water use (mm)	366	379	379	379	379	379
		Actual irrigation reqt (mm)	22	51	39	30	21	24
		Cumulative reduction in yield (%)	3	18.2	7.6	3.3	2.9	2.9
	08-Oct	Actual water use (mm)	413	393	406	415	420	421
		Potential water use (mm)	424	425	425	425	425	425
		Actual irrigation reqt (mm)	24	56	32	23	15	15
		Cumulative reduction in yield (%)	8.7	20.5	13.2	7.8	4.3	3.6
Cotton	Sep-23	Actual water use (mm)	510	486	499	514	529	542
		Potential water use (mm)	653	685	685	685	685	685
		Actual irrigation reqt (mm)	275	330	316	303	286	288
		Cumulative reduction in yield (%)	28.5	36.0	34.1	31.7	29.4	27.3
	07-Oct	Actual water use (mm)	697	710	710	710	710	710
		Potential water use (mm)	697	710	710	710	710	710
		Actual irrigation reqt (mm)	23	99	63	35	21	16
		Cumulative reduction in yield (%)	0.0	0.0	0.0	0.0	0.0	0.0
Pasture	Sep-23	Actual water use (mm)	1095	998	1047	1100	1146	1194
		Potential water use (mm)	1773	1797	1797	1797	1797	1797
		Actual irrigation reqt (mm)	731	855	803	749	698	659
		Cumulative reduction in yield (%)	86.3	92.0	89.9	87.2	84.5	81.4
	08-Oct	Actual water use (mm)	1152	1032	1098	1157	1195	1233
		Potential water use (mm)	1773	1797	1797	1797	1797	1797
		Actual irrigation reqt (mm)	695	842	774	714	670	645
		Cumulative reduction in yield (%)	86.0	92.0	89.6	86.8	84.4	81.7

Table 2.7 Current water resources and water supply and demand situation

Descriptive Statistics	
Population of Antigua	65,000
Population of Barbuda	1,200
Area of Antigua	277 km^2
Area of Barbuda	160 km^2
Annual precipitation in Antigua and Barbuda	1000 mm

Water Resources	**Mill. m^3**
Existing Storage Capacity of Surface Water	7.4
Potential Storage Capacity of Surface Water	8.7
Total storage capacity/yield surface water	16.1

Renewable Water Resources	**Mill. m^3/yr**
Total surface water yield (10% of precipitation in watersheds)	12.9
Groundwater yield	1.5
Desalination capacity	18.3
Per capita renewable water resources	281.5

Water Supply by Source	**Mill. m^3/yr**
Groundwater (APUA)	0.6
Surface water	0.9
Rainwater harvest – private (estimated)	0.1
Surface water – private dams (estimated)	0.1
Desalinated water (APUA)	2.8
Total water production average, 1993-96	4.6

Water Consumption by Sector	**Mill. m^3/yr**
Domestic water supplied by APUA	1.4
Rainwater harvesting – private (estimated)	0.1
Commercial and hotels (APUA)	0.8
Government (APUA)	0.1
Agriculture (APUA)	0.1
Agriculture – private dams	0.1
APUA	0.0
Unaccounted for water – physical and commercial (APUA)	1.9
Total water supply – average, 1993-94	4.6

APUA = Antigua Public Utilities Authority

Table 2.8 Prediction of water production cost (million USD/year).

Water Source	**1996**		**2000**		**2010**		**2020**	
	Scen.1	Scen.2	Scen.1	Scen.2.	Scen.1	Scen.2	Scen.1	Scen.2
Ground	1.60	1.60	1.60	2.00	1.60	2.50	1.60	3.00
surface	2.60	2.60	2.60	3.60	2.60	4.50	2.60	5.40
desalination	13.16	13.29	12.22	9.72	13.63	9.86	17.39	12.14
Total production cost (mill USD/yr)	17.36	17.49	16.42	15.32	17.83	16.86	21.59	20.54
Average production cost (USD per m^3)	4.24	4.24	4.22	4.02	4.25	3.87	4.33	3.86

Note: Scenario 1 assumes constant surface and groundwater supply and Scenario 2 assumes a doubling of the surface and groundwater supply towards the year 2020.

Antigua has been divided into 86 watersheds that follow natural drainage boundaries. In 1985, these were aggregated into 13 watersheds by the Natural Resource Assessment Project of the Organization of the American States (OAS). Six of the thirteen watersheds have been identified as major catchments, based on socioeconomic and agro-ecological conditions. Within these major watersheds, there are important catchments that channel water to major reservoirs.

The six major watersheds cover 43% of the island's area and contain approximately 70% of Antigua's population, 80% of the groundwater supplies, and 90% of the surface water supplies. They also correspond to the main centers for economic activity. The situation in Barbuda is quite different. An arid island with no perennial surface streams and only a few seasonal lakes and inland depressions, its main source of water supply is groundwater, which is becoming increasingly saline.

Reservoirs are the main hydraulic structures in flood control and storage of water for supply over long periods. Antigua has about 10 small to medium reservoirs, and about 550 ponds and earth dams. The total combined capacity of all reservoirs, ponds, and mini-dams is approximately six million cubic meters. The water in reservoirs is characterized by high turbidity and bacteriological contamination. Due to the low quality of the surface water from the reservoirs, water is fully treated at mechanical-chemical treatment plants before it is distributed.

The total reservoir storage capacity is only equivalent to about one year's water demand, and is therefore dependent on full annual replenishment to avoid shortages. Relatively small changes in temperature and precipitation, together with the cumulative effects on evapotranspiration and soil moisture, can result in relatively large reductions in runoff due to the combined effects of decreased precipitation and increased evapotranspiration. On the other hand, more intense rainfall would increase runoff and the risk of flash flooding. Preliminary observations suggest that high intensity rainfall conditions are more favorable when it comes to the filling of reservoirs than more evenly distributed rainfall.

There are two desalination systems in Antigua, located at Crabbs Peninsula. One of the plants is government owned and produces 7575 m^3 per day through the process of flash distillation. The heat that is produced by this process is used to power two generating plants that supply a total of approximately 9.1 MW of electricity to the national grid. The other desalination plant, which is currently privately owned under a BOT system (Buy, Operate, and Transfer ownership to government), uses the reverse osmosis technique to supply approximately 3030 m^3 of water daily to the national water supply. This water requires further treatment to reduce the corrosion of pipes.

Harvesting of rainwater contributes an important source of safe drinking water to households and is universally practiced throughout Antigua and Barbuda. The process of collecting rainwater is based on gutters that collect water from roofs, where it is then channeled into holding tanks. Rainwater is soft and contains minor amounts of salts or minerals, and thus is considered useful for domestic and irrigation use. It is, of course, important that the collection and storage system is hygienic and well maintained. By law, all new houses are to be equipped with rainwater collection and storage systems. The average size of storage containers is 200 m^3.

A number of methods can be applied in the assessment of consequences of climate change for the water resources sector. The selection of a method must take into consideration the limited data on the hydrological characteristics of Antigua and Barbuda, as well as the limited availability of data for quantitative assessments of impacts.

Key Point: If rainfall increases as a result of climate change, reservoir capacity will have to be increased to satisfy growing demands for water. If rainfall decreases, the production of desalinated water will have to increase. In any case, the price of water is likely to increase in Antigua and Barbuda under climate change.

One approach to describing watershed recharge and runoff patterns is to calculate the water balance of the storage reservoirs over certain periods of time in selected reference watersheds. The method calls for calculation of monthly streamflows on the basis of rainfall data, reservoir records and pertinent water production figures, in order to make rainfall-runoff correlation plots. One of the shortcomings of the water balance model is that it is based on average monthly data. It does not take into account daily or hourly precipitation events, which would affect evapotranspiration and the response of the watershed to extreme rainfall inputs. The estimation of the effect of climate change on water resources will depend on the ability to relate changes in actual evapotranspiration to predicted changes in precipitation and potential evapotranspiration.

Since Antigua and Barbuda is located in a single hydro-climatic zone, a single basin approach can be used in the study. Two watersheds were selected as reference areas for the analysis: Potworks and Creekside. The Potworks watershed provides more than 90% of the island's surface water supply. It is located in the southern part of the central plain region of Antigua. It encompasses 2,600 hectares of drainage area, which supplies the Potworks and Collins Reservoirs. The watershed is sparsely covered with vegetation. Most of the watershed is pasture and agricultural land, and only 5% is inhabited. The land adjacent to the Potworks Reservoir is dedicated to large-scale agriculture, which has raised concern about silting and organic and bacteriological contamination. The Creekside watershed is second largest, and displays a low reservoir capacity to run-off ratio. It encompasses a drainage area of 780 hectares.

Monthly rainfall data, reservoir volume and water abstraction from the Potworks Dam were analyzed for 1994, 1995 and 1996. A time-line analysis of rainfall and water volume shows that the filling of the reservoir seems to depend not only on the amount of rainfall during the peak months, but also on the distribution of that rainfall. The study stresses the importance of daily rainfall distribution and intensity in the filling of reservoirs, and suggests that it should be considered together with annual rainfall when assessing drought and water scarcity.

By using a simple mass balance, the losses from the dam were estimated. It was found that approximately three times the outflow of water supply to the APUA and agriculture was lost during a six-month period. In fact, only about 10% of the rain in a catchment area will be utilized for water supply.

Lack of adequate freshwater resources will have to be addressed by developing more surface and groundwater supply capacity, or increasing the production of desalinated water. Either of these actions will lead to increased water costs. The differences between water production costs and water revenues show that piped water is already a subsidized commodity. It remains to be seen whether consumers will be forced to pay the real cost of water in the future. It is more likely that the existing differentiated tariff structure will be maintained, whereby certain consumer groups have to pay a higher price for water.

Options for coping with the possible impacts of climate change and increased uncertainty about future supply and demand for freshwater include the following:

- More efficient management of existing supplies and infrastructure
- Institutional arrangements to limit future demands
- Promoting conservation
- Improving monitoring and forecasting systems for floods and droughts
- Rehabilitation of watersheds
- Construction of new reservoir capacity to capture and store excess flows
- Construction of deep wells

The APUA has plans to develop supply systems to satisfy the growing demands for water. These plans include increasing the supply capacity by constructing new reservoirs and rehabilitating existing ones. There are also plans to install a desalination plant in Barbuda and to explore deep aquifers. The water division is also in the process of automating the pumping stations as well as the water levels in holding tanks. This will allow the national water transmission and distribution network to function more efficiently and provide a more reliable supply to consumers. Finally, the APUA has initiated a comprehensive program to reduce the high portion of water that is unaccounted for, which currently amounts to about 40% of total supplies.

Due to Antigua's small landmass and its increasing demands for water, the expansion of reservoir capacity is likely to decline in the future. The feasibility of constructing more dam capacity to meet future requirements for flood control and water supply should, nevertheless, be investigated. Given the limited possibilities for increasing the storage capacity of surface water in Antigua and Barbuda, there is a strong possibility that the country will become more dependent on freshwater from desalination of seawater or saline groundwater. The desalination process is rather expensive, and this high water cost will prohibit its use for irrigation unless the supply is subsidized.

At present, the desalination process costs the APUA approximately USD 4.70 per cubic meter of water produced. In addition to the energy consumed in the desalination process, brackish water is discharged back into the local coastal environment, thereby affecting marine life. Such impacts can be minimized with an appropriately designed desalination plant. The selection of desalination technology is also an important issue. The flash distillation technique results in much lower residual flows and offers the advantage of energy recovery. The membrane filtration technology results in a small freshwater flow compared to the total raw water consumption. This could lead to a rapid deterioration of adjacent groundwater reserves through saltwater intrusion.

Another adaptation option to consider is the import of water to Antigua and Barbuda. This involves the physical transportation of water from one location to another by sea, using barges, tanks or plastic bags. The storage tanks for this operation must be cleaned and maintained regularly to prevent water contamination. During the drought of 1982/1983, approximately 20 million gallons of water were imported from regional islands. However, this option proved to be very expensive over prolonged periods. To barge and land water from the island of Dominica to Antigua cost approximately US$20 per 1000 gallons. This experience was a driving force behind the government's investment in a desalination plant in 1987.

Disadvantages to importing water include high transportation costs and slow journeys; the effects of bad weather, which can affect shipping; reduced water quality from leaks in the tanks; and transport and distribution requirements once at port in Antigua. New technology involving the towing of water in large 100,000 m^3 plastic bags is now being developed as an alternative to the more expensive transport in barges or tankers.

Water conservation options at the household level include the following:

- Installing a displacement device that reduces the water a toilet tank will hold
- Using low-flow faucets
- Allowing lawns to grow one to two inches
- Irrigating lawns in the evening
- Washing vehicles with water in buckets

Harvested rain may contain impurities from the atmosphere, as well as from animal droppings. As a result, the quality must be monitored regularly. As an adaptation strategy, the government may consider offering incentives to the public to construct larger holding tanks, so that the additional water can be used during dry spells.

The scarcity of water resources and intensifying competition for clean water demand an integrated water resource management initiative. This would be one of the most important actions to meet the water sector challenges caused by the current climate variations as well as the possible impacts of future climate change. The study team proposed a Water Resource Management Action Program to mobilize to carry out the following objectives:

- Mobilize and build capacity within public and private sector for cross-sectoral water resources management
- Analyze the legal and regulatory framework related to water resources
- Build public awareness related to the challenges and opportunities in the management of water resources
- Ensure participation of civil society as stakeholders in water resources management
- Develop appropriate water resources monitoring systems and information services
- Review and analyze key issues constraining effective water resource management, bringing international expertise when necessary

2.9 Human Health

The study identified climate change as a major threat to human health, particularly if it results in increased temperatures, droughts, and extreme weather events such as hurricanes. Health impacts can be either direct or indirect, through food, water, or waste management. Heat-related health phenomena usually result from extreme heat events, and not from trends in average temperatures. In fact, humans can be expected to acclimatize to gradual and long-term temperature increases. Direct heat-related impacts of increased temperature extremes include heat stroke, dehydration, respiratory diseases, and cardiovascular deaths. These are likely to disproportionately affect vulnerable groups of the population, namely the young and the elderly.

Changes in precipitation patterns may affect the availability of water for consumption and other domestic and agricultural uses. Flooding may lead to the biological contamination of water sources and an expansion of the habitat for vectors like the *Aedes aegypti* mosquito, which transmits dengue fever. Droughts, on the other hand, may lead to shortages of water, forcing populations to use unsafe source of water for drinking and other purposes. This results in an increased risk of the transmission of diseases such as cholera, typhoid, bacterial dysentery, and parasitic diseases such as schistosomiasis.

Extreme weather events such as hurricanes present direct threats in terms of human mortality and morbidity, and greater threats to public health infrastructure. Hurricane Luis caused extensive damage to Antigua's main hospital and most of the clinics and health centers.

There have been no recent outbreaks of vector-borne illnesses in Antigua and Barbuda. There is constant surveillance to prevent the importation of malaria. However, dengue is endemic in the Caribbean. The vector of dengue and yellow fever, the *Aides aegypti* mosquito, is present on the island, threatening the country with disease outbreaks. The vector control program of the Ministry of Health focuses on the control and eradication of mosquitoes. Fogging, community education, inspection, treatment, and the provision of larvae-eating fish for water storage facilities comprise a technical approach to the control and eradication program.

A cholera plan has been prepared for Antigua and Barbuda and is presently in force. No cases have been identified in Antigua to date. There is increased surveillance on wastewater and sewage disposal systems. The open drains in the city that guide overflow into the sea are a major concern, and regular washing and cleaning is done to prevent the system from backing up.

There is much concern over existing liquid waste management. Local and international consultants are presently developing a project for a central system for St. John's. Sixty to sixty-five percent of the population is still served from septic tanks and soakways. The bulk of the remainder is served by pit latrines, and less than 250 homes on the city outskirts are served by pail closets, which are removed by the night soil service of the Central Board of Health. The Holberton Hospital and most of the coastal hotels are served by private sewage plants.

The Holberton Hospital is the only public acute care health institution. Consequently, it is central to the health system. General and specialized services are provided in medicine, surgery, obstetrics and gynecology, pediatrics, radiology, and pathology. In addition, consultants in the private sector or from overseas provide services in otorhinolaryngology, ophthalmology, orthopedics, neurology, and radiology. The hospital was damaged in the 1995 hurricane, reducing the number of beds from 200 in 1991 to 135 after 1995. This has led to situations of overcrowding, and it is not uncommon for occupancy rates to be over 90% at peak times. The government of Antigua and Barbuda plans to build a 200-bed acute hospital to replace the existing facility.

Community health services are provided through a network of nine health centers and eighteen satellite clinics or sub-centers linked to the health centers. There is a fairly even distribution of community health services across Antigua and Barbuda. Health care is financed through public taxation or levies to a Medical Benefit Scheme, a contributory scheme in which all employed persons and persons suffering from a list of chronic diseases are beneficiaries. The participation of private insurance in the financing of health care is still minimal. In 1996, health expenditures represented 13 % of the country's recurrent budget, or USD 14.89 million.

The process of ecologically-based risk assessment was applied to the study, as described in the UNEP handbook. Of the ten tropical vector-borne diseases listed in the UNEP handbook, only four were found to be of concern to Antigua and Barbuda. These were malaria, dengue, yellow fever, and to a lesser extent, schistosomiasis. All of these diseases are expected to show an increased distribution as a result of climate change (see Table 2.9). However, the handbook also stresses that it is the current health problems that are likely to be exacerbated by climate change. Since neither malaria, yellow fever, nor schistosomiasis is currently a health problem, they were eliminated from the study. Dengue, on the other hand, is a serious concern in Antigua and Barbuda, thus the implications of climate change on transmission rates are important to consider.

Table 2.9 Tropical vector-borne diseases

Disease	Relevance to Antigua and Barbuda	Possible change of distribution as a result of climate change
Malaria	+	+++
Schistosomiasis	+/-	++
Dengue	+++	+
Yellow fever	+/-	+
Lymphatic filiariases	None	+
African trypanosomiasis	None	+
Leishmaniases	None	+
Onchocerciasis	None	++
American trypanosomiasis	None	+

Legend:
+/- potentially significant
+ significant
++ very significant
+++ extremely significant

Dengue-like illness has been reported in the Americas for over 200 years. Until the 1960s, most dengue outbreaks occurred at intervals of one or more decades, but thereafter the intervals have shortened. The last major outbreak in Antigua and Barbuda was in 1981, when 77 cases were identified. The potential for dengue transmission is dependent on the population of the *Aedes aegypti* mosquito, as measured by the *Aedes* household infestation index and a number of other factors related to temperature and precipitation.

Aedes aegypti is a tropical and subtropical species of mosquito with a distribution focused between 35°N. and 35°S. latitude, corresponding to a winter isotherm of 10°C. It is primarily a domestic species, infesting human-made or natural containers found in or near human dwellings. The mosquito is rarely found farther than 100 meters from houses.

The dengue virus persists through a human-*Aedes aegypti*-human transmission cycle. Following an infective blood meal, the mosquito can transmit the agent after a period of 8-12 days of extrinsic incubation. In addition, mechanical transmission can occur when feeding is interrupted and the mosquito immediately feeds on a nearby susceptible host. Infection may be asymptomatic or may lead to undifferentiated fever, dengue fever, or dengue hemorraghic fever. The incubation period lasts 4-6 days.

Key Point: Dengue is considered the only tropical vector-borne disease to be of concern in Antigua and Barbuda. Fortunately, the country already has the technology and manpower necessary to adapt to changes in the transmission rates under climate change.

The female mosquito lays eggs that are attached singly to the inside surface of containers in the damp area just above the water surface. Embryonic development is usually completed within 48 hours if the environment is warm and humid. Once embryonic development is complete, the eggs can withstand long periods of desiccation, sometimes more than one year. The capacity of the eggs to withstand drying is one of the greatest obstacles to eradication. Eggs can be transported over great distances in dry containers. Elimination of adults and larvae from a locality during rainy months does not prevent re-infestation by recently flooded eggs that had been hidden in dry containers.

There is a close relationship between human settlements and proximity to water in all areas of Antigua. Most houses have cisterns or above-ground tanks for water storage, as many new communities have not been provided with piped water. This encourages water storage, which provides breeding habitat for the *Aedes aegypti* mosquito and other vectors, along with many other types of bacteria.

The social determinants of dengue risk include high human population densities and unplanned urbanization. Houses that are not screened, blocked rain gutters, and uncovered water storage tanks create habitats for the mosquitoes, as do inadequate systems for collecting and storing solid waste, discarded tires, and small containers with less than 50 liters of water.

Studies in Mexico showed that the most important risk factor at the household level was the number of potential breeding sites per premise. At the community level, the most significant risk factors were the mean temperature during the rainy season, the proportion of houses with larvae, and the proportion of houses with uncovered water containers.

The level of *Aedes aegypti* infestation is usually indicated by three indices: the house index (the percentage of houses infected with larvae); the container index (the percentage of water holding containers infested with larvae or pupae); and the Breteau index (the number of positive containers per 100 houses inspected). An analysis of the relationship between the house index and various climate parameters revealed no significant correlations, even when a lag time of thirteen weeks between climate phenomena and the potential transmission was considered. The lack of a relationship can possibly be attributed to adaptive interventions of health authorities.

Various models have been developed by specialists with substantial knowledge of dengue and the biology and control of its vectors (Focks, Haile, Daniels, & Mount, 1993a; Focks, Haile, Daniels, & Mount, 1993b). In the case of dengue, the relationship between temperature and model parameters is based on the well-validated mosquito simulation model (CIMSim) (Focks et al., 1993a; Focks et al., 1993b) and the accompanying dengue transmission model (DENSim). These models, which combine the influence of temperature on adult mosquito survival with biological variables, have accurately predicted dengue transmission.

The epidemic potential model was run using several scenarios of temperature changes: baseline, +1ºC, +2ºC, and +4ºC. Although the model was run with inadequate data, results indicated that the transmission of dengue was dependent upon both temperature and precipitation. However, the epidemic potential also apprears to increase as a result of temperature increases alone.

The technology, manpower and knowledge needed to undertake adaptation strategies against the transmission of dengue under potential climate change are presently available in Antigua and Barbuda. There is good access to the media, adequate transportation to cover and investigate a relatively small area, and most citizens have the economic ability to meet the relatively low cost of simple prevention methods. Nevertheless, the Antigua government must ensure the availability of piped water in new housing developments, as this will reduce the population's dependence on stored water, which serves as breeding sites for mosquitoes. In addition, services for early diagnosis and better epidemiological surveillance will enhance the ability to study the incidence and geographical distribution of the disease, thus enabling more accurate predictions of outbreaks.

2.10 Adaptation Strategies

The previous sections illustrate that a small island state like Antigua and Barbuda is vulnerable to many aspects of climate change, and that the small size of the country imposes physical, economic, and geographical constraints that limit options for adaptation.

Some commentators have suggested that existing impacts from non-climate factors on the marine and terrestrial environments have already weakened the ability of Caribbean societies to cope with impacts emanating from global climate (Maul, 1993). It is therefore important, from a policy perspective, to view climate change as exacerbating environmental changes already taking place. In many instances, the development and modernization process have heightened vulnerability by resulting in non-sustainable alterations to terrestrial and coastal environments.

Recommendations for adaptation responses presented in the Antigua and Barbuda country study are targeted primarily at decision-makers, with the intention of providing practical measures for promoting enhanced awareness of measures that can be pursued within the framework of sustainable development. Adaptation responses should satisfy several criteria, according to Sarma (1991): flexibility to suit a range of likely impacts; feasibility given political, socioeconomic and institutional realities; satisfaction of environmental impact considerations; and economically affordable. Adaptation measures should also be directed at providing policy-makers with enhanced data and information on changes in local and regional climate.

For small island states such as Antigua and Barbuda, response options to climate change impacts may vary depending on existing conditions within individual areas. According to the IPCC Common Methodology and Technical Guidelines, four basic options may be taken: Do Nothing, Retreat, Accommodate, or Protect. Each strategy can be categorized as either short-term or long-term, depending on its application.

All of the responses identified in the study can be considered "win/win" responses, in that they are measures that are valid and necessary even in the absence of climate change. The first set of adaptation responses seeks to strenthen the institutional capacity of Antigua and Barbuda to respond to the impacts of climate change. For example, one adaptation strategy is to address the weak and underdeveloped land-use development control and physical planning functions in Antigua and Barbuda, including the preparation of a comprehensive national physical development plan and a review and upgrading of physical planning laws and regulations. The preparation and implementation of a water resources management plan was also recommended to address the impacts of climate change on an already critical situation for freshwater supply and availability. Likewise, the implementation of a coastal area management program aimed at improving technical capabilities for fisheries management was recommended, as was the formulation and adoption of a public health policy on climate change, especially for dengue and other vector-borne diseases.

Key Point: Insurance and reinsurance play an important role in the economic development of Antigua and Barbuda. Insurance reforms can help to promote measures that reduce climate vulnerability.

A second set of responses addresses the need for improved management and conservation efforts in relation to climate change. For coastal resources, adaptation responses seek to strike a balance between economic growth and reduction in vulnerability, in a manner that promotes the sustainability of Antigua and Barbuda's coastal and marine environments. They include the establishment and implementation of a policy for coastal development setbacks, technical and economic assessments of beach enrichment programs, strengthening institutional capacity for coastal resources management, and the development and expansion of beach and coastal monitoring programs. For water resources, measures to protect upper watershed catchments against construction and other human encroachments were recommended, and for fisheries, the conservation, restoration and enhancement of mangroves, seagrass beds and coral reefs were deemed important.

To reduce vulnerability to increased weather extremes, a recommendation was made to modify farming practices through the use of drip irrigation technologies, improved field drainage, selection of drought tolerant species, and improved shelter or housing for livestock. For the fisheries sector, modernization and upgrading of on-shore moorings and storage facilities was recommended, as well as measures to promote greater sea worthiness and safety for fishing vessels.

Disaster risk levels in Antigua and Barbuda have increased in recent decades, as development on the islands has intensified. Factors that have contributed to this increase in vulnerability include shifts from traditional Caribbean architectural practices and materials to more vulnerable forms of construction. Extensive deforestation and the improper development of coastal and beach-front sites have also contributed to increased levels of risk. To strengthen the capacity to manage natural disasters in the context of climate change, the study recommends upgrading the role of sectoral and community level disaster management and strengthening key agencies that deal with disaster management. It also recommends improving the telecommunications system (particularly radio) so that it can provide links to disaster communications.

In Antigua and Barbuda, insurance and reinsurance are important cornerstones of the economic development process. However, as in other Caribbean countries, access to insurance is being increasingly restricted in Antigua and Barbuda, as global reinsurance companies reduce the level of coverage available, particularly to vulnerable coastal properties. Among the problems confronting the insurance sector in the Caribbean are its weak capital structure, the existence of a large number of entities providing insurance, and a weak regulatory and supervisory capability.

A regional working group appointed with the task of studying the insurance industry in the Caribbean came up with the following recommendations for the insurance industry, which are relevant within the context of climate change adaptation strategies:

- Develop public awareness activities aimed at sensitizing insurance policy-holders to risk reductions and mitigation options for their properties, including more proactive measures in promoting vulnerability reduction.
- Discriminatory premium pricing by insurance companies based on vulnerability reduction and risk assessment, including the use of hazard and risk mapping tools as well as enforcement of building codes and other development control procedures.
- Collaboration between government and the insurance industry to identify practical mechanisms to expand availability and affordability of catastrophe insurance to vulnerable communities and groups that are traditionally excluded from insurance markets (e.g. fisherman and farmers, low-income households).

Adaptation options were screened in order to assist in evaluating the various proposals against the objectives identified for the country study, identifying any potential constraints to effective implementation, and in prioritizing areas for action. The screening was limited by the lack of detailed costs associated with different adaptation recommendations. The exercise showed that all of the identified sectoral recommendations are practical and should be pursued. Nevertheless, two principal activities were identified as priorities: 1) establishment of a national climate-change coordinating structure with an intersectoral composition, and 2) a strengthened physical planning and development control system.

The implementation of most of the adaptation options identified in the study requires or would be facilitated through external bilateral and/or multilateral assistance. To extend access to available external sources of technical and financial assistance, it was suggested that Antigua and Barbuda develop a portfolio of climate change adaptation projects.

The climate change scenarios projected for Antigua and Barbuda would have severe consequences for continued efforts at sustainable development. This comes against a background of existing vulnerabilities – environmental, economic, and political – that small island states such as Antigua and Barbuda are already confronted with. Uncertainties in relation to the science of climate change makes it difficult to identify appropriate responses and suggests that recommended strategies should address existing priority concerns for enhancing sustainable development and reducing vulnerability.

3 Cameroon

The climate change impact and adaptation assessment for Cameroon began in September 1996, and was conducted by a team of national experts under the coordination of Roger Tonleu at the Climate Change Unit of the Ministry of the Environment and Forestry (MINEF). A copy of the full report can be obtained from the Climate Change Unit, Ministry of the Environment and Forestry, Yaounde, Cameroon.

Source:CIA World Factbook (1999)

3.1 Introduction

Cameroon is located on the Gulf of Guinea in Central Africa. It lies between 1°40' and 13°05' north latitude and between 8°30' and 16°10' east longitude. With a surface area of 475,412 km^2, it has an extremely diversified landscape, including a variety of climatic and geomorphologic zones. The four major ecological zones of Cameroon include a tropical forest zone; a coastal and maritime zone; a savannah zone; and a Sudano-Sahelian zone. The climate of Cameroon is equatorial humid in the south, tropical in the Sahelian region, and dry in the far north.

Cameroon consists of a narrow, low-lying coastal plain that is adjacent to high plateaus in the west, center, and south. The Far North province consists of a low-lying plain. The main watershed of Cameroon is on the Adamaua plateau, which feeds four major river basins. The main rivers of Cameroon are the Logone in the Chad basin, the Benoue in the Niger basin, the Sanaga in the Atlantic basin, and the Sangha in the Congo basin.

The population of Cameroon was estimated to be 13 million in 1995. This represented a 2.9% annual growth rate from the 10.5 million inhabitants that were recorded in the 1987 census. The population density varies greatly over the territory, with an average of 30 people per km^2. Rapid population growth has affected resources, including arable land, food supplies, water and energy.

According to the 1987 census, 49% of the Cameroon population over 15 years old are illiterate. The provinces in the North and Far North have the highest illiteracy rates in the country, estimated at over 70%. About 45% of the population live in the urban areas of Cameroon. The urban population tends to be more educated than the rural population.

Cameroon has a fairly diversified economic base, and is a net exporter of oil. Although oil production has declined in recent years, it stood at seven million metric tons in 1991/1992. Cameroon exports a wide range of other commodities, including coffee, cocoa, bananas, natural rubber, palm oil, timber, and aluminum. With the exception of aluminum, most manufacturing activity is targeted at the domestic market. Fuel wood remains the most common source of energy, followed by gas, electricity, and kerosene.

The economy of Cameroon grew steadily from 1970 to 1977, and rapidly from 1978 to 1986. Economic growth in the 1970s, which reached about 5% per year in real terms, was fueled by the agricultural and agro-industrial sectors. Between 1970 and 1986, per capita GDP increased from 51,000 to 395,000 FCFA (1 FCFA equals approximately USD 0.00014). However, after 1986 the economy collapsed. Between 1986 and 1993, per capita GDP declined by an average of 6.3% per year, falling to 301,000 FCFA by 1990. Unemployment has been increasing in Cameroon as a result of the economic crisis. The level of poverty has risen as well, and health and education expenditures have been cut.

Since 1988, Cameroon has been undergoing a Structural Adjustment Program (SAP), supported by the World Bank and the International Monetary Fund. The SAP emphasizes economic liberalization, with a limited role for the state in favor of the private sector, along with a heavy reliance on markets and increased competition and efficiency to reduce domestic costs and prices. Since 1994, there has been evidence of a slow economic recovery.

The sectoral contributions to GDP have remained fairly stable over the past decades, with the primary sector contributing about one-third, the secondary sector contributing just over 20%, and the tertiary sector contributing over 40%. Agriculture, stockbreeding, fishing, hunting, and silviculture are the main activities of the working population in rural areas. Manufacturing and industries, commerce and services, transport and communications, and administration and banking are the dominant economic activities of the urban population.

The approach adopted in this country case study was based on the UNEP Handbook on Methods for Climate Change Impact and Adaptation Strategies (UNEP, 1996), with some minor modifications. These modifications were related to data quality and availability as well as to the accessibility and applicability of suggested models. The Cameroon study team selected the IPCC scenario referred to as "IS92a" (the "business-as-usual" scenario) as a basis for evaluating climate impacts. This medium scenario is based on World Bank global population projections of 10 billion people in 2050 and 11.3 billion in 2100. It assumes a continued heavy reliance on fossil fuels, despite a decrease in energy intensity. Coal consumption is projected to increase significantly by the year 2100. This scenario was adopted because it has been widely used in other country studies, and would thus facilitate comparisons. Time constraints were also a consideration in deciding not to examine other emission scenarios.

Two regions of the country were selected for the impacts and adaptations assessment: The coastal zone of Cameroon, which is its most densely populated area, and the Sudano-Sahelian zone, which is the region most affected by extreme events, including droughts and floods.

3.2 Climate Change Scenarios

The climate of Cameroon varies across its diverse terrain, from tropical along the coast to semi-arid in the north. The climate is influenced by the trade winds of both hemispheres, with one system or the other predominating, depending on season and location. North of 6°N latitude, the "Harmattan" winds dominate from November to March, with winds from a N-NW direction. From April to October the Atlantic Monsoon dominates, with winds from a S-SW direction. In the southern part of the country, below 6°N latitude, the Atlantic Monsoon circulation dominates year-round, but with frequent incursions of the "Harmattan" from January to March. Very strong winds are infrequently experienced in Cameroon, and when they do occur, they tend to be easterly. In a study of wind speed and direction in Cameroon over a ten-year period, the highest observed speed was 50 m/s (180 km/h). One-third of the measuring stations showed no observation above 25 m/s.

The mean annual temperature is determined by many factors, including latitude and elevation. The highest temperatures are found in the north, where clear skies lead to strong heating during the day and strong radiative cooling at night, resulting in high average temperatures and a high diurnal temperature range. Solar radiation varies little during the year in the southern part of the country, due to the persistent presence of clouds. The lowest temperatures are experienced in the mountainous west, the Adamaua, and the South Cameroon plateaux.

Monsoon circulation is the main source of precipitation in Cameroon. The coastal areas of the south receive the most rainfall, with annual totals reaching 3850 mm or more. There is a strong west-east rainfall gradient reflecting the rising topography and the depletion of moist oceanic air. Above 7°N latitude, annual rainfall averages between 600 and 1500 mm. In recent years, repeated droughts in northern Cameroon have made people aware of the possible effects of climate variability and change.

To explore the implications of climate change for Cameroon, the study team used the results from a simple climate model developed at the Climate Research Unit at the University of East Anglia. The model, called MAGICC, was used to project mean global temperature and sea level rise (Hulme, Raper, & Wigley, 1995b). Using the IPCC IS92a emission scenario, MAGICC (version 2.3) generated projections of mean global temperature and sea level rise to the year 2100. The projected mean temperatures and sea level rise are shown in Table 3.1. The global sea level rise was used for the Cameroon coastal zone without further corrections, since coastal subsidence due to groundwater or oil pumping is known to be negligible.

Table 3.1 Projected mean global temperature increases and sea level rise from 1990 levels based on the IPCC IS92a emission scenario using MAGICC

Year	Temperature increase from 1990 levels (C°)			Sea level rise from 1990 levels (cm)		
	Low	Mid	High	Low	Mid	High
2025	0.3	0.5	0.6	3.3	9.3	19.4
2050	0.6	0.9	1.3	7.4	19.8	38.6
2075	1.0	1.4	2.1	13.0	33.5	61.0
2100	1.4	2.0	2.9	19.8	48.9	85.9

Regional climate change scenarios were generated with SCENGEN software. SCENGEN enables the extraction of results from both simple models and general circulation models. Combining the extracted results with observed regional climatologies, SCENGEN produces geographically explicit climate change scenarios. The scenarios stored in SCENGEN are patterns of monthly mean changes of different variables per 1°C increase in temperature. These patterns are scaled up by the transient global mean temperature changes obtained from MAGICC, which use greenhouse gas emission scenarios as a starting point. One of the strengths of SCENGEN is that a large number of model outputs can be used to generate scenarios, and these scenarios can then be compared.

The land surface of Cameroon spans across eight 2.5° x 2.5° grid cells in SCENGEN. The results from two grids were averaged to obtain scenarios for the coastal zone of Cameroon; likewise two grids were averaged to represent the results from the Sudano-Sahelian zone. The results from three GCMs were compared: UKTR, ECHAMTR, and HADCM, using different assumptions regarding model sensitivity (high, middle, and low).

For the coastal zone, average changes in annual temperatures by 2100 ranges from 1.5°C to 4.5°C, depending on climate sensitivity (see Table 3.2). These compare with the results from MAGICC, which show potential temperature increases of 1.58°C to 3.33°C, with a mid-value of 2.31°C. For precipitation changes, the GCM results fall within present-day variability, thus no dramatic changes are expected. This compares to small positive changes generated by MAGICC, ranging from a 4% to an 8% increase, depending on climate sensitivity. However, changes in year-to-year variability and seasonal shifts in rainfall can produce more profound impacts that are not captured in the annual changes.

Temperature increases are higher in northern Cameroon, where the three GCMs project increases of 2.0°C to 6.0°C by 2100 (Table 3.3). These can be compared with MAGICC results ranging from 2.13°C to 4.53°C. Precipitation changes are also likely to be more dramatic in the Sudano-Sahelian zone, with the ECHAMTR model projecting a 100% increase assuming high climate sensitivity, and the other models projecting smaller increases. The study team also considered the results from two additional GCMs that project rainfall decreases in the Sudano-Sahelian zone.

These scenarios were used as the basis for impact assessments on different sectors. In general, they indicate that no dramatic changes are expected to occur in mean precipitation along the coastal zone, but that some important changes might occur in the Far North province. Sea level rise is expected to have large impacts on the coastal city of Douala. The sectoral assessments used a variety of methods, including expert judgement, historical analogues, and mathematical models.

Table 3.2 Projected annual temperature and rainfall changes for the coastal zone based on the IS92a emission scenario

Time Horizon	Climate Sensitivity	Annual Temperature Rise (°C, from 1990 levels)			Annual Rainfall Change (%, from 1990 levels)		
	GCMs	HADCM	UKTR	ECHAMTR	HADCM	UKTR	ECHAMTR
2025	High	1.3	1.0	1.2	4.2	2.4	-3.5
	Mid	1.0	0.6	0.9	3.2	1.2	-2.3
	Low	0.6	0.4	0.6	2.5	1.7	-1.6
2050	High	2.4	1.6	2.2	7.9	4.2	-6
	Mid	1.7	1.2	1.6	5.6	3	-2.8
	Low	1.1	0.8	1.1	3.9	2	-4.1
2100	High	4.5	3.1	4.2	15	8	-11
	Mid	3.1	2.1	2.9	10	5.5	-7.5
	Low	2.1	1.5	2.0	7	3.7	-5

HADCM = Hadley Center, UK
UKTR = UK Meteorological Office, transient
ECHAMTR = European Center, Hamburg, transient

Table 3.3 Projected annual temperature and rainfall changes for the northern region based on the IS92a emission scenario

Time Horizon	Climate Sensitivity	Annual Temperature Rise (°C, from 1990 levels)			Annual Rainfall Change (%, from 1990 levels)		
	GCMs	HADCM	UKTR	ECHAMTR	HADCM	UKTR	ECHAMTR
2025	High	1.8	1.3	1.3	1	7	30
	Mid	1.3	1	0.9	0.7	5	21.7
	Low	0.9	0.7	0.6	0.5	3.9	15
2050	High	2.4	1.6	2.2	1.9	12.5	53.4
	Mid	1.7	1.2	1.6	1.3	8.9	38
	Low	1.1	0.8	1.1	0.9	6.2	26
2100	High	6	4.5	4.2	3.4	23.3	100
	Mid	4.2	3.1	2.9	2.4	16.2	69.4
	Low	2.8	3.1	2.0	1.6	11	47.4

3.3 Baseline Scenarios

A descriptive approach and tables were used to assess the economic and demographic trends in Cameroon. The population of the study areas was projected up to the year 2100. According to the World Bank, the population growth rate should stabilize at 1% around the year 2045. Projections show the population of Cameroon to be 25.7 million by the year 2050. Of these, 3.2 million will be in the coastal zone, and 3.6 million in the Sudano-Sahelian region. Using a 4%

economic growth scenario, GDP is expected to rise from FCFA 877 billion in 2000 to FCFA 6,235 billion in 2050.

At the national level, the volume of trade and services will increase with population. Although tourism is likely to become an important economic activity in the Sudano-Sahelian zone, agriculture and livestock will continue to be the major economic activities up to 2100. In the coastal zone, little expansion is expected for agriculture, but its intensification is likely to lead to increased production.

Key Point: The rapid urbanization of Douala has led to an expansion of settlements into areas that are considered to be vulnerable to climate change and sea level rise

The population of wild animals in Cameroon's Waza National Park is expected to increase throughout the period to 2100. This is assuming that other factors that influence animal populations remain constant. These other factors include the availability of forage and water, the rate of reproduction, intensity of poaching, migration of species, and frequency of epidemics.

To determine the economic value of non-marketable goods, such as mangrove ecosystems, an approach based on the willingness of individuals to pay was used. This is an indirect approach to valuing resources that are not traded in markets. A model was used to determine the GDP at risk, and the present value of potential GDP or economic output that will be at risk in the case of future climate changes. The years under consideration include 2000, 2010, 2020, 2035, and 2100. However, because of large uncertainties, long-term projections may have little practical meaning.

3.4 Coastal Zone

The coast of Cameroon is 360 km long, and is the most populated area of the country. Situated along the Gulf of Guinea, it covers an area of 9,671 km^2. It extends from the Rio del Rey estuary (4º 40' N) to Campo (2º 3' N). Physically, the coast is made up of sandy and rocky beaches, sand dunes, mud and sand flats, rocky cliffs, lagoons, and extensive mangroves. For the country study, the city of Douala was chosen for an assessment of climate impacts on infrastructure. In addition, a sectoral study of the impacts of climate change on mangroves was carried out in the coastal zone.

The coastal zone is under the influence of monsoon circulation for most of the year. The rainy season extends from March to November, followed by a short dry period. Annual rainfall totals are generally high, ranging from 4000 mm in Douala to 8000 mm at Debuncha. Temperatures are also high and steady, averaging between 24ºC and 27ºC. The mean annual humidity is about 83%.

The majority of the 2.5 million inhabitants of the coastal zone are concentrated in major towns such as Douala, Edea, Limbe, Tiko, and Kribi. In fact, the coastal area has the highest population density in the country, with 132.6 inhabitants per km^2. Seventy percent of national industries, including extensive agro-industrial plantations, are also located in the coastal zone.

Douala, the largest city in Cameroon and the principal center of economic development, is situated on one of the major sedimentary basins along the coastal plains of Cameroon. It lies along the banks of the River Wouri, at a distance of about 40 km from the Atlantic Ocean. The city of Douala has a population of 1.5 million, and is the main port for the import and export of goods. It also serves the needs of neighboring land-locked countries, such as Chad and the Central African Republic. The rapid growth of Douala has led to the urbanization of low-lying areas that are threatened by inundation and erosion. The city's highly populated and industrialized areas, including the seaport, its wharf, and the airport, are located at elevations of no more than 10 meters, making them vulnerable to a sea level rise associated with climate change.

The physical infrastructure of Douala consists of roads, bridges, buildings, and port facilities. There are an estimated 376 km of paved roads in Douala, and 560 km of earth roads in the city. The Seaport is vital to the economy of Douala. It currently costs FCFA 2 billion per year to dredge the port to a depth of 6.5 meters.

There are three main types of land use in the coastal area: agriculture, human occupation, and industries. Land dedicated to urban use expanded from 2,750 ha in 1970 to 10,030 ha in 1992. Most of this land has been used for housing. Development has been most rapid in the low-lying plains, which are known to be highly vulnerable to floods. In 1990, the total population of these areas was estimated at 382,000, or about 41% of the Douala population. The majority of the population in this area can be characterized as low-income.

The main estuaries of the Cameroon coast are covered with mangrove ecosystems. Mangroves, which occur at the zone of mixing of salt water and fresh water, have important environmental and ecological values, and provide significant benefits to local and national economies. The area is a feeding and nursery ground for fish species that account for more than 90% of national fisheries production. The mangroves also constitute a natural protection against coastal erosion. Towns that are located at the fringe of mangrove forests, such as Douala and Tiko, benefit from this natural protection.

The Cameroon estuary mangrove and its adjacent coastal waters play a major role in the country's fishery activities. Industrial fishing is estimated to be worth FCFA 38.16 billion at current market prices. However, industrial fishing is capturing its maximum sustainable yield, and any further increases in fishing are likely to have negative long-term impacts on fishery stocks.

Artisanal fishing takes place within two nautical miles of the shore, as well as within the mangrove zone. In 1993, the annual catch was estimated at 65,000 tons, with shrimp accounting for over 15 % of the catch. Ethmalosa and Sardinella, known locally as "bonga" and "strong kanda," are the dominant species, accounting for nearly 70 % of the catch.

Mangrove forests are being harvested for wood for fuel and construction. Some of the forests are removed to allow for agricultural expansion, as land becomes scarce. Sand mining is also modifying mangrove ecosystems. In short, mangroves are under increasing pressure in coastal Cameroon, and climate change is likely to exert an additional stress on these important ecosystems.

3.5 Sudano-Sahelian Zone

The Sudano-Sahelian zone of Cameroon lies in the semi-arid tropical region of sub-Saharan Africa. This zone of 102,068 km2 includes the ecological regions of the Mandara Hills, the plains of the Far North and the Benue Valley. It also includes the Waza-Logone wetlands, locally called yaéré or "dry season pasture." After seasonal floods subside, a rich cover of perennial weeds develops. Herdsmen from Cameroon, Chad, Central African Republic, and Nigeria use these areas for pasture. For the country study, the Far North province was selected as the exposure unit for the health sub-sector, and the Waza-Logone flood plains were chosen for the biodiversity sub-sector.

The Sudano-Sahelian zone has a population of 2,2240,000 (1995), and an average population density of 53.5 inhabitants per km^2. The main towns are Maroua, Yagoua, and Kousseri. Twenty-three percent of the land is dedicated to agriculture, and 9% is held in national parks. The principal food crops include millet, sorghum, maize, okra, groundnuts and pumpkins. The most important cash crops are rice and cotton. Over 35% of the national's livestock is found in the Sudano-Sahelian region. Livestock, especially cattle, is used as a store of wealth, and nomadic herdsmen migrate over long distances with cattle in search of pasture. Tourism is seen as potentially one of the most important economic activities of the Sudano-Sahelian zones, given its picturesque landscape and diverse flora and fauna.

Key Point: The Sudano-Sahelian zone is the poorest region of Cameroon, and subject to epidemic diseases and health care challenges that are likely to be exacerbated by climate change.

The poverty index in this region is the highest in the country. Epidemic diseases are very common, including bacterial meningitis, cholera, and yellow fever. Although health care coverage has improved since independence in 1960, access to health care remains difficult in rural areas. The health situation is exacerbated by climatic factors, along with difficulty accessing safe water and the low educational status of women. The economic crisis has also affected the health situation in the Sudano-Sahelian zone. For example, the devaluation of the FCFA has had an impact on the cost of health-care commodities.

The climate of the Sudano-Sahelian zone is characterized by a short rainy season lasting from June to October, and a dry season that can last up to 9 months. Annual rainfalls vary from 500 mm to 900 mm. The mean annual temperature is 28ºC, but can reach up to 40ºC during the dry season. Annual rainfalls are low and unevenly distributed. The Sudano-Sahelian zone is covered by a dense network of seasonal streams and rivers, along with a few permanent ones. Most small ponds and temporary rivers (*mayos*) disappear a few months after the rains stop. The vegetation consists of shrubs on soils of sand and clay. The grasslands of this region are scorched by the dry season heat. In the most severely affected areas, only occasional clumps of grass subsist. The major ecological problem in the zone is the constant threat of desertification, characterized by a scarcity of trees and water. High population pressure, inefficient management of rural soils, soil degradation, irrational exploitation of water resources, inefficient management of protected areas, and overexploitation of fishery resources are also threats to the environment in the Sudano-Sahelian zone of Cameroon.

The Waza-Logone flood plains are situated between 10ºN and 12ºN, on the Maroua-Kousseri road. With a total surface area of 2,400 km^2, it is one of the most unique ecosystems of the Sahel region. The plains stretch over a distance of about 200 km from north to south. They reach a width of 40 km towards the north, and narrow to no more than 20 km in the south.

Approximately 130,000 people live on these prairies, but there are significant seasonal migrations.

The Waza-Logone is characterized by quasi-permanent availability of water, arable farmland, and a diverse flora and fauna. During the dry season, nearly 200,000 animals migrate to the region from Cameroon, Niger, Nigeria, and Chad. In fact, the Waza-Logone flood plains have been identified as a RAMSAR wetland site for migratory birds. The Waza National Park, a UNESCO biosphere reserve, is also located in this area. This park has an area of 170,000 ha, consisting of uneven plains ranging in elevation from 300 to 320 meters. It was created in 1934 as a hunting reserve, upgraded to a national park in 1968, and declared a biosphere reserve in 1979. Wildlife in the park is rich and varied.

The vegetation of the Waza-Logone flood plains consist of submerged grasses. The dominant species are *Echinochloa pyramidalis*, *Vetivera nigritania*, *Orriza barthii,* and *Hyparrhenia rufa Anthropic*. The significant volume of hydrophilic vegetation, combined with contributions of organic and mineral matter of animal origin, give these waters a nutritional richness. They serve as spawning grounds for most of the fish in the Logone, Chari, and Lake Chad.

An artificial retention lake, the Maga, is located on the upper part of the flood plain. It covers 39,000 hectares, and is a zone of significant hydrobiological production. However, it also contributes to the desiccation of yaérés located below the lake. Fish production, estimated at 2,300 metric tons/year, has been decreasing considerably as a result of this desiccation.

The Sudano-Sahelian zone could be especially at risk from extended dry periods that could result from climate change. Higher temperatures would affect agriculture and water supplies, as well as human and animal populations. In fact, the scarcity of water in the Sudano-Sahelian zone is already a major constraint to local development.

3.6 Mangroves

Intense human development within mangrove ecosystems, coupled with the rapid urbanization of adjacent towns and the excessive utilization of trees for the production of firewood, charcoal, and clearing for agricultural purposes, have led to the gradual degradation of these ecosystems. This degradation is expected to worsen in future years, largely as a result of a climate-change induced sea level rise and salt water intrusion.

The floristic composition of mangroves in Cameroon is dominated by two species of *Rhizophora* (*R. racemosa* and *R. harrisonii*). Nevertheless, all species of West African mangroves are found in Cameroon. Mangrove formations develop in shallow waters and calm areas, and play an important role in the fixation of sediments. Although the terrestrial fauna of mangrove ecosystems has not been well studied, it is known to be diverse, including antelope, birds, crocodiles, and snakes. Mangroves also provide a habitat for many fish species. The diversity of fish species tends to be very high, whereas total biomass is generally low.

The salinity of mangrove creeks is relatively low, but varies with time and location. Keita et al. (1990) reported that salinity on the same day varied between 17.5% and 19.5% at Mabeta, and between 12% and 17.5% at Tiko. The phenomenon of salt water intrusion occurs in all of the rivers of the Cameroon estuary, including the Wouri, the Mungo, and the Dibamba. Cameroon estuary mangroves are subjected to persistent inputs of a range of pollutants from land-based sources, such as petroleum refining, food processing, chemical production, and domestic waste.

Sea level rise will lead to different types of responses in different coastal ecosystems. Increased inundation and erosion are the two main mechanisms by which land can be lost as a result of sea level rise. In the mangroves of the Cameroon estuary, the effects of inundation will be more important than erosion, since the zone is largely dominated by muddy coasts. However, the predicted sea level rise will contribute to an increased efficiency of wave erosion, leading to sediment removal from the upper part of the tidal spectrum and deposition in the lower part. Consequently, the few sandy beaches in the mangrove area could be destroyed.

Increased erosion could also result in the removal of mangrove soils that lie above mean sea level, with subsequent deposition offshore (Ellison, 1992). This would lead to a gradual inland retreat of the mangroves. As the trees recede, more rapid erosion would occur, resulting in the formation of small cliffs in the seaward front. Erosion along the seaward margin of the mangrove would also expose less productive anaerobic soils, leading to a better-oxidized and more productive soil system.

The mangrove environment receives large volumes of allochthonous sediments from inland rivers. If there is a significant increase in rainfall patterns within the river catchment, then vertical accretion of sediment will keep pace with the predicted sea level rise. Currents associated with sea level rise will promote higher sedimentation rates in the mangrove zone.

The IPCC's simple inundation model was used to assess land loss due to inundation. Taking into account the change in sea level and the micro-topography of the mangroves, the mean water level mark corresponding to the selected sea level rise scenarios is shifted inland. The predicted land loss was evaluated for the years 2025, 2050, and 2100. The results of the model indicate that land loss is expected to vary between 4950 ha for a sea level rise of 20 cm and 33,000 ha for a maximum sea level rise of 90 cm.

The assessment of saltwater intrusion in rivers and estuaries was a difficult task due to a scarcity of data. A regression analysis performed on the maximum salinity recorded at Japoma, located along the River Dibanba about 35 km from the estuary, projects an increase in salinity of up to 30%. The present maximum value of salinity in the mangrove zone ranges between 17 and 19% in the dry season. With a projected sea level rise of 86 cm in the year 2100, the intrusion of sea water in the mangroves could bring salinity to 25%, corresponding to a 30% increase. Salinity in the estuary could also reach 25%. A decrease in rainfall would not affect this maximum possible salinity. Increased rainfall could result in a lower change because of increased river discharge.

The Oude Essink model (Oude Essink, 1996) was used to assess the spatial extent of saltwater intrusion in the River Wouri. When the model was run under present conditions, it gave a saltwater wedge of 42 km. This compared favorably with the observed value of 40 km. In 2100, the projected salt water wedge length will range from 39 km (–2.6%) to 67.5 km (+26%) as a result of an increase or decrease in rainfall.

Most toxic metals such as lead, cadmium, zinc, and copper accumulate in mangrove sediments in the form of insoluble sulfides (Harbinson, 1986). Oxidation of waters and sediments resulting from increased erosion from sea level rise would dissociate these sulphides, releasing trace metals. This would pose a threat to the mangroves and other coastal food chains, and represent a considerable health risk through consumption of fish and other resources harvested in the estuary.

Temperature is rarely a limiting factor for plant growth in the equatorial belt. With a projected absolute maximum temperature change of 3.3ºC for Douala in 2100, evapotranspiration would increase, and mangrove plants would have problems with water nutrition. However, a comparison of the distribution of mangrove vegetation in Senegal suggests that temperature increases will not have serious impacts on mangrove distributions in the Cameroon estuary. Nevertheless, plants may experience periods of intense physiological stress when high temperatures combined with full sunlight and prevailing winds give rise to high evapotranspiratoin and increased surface salinity as a result of capillary uptake (FAO, 1994). An increase in sediment temperature will increase the rate of decomposition of litter, leading to higher rates of nutrient recycling and regeneration in the mangrove ecosystem.

The availability of water to mangrove plants and animals depends on the frequency and volume of tidal exchange, freshwater supply, and evaporative demand of the atmosphere. As salinity rises, there is a corresponding increase in the osmotic potential of the intertidal soil water, which makes water uptake by plant roots more difficult. Increased rainfall will bring more nutrients and particulate material to the estuary. At the same time, more agricultural pollutants, including pesticides, herbicides and fertilizers, will be carried into the area from surrounding plantations. On the other hand, an extension of the dry season, combined with increased temperatures, could stress plants longer, and increase soil salinity. This would have a negative effect on forest growth and contribute to decreased natural regeneration through the reduction of propagule production.

Many intertidal mangrove animals adapt to thermal stress by living in burrows, under fallen leaves, and in decaying wood and other special habitats. Mangrove molluscs live close to their thermal stress limits, and a temperature increase of 3ºC might therefore be detrimental to this group (Hong & Chin, 1983). Mangrove gastropods could better accommodate a temperature increase. These species are mainly grazers or predators active at low tides when the mangrove habitat is exposed to air (Berry & Chew, 1973). At extreme temperatures, they use an evaporative cooling mechanism to keep their body temperature at the physiological limit (Lewis, 1963). Consequently, given the moderating influence of shade, the expected temperature increase by 2100 will have no major impact on fauna distribution.

Key Point: Increased rainfall under climate change could lead to a higher shrimp catch, but the benefits will not be realized if the shrimp fishery continues to be over-exploited.

Fluctuations in salinity are an important characteristic of mangrove ecosystems. Surface salinity can drop to zero during the rainy season, and rise to 19% during the dry season. The majority of animals living in this environment are therefore eurhyaline and have osmo-regulatory adaptations to reduce their exposure to salinity. For example, estuarine shrimp (*P. notialis, P. atlantica*) show a large regulatory ability, and they could probably adapt to 35-40% salinity. Consequently, an increase in salinity is not expected to pose a major threat to mangrove fauna.

With respect to coastal fisheries, there is a positive correlation between shrimp catch per unit effort (CPUE) and rainfall (or river discharge). For a rainfall increase of 15%, shrimp productivity (catch) is expected to increase by 14%. However, over-exploitation of the Cameroon fishery, especially demersal stock, could cancel this beneficial effect of climate change. A reduction in rainfall would further reduce shrimp production, exacerbating the decreasing trend caused by over-exploitation (see Table 3.4).

Table 3.4 Projected changes in shrimp catch due to rainfall changes

Expected Catch (Kg/day at sea)								
2025			**2050**			**2100**		
Rainfall Change	CPUE	Change (%)	Rainfall Change	CPUE	Change (%)	Rainfall Change	CPUE	Change (%)
-3.5%	238.5	-3.1	-6%	291	-5.5	-11%	277.5	-9.9
+4.2%	320	+3.9	+8%	331	+7.4	+15%	350.4	13.8

Many studies have documented a direct relationship between estuarine and intertidal areas and fishery harvest. A sea level rise of up to 50 cm results in a small land loss, therefore the extent of the intertidal and estuarine area can be considered unchanged. Above 40 cm, the area lost becomes important, with a negative impact on habitat availability and shrimp yield.

Climate change will have serious socioeconomic impacts on the human population located within the mangrove zone. Indundation due to seal level rise is expected to be a major cause of migration from the zone. At the maximum sea level rise of 90 cm, 38 out of the 72 fishing villages within the mangrove zone will become permanently inundated. An estimated 5900 fishermen and their families would be displaced (see Table 3.5). There will be greater pressure on mangrove trees as more will be cut for the construction of new dwellings. It is expected that inundation and other impacts of climate change will have only a negligible effect on ecological tourism within the mangroves.

Table 3.5 Vulnerability assessment of selected fishing villages in the Cameroon Estuary Mangrove due to sea level rise

Year	SLR (m)	Fishing villages at risk	Number of fishermen (1)	Number of houses	Damage Costs (KFCFA) (2)
2025	0.20	Kange East	279	87	
		Kange West	280	100	
		Cap Cameroon	574	191	
		Accra Kombo	147	55	
		Dengde	37	22	
		Ndongo	212	100	
		Sissio	304	116	
		Mapa	101	51	
		Yoyo I	470	111	
		Yoyo II	197	60	
		Bonanga	217	50	
Total			*2818*	*1009*	*330,050*
2035	0.30	Manoka	152	80	
		Mammy water	10	9	
		Epassi	93	51	
		Ndiguele	26	12	
		Mokake	14	8	
		Creek No. 1	160	62	
		Poka 1	42	21	
		Poka 2	159	35	
		Monkey	150	60	
Total			*806*	*338*	*118,300*
2050	0.40	Toube	150	98	
		Bessoukoudou	13	8	
		Big kombo	130	40	
		Djebale	98	61	
		Mbiako	323	130	
Total			*714*	*337*	*117,950*
2100	0.90	Creek No. 2	22	8	
		Missellele	45	10	
		Mangasamba	46	15	
		Mokota	50	12	
		Small Kombo	27	10	
		Mboko I	96	47	
		Mboko II	61	25	
		Bome I	410	152	
		Bome II	84	27	
		Kombo	125	45	
		Moukanda	267	117	
		Nyanga Kombo	320	112	
		Youpwe	8	15	
Total			*1561*	*595*	*208,250*
Grand total			**5897**	**2213**	**774,550**

(1) Actual population to be moved
(2) Present capital value of future loss

3.7 Coastal Infrastructure

In this study, only the infrastructure of Douala that is considered to be vulnerable to climate change and sea level rise has been considered. The main infrastructure in this zone is associated with oil exploitation, refining and distribution; power generation and distribution; commercial buildings; land, sea, and air transportation; and water treatment and distribution. Vulnerable categories of infrastructure were selected on the basis of the elevation above sea level and susceptibility to inundation and flooding. The areas between contour lines of 0 and 2 meters were identified as particularly vulnerable.

The following areas are considered to be highly vulnerable to flooding and inundation: 1) Houses constructed in low-lying plains such as Deido, Akwa, Bonamoussadi, Bobongo, Youpwe, and Bolnaberi. Akwa-Nord and Deido are at high risk of soil erosion after floods. 2) Industrial zones (IZ) that are dependent on water from aquifers, which has high saline concentrations during dry seasons. The Bonaberi and Bassa industrial zones fall into this category, while Bali-Koumassi is at risk of saltwater intrusion (see Table 3.6).

Table 3.6 Vulnerability of coastal infrastructure and human settlements, based on expert judgment

Risk Zones	Inundation		Erosion		Salt water intrusion
	Sea water	Rain	Sea water	Rain	Ground water
Sea port	xxx	x	xx	x	xx
Airport	xx	xxx	xx	x	x
Bassa IZ		xxx		xx	
Bonaberi IZ	xxx	xx	xxx	xx	xxx
Bali-Koumassi IZ		x		x	xxx
Deido	xx	xx	xxx	xx	x
Akwa-Nord	xxx	xx	x	x	X
BonaMoussadi	xxx	xx	x	x	X
Bobongo	xx	xxx	xx	x	X
Bonaberi	xxx	xxx	xx	xx	Xx

x = low vulnerability
xx = moderate vulnerability
xxx = high vulnerability

Due to its location on a low-lying plain within the Wouri drainage basin, the Douala international airport is at risk from floods induced by a sea level rise, which could be aggravated by sea waves and storms. The airport is now naturally protected by mangroves. However, future developments for housing and infrastructure are likely to destroy these mangroves, increasing vulnerability to climate change.

The vulnerability of coastal infrastructure to saltwater intrusion was assessed with two climate parameters, temperature and rainfall. Changes in these two parameters will have significant implications for water and energy supplies, human settlements, and transport infrastructure. A projected sea level rise of 50 cm in the year 2050 would lead to a total land loss of 12 km^2. This would result in 20,037 houses destroyed and 235,000 persons displaced. Infrastructure worth FCFA 322.1 billion (i.e., USD 463 million) could also be damaged (see Table 3.7).

Table 3.7 Property and infrastructure at risk to inundation due to SLR 10 by 2050

Risk zones	Population at risk	Number of homes at risk	Property at risk (billions of FCFA)			
			Land area (ha)	*Value of land*	*Value of infrastructure*	*Total value*
Deido	5,000	500	2.5	0.13	1.9	2.0
Akwa-Nord	30,000	3,750	100.0	5.0	36.6	41.5
BonaMoussadi	30,000	3,500	150.0	7.5	91.0	98.5
Bobongo	60,000	3,600	200.0	6.0	35.1	41.1
Youpwe	35,000	3,062	50.0	1.5	11.2	12.7
Bonaberi	75,000	5,625	250.0	7.5	146.2	75.0
Total	233,000	20,037	752.5	21.6	322.1	343.7

During the dry months (December to February), an additional 14.9 km of saltwater wedge will intrude into the Dibamba if the sea level rises and precipitation does not change. If rainfall is reduced by 15.5%, the Oudde Essink model shows that the wedge will increase by 32 km. The value of damages to coastal infrastructure was estimated at 756 billion FCFA, or 17% of the national GDP in the 1994/1995 financial year. By the year 2100, these damages will increase to 580,000 people displaced and 39,000 homes destroyed.

3.8 Biodiversity

The projected impacts of climate change on biodiversity were based on analogue studies and expert judgement. The major impacts of climate change in the Waza Logone region are likely to depend more on rainfall, as a progressive change in temperature is not likely to endanger the equilibrium of the ecosystem. Climate projections indicate an increase in tree cover and perennial grass. In fact, trees and perennial grasses have been observed to perform well under high temperatures, if sufficient water is available.

The existence of the yaérés and a good vegetation cover is a direct effect of floods in the plains (Donfack & Boukar, 1997). In the past, the water from the Mandara region flooded the Waza Logone yaérés, which were rich in biodiversity. A rise in water levels has been prevented since the construction of the Maga dam in 1979, which retains all of the water from the Mandara region, and the construction of dikes along the Logone river. Since the Waza-Logone plain became dry, some animal species have migrated to the Benue valley, where conditions are more favorable. There is a risk of serious degradation of the vegetation cover unless measures are taken to restore water to the plain.

Key Point: The destruction of mangroves can increase the vulnerability of infrastructure to sea level rise.

Based on analogue studies, a temperature increase is unlikely to threaten the composition of the region's fauna (Donfack & Boukar, 1997). In addition, an increase in rainfall would improve plant growth, with a positive effect on the fauna. Projections of the fauna population within this area are shown in Table 3.8. Potential negative impacts are associated with extreme events such as droughts and floods.

Table 3.8 Projection of fauna population with climate change

Horizon	2050	2100
Elephants	35,8	64,4
Giraffes	48,3	86,9
Hippopotamus	12,1	21,4
Red-fronted gazelle	3,6	6,2

3.9 Human Health

Climate change could have both direct and indirect impacts on human health in the Sudano-Sahelian zone. Longer lasting and more severe droughts are likely to lead to a higher frequency of heat-related diseases and disorders, an altered distribution of vector-borne diseases, modified water supplies, and modified food production. The transmission of malaria, schistosomiasis, cerebrospinal meningitis, and cholera will be affected.

Changes in disease transmission under scenarios of climate change were based on geographical analysis, ecologically-based risk assessment, and historical and regional analogues. No single approach can predict with certainty the impacts of climate change on human health, given that factors such as literacy rates, education of females, and the undertaking of disease control programs can alter the projected outcome. The projections made by the study team assume that no major disease control programs will be implemented, and that the current trends in health budget allocations will be maintained, including the relative per capita health investments. It was also assumed that there will be no major changes in water supply or sanitation.

Key Point: Drier climate conditions may decrease malaria transmission rates, but the construction of water projects in response to climate change might offset this by providing new breeding ground for the vector.

The lowland regions of the Far North province currently has one of the lowest malaria morbidity rates (2.5%). The rate is higher in the Mayo Danai division and Mandara regions (7.5% – 10%), where water projects such as dams have been developed to support small-scale farming, livestock, and human domestic activities. It appears that droughts may decrease malaria transmission rates. However, given population increases and water demand for human consumption and economic activities, it is likely that more water projects will be constructed in response to climate change. This could increase the vector population and malaria transmission.

Schistosomiasis rates are also presently low in the Far North province. The low prevalence of intestinal schistosomiasis corresponds to high temperatures and low rainfall, as well as the scarcity of permanent water habitats suitable for colonization by the snail host, *Biomphalaria pfeifferi.* As with malaria, the occurrence of schistosomiasis is higher in the Mayo Danai and Mandara regions, where water development projects have been constructed.

For both malaria and schistosomiasis, higher temperatures, when they are below 35°C, shorten the extrinsic incubation period, such that several broods of infective parasites are produced. Under a warming projection of 6°C by the year 2100 (assuming high climate sensitivity), the incidence of malaria will increase as a result of accelerated metabolic processes and nutritional requirements of the vector. It is likely that the vector's biting rate will increase, which in turn will lead to increased egg production, vector population, and malaria transmission potential.

The projections above were based on a theoretical understanding of how vector borne diseases might be affected by changes in climate. However, when linear regression techniques were used, the projections were quite different. By treating temperature and precipitation as independent variables, the study team calculated a projected decrease in the number of cases of malaria by 2100. There is a high degree of uncertainty associated with these projections, and they contradict expert predictions indicating that an increase in temperatures and changes in rainfall patterns accompanied by changes in evaporation and humidity are likely to increase malaria transmission rates. The non-conformity of the results obtained from regression modeling may be related to a statistical bias due to underreporting.

The study team calculated a similar decrease for schistosomiasis. Assuming low climate sensitivity, a temperature increase of 1.5°C accompanied by a precipitation decrease of 10% would lead to a 28% reduction in the incidence of schistosomiasis. In contrast, under a projected 6°C change, it is expected that schistosomiasis will spread southward of its current hyperendemicity zone, following the migration of isotherms. Temperature has an effect on snail reproduction and growth, schistosome cercariae mortality, infectivity, and human–water contact.

Other diseases will also be influenced by climate change. For example, increased frequency of droughts (under a scenario of –10% precipitation) would lead to longer transmission periods for meningococcal meningitis, including increased epidemic potential and a southward spread beyond the current distribution belt. Cases of cholera, on the other hand, are tied to flooding in the lowlands. An increased frequency of flooding (under a scenario of +70% precipitation) would lead to a higher transmission potential for cholera, as sources of drinking water are more likely to be exposed to contamination.

As mentioned above, the projected changes are likely to be influenced by rates of economic growth, social development, population growth, land use changes and the implementation of disease control programs. Furthermore, climate change could have a major impact on water resources and sanitation by reducing the quality and quantity of water supplies. This could reduce the water available for drinking and washing, and lower the efficiency of local sewer systems. This in turn could lead to increased concentrations of pathogenic organisms in water supplies. Water scarcity favors the use of poorer quality water resources, such as rivers, ponds, and unprotected wells, which are often contaminated.

3.10 Adaptation Strategies

Adaptation measures to address the major impacts of climate change included new constructions, increasing public awareness, and sensitization. Adaptations were recommended in relation to institutional, organizational, and legal measures. The economic, financial, technical, cultural, and social aspects of their implementation were also considered.

Adaptive responses to sea level rise seek to protect property and population, and to preserve and restore mangrove biodiversity and water quality, while at the same time securing and improving regional economic development. For mangrove ecosystems, the most important impacts of climate change would result from inundation, rainfall, and salt water intrusion for fisheries and forestry. Inundation alone could significantly affect mangrove-related infrastructure and human settlements. Existing laws on land use, fisheries, and forestry were formulated with economic concerns, without any specific regard for the mangroves themselves. For example, no protected areas have been established in mangrove ecosystems. As a result, bordering towns such as Douala and Tiko are expanding rapidly into mangrove areas. Furthermore, there is no control or supervision of activities taking place within mangrove ecosystems, and implementation of regulations is rare.

The study team identified three categories of response options to the threat of accelerated sea level rise. The first, known as retreat options, includes the creation of a set-back line, within which no building or development activity can take place, and the relocation of housing and infrastructure situated on vulnerable coastal land. Retreat options allow for the natural landward migration of mangroves in response to sea level rise. The second, known as accommodation responses, include changes in housing styles and lifestyles of fishermen. This involves, for example, raising houses to one meter above the highest flood level to avoid inundation. The third category of response options is protection strategies. These include efforts to preserve the present status of infrastructure and development activities. This might involve building dikes with sandbags, or nourishing beaches. Other measures include rain water collection and preservation as a preventative measure against salt water intrusion; injection of fresh water into mangroves from the River Sanaga; reforestation; establishing parks or reserves; and maintaining undeveloped inland areas to which mangroves can retreat.

A number of adaptation strategies were identified for the fisheries sector. These include a reduction of the current catch of *sciaenidae* and shrimp stocks, an increased mesh size of demersal fishing nets and shrimp fishing nets, closed seasons to regulate artisanal fishing, increased control and monitoring of catches, reduced post harvest losses, and the development of aquaculture. This last option is considered to have enormous potential along the coast of Cameroon, but requires that the appropriate technology is available.

Within the forestry sector, adaptation measures included the reforestation of degraded or cleared areas, control and monitoring of timber exploitation, regulation of sand mining, reduction of land-based pollution, and relocation of fishing camps to behind the mangroves.

The policy objectives for management of mangroves and coastal fisheries are to make fisheries sustainable, protect biodiversity, and develop alternatives to present-day artisanal fishing. All of the above adaptation measures for mangrove ecosystems are considered feasible, with no significant barriers to implementation. Sand nourishment, sand bags, injection of fresh water and direct purchase of land were considered to be the most costly adaptation measures, thus they were eliminated as options. For fisheries, the closed-season option is not considered feasible, as it will reduce revenues from fishing. Relocation of fishing camps is also not feasible. Most of the remaining measures are considered cost effective. However, the cost analysis considers only economic benefits (i.e. the damage cost avoided) of protection, without considering other mangrove funtions. The economic cost-benefit decision that maximizes the present value of net benefits is retreat. Retreat is considered a practical strategy because population density is low and fishermen are used to migration.

Social acceptability seems to be a common barrier to most adaptive measures. Education and enforcement of legislation are necessary to overcome these barriers. Political acceptability and technical capabilities are not expected to be a problem. The recommended strategy of implementation would take into account traditional knowledge through a participatory approach. The selected adaptation measures have been mentioned in the National Environment Management Plan and National Fisheries Plan of Cameroon. The fact that different government institutions are familiar with the measures increases chances for implementation.

For coastal infrastructure, adaptation objectives include sustainable management of the coastal zone through a reduction of coastal erosion, protection of marine ecosystem, and cleaner industrial processes. They also include the protection of human health and the reduction of vulnerability by minimizing risks from floods and inundation. Finally, they include an improvement of climate and socioeconomic databases to support decision-making, and a strengthening of the legal institutional capacity to respond to the impacts of climate change. In short, there is a need to integrate climate change considerations into development plans.

In order to prioritize adaptation measures, a screening process based on Multi-Objective Criteria and a decision-making matrix was applied (Smith et al., 1996). The process of screening is based on multi-objective criteria that is sought at the regional and national levels, culminating at a stage where policy dialog among actors could be improved and where decisions taken are placed under periodic review. Flexibility and cost-effectiveness are the two main criteria considered in the matrix. Other factors considered include high priority, target of opportunity, effectiveness, other benefits, low costs, and low barriers. From the analysis, protection options emerged as the most costly, followed by accommodate and retreat options. The priorities, from highest to lowest, were identified as follows:

- Increase the level of public awareness
- Raise the height of the quay in the seaport harbor
- Create incentives that encourage rolling back easements
- Use setbacks for land use developments
- Develop new sources of water intake for Douala City

Adaptations options for coastal infrastructure range from "soft" measures such as increasing public awareness and modifying legal and regulatory frameworks, to "hard" measures that include major constructions. Cameroon's National Environmental Management Plan (NEMP) provides the appropriate policy framework for implementing the different options. However, institutional, legal and organizational requirements are presently an obstacle for implementing Integrated Coastal Zone Management (ICZM) in Cameroon, and there is a lack of coordination between government departments, non-governmental organizations, and other stakeholders involved in coastal zone management. Cameroon also lacks adequate financial resources to undertake proper drainage, enforce zoning rules, update databases on land use and pollutant releases, and undertake environmental impact assessments for new projects. Given Cameroon's heavy debt burden and the lack of financial resources, inputs from international organizations and collaborations will be critical to the implementation of adaptation measures.

Adaptation options for biodiversity in the Waza Logone wetlands were also considered. The general objectives of adaptation strategies include sustainable development and reduction of vulnerability. Sustainable management includes protection of habitats and species, enlarging habitats to ensure species survival, and regeneration of degraded areas. The management of fauna can be achieved through the creation of corridors and buffer zones, the promotion of game farming, species relocation, assisted migrations, and re-introductions, disease control, and food and water provision. The protection of aquatic resources can be facilitated by taking inventories of fish and other aquatic resources, and by promoting stock conservation and sustainable fishing practices. The protection of Other strategies include sustainable agro-pastoral farming through the promotion of permanent crop and livestock farming, introduction of drought-resistant and high yielding varieties, and intensification of extension activities. Vulnerability can be reduced by controlling demographic pressures; developing tourism at the Waza National Park, including infrastructure; introducing environmental education in schools; strengthening traditional institutions and laws; and reforming land and fishing laws in the wetland area.

Various agencies are currently involved in the area, with the overall objective of sustainable development and control of desertification. These organizations can serve as potential partners for implementing the adaptation strategies. Some constraints to adaptation include financial limitations, as well as potential social conflicts among local communities in response to protection measures. For example, there could be conflicts between recommended adaptation measures and the economic interests of the rice development corporation (SEMRY), the major user of water in the Mandara watershed.

Key Point: Constraints to adaptation include potential conflicts with economic interests

One of the main adaptation objectives for the human health sector is to strengthen current management strategies. An early warning system has been in place for early detection of cholera and meningitis epidemics in the North and Far North provinces. Unfortunately, the limited number of trained health workers makes the system inefficient in some health districts and health areas. As a result, the surveillance system is not fully functional and operational.

Autonomous adjustments to disease transmission were identified, such as protective clothing to avoid mosquito bites. However, policies that promote social welfare, such as the sustainable provision of social amenities, road infrastructure, hygiene and sanitation, primary health care, food security, health education and emergency preparedness, are considered most cost effective in lowering the potential impacts of climate change on human health. These measures will produce near term benefits, including benefits in the absence of climate change. However, external support from developed countries is needed to implement these policies.

The study team also identified primary preventative measures and secondary preventative measures, along with measures to reduce damage to health infrastructure and to reduce the incidence of malaria and schistosomiasis. Vector control measures for malaria and schistosomiasis were identified as part of the latter initiative. From a technological perspective, the study team identified pyrethroid insecticide for malaria control as a very effective and low-cost means of controlling the vector. However, large scale indoor or aerial spraying was considered too costly to be sustainable without the exemption of health-related material from import duties or external financial assistance.

The study emphasized the need for a legal framework allowing for adequate inter-sectoral collaboration and coordination in the case of epidemics and natural catastrophes. They also identified the need for a national program for prevention and management of natural catastrophes. Efforts that are currently underway to improve health conditions in Cameroon were recognized, and it was recommended that many of these programs be expanded.

The major constraints to adaptation in the health sector are related to the insufficient amount of human, material, and financial resources. Some constraints, such as the inadequate number of trained health workers, may render adaptation measures inapplicable. Other constraints include inadequate policies or a lack of policies; beliefs or cultural habits that are counterproductive to adaptation; and low literacy rates, especially among females. The involvement of local development and health committees, women and youth associations, traditional authorities, and community opinion leaders could improve adherence to preventative measures. It was concluded that adaptive measures are likely to be accepted by the population if they contribute to reducing poverty, conserving biodiversity, and protecting and respecting social and cultural norms.

The Cameroon country study was limited both in time and in financial resources. The study team recognized that further research is needed to better understand the present state and future impacts of climate change on the various sectors of Cameroon's economy. There is also a need to extend the study to other ecological zones. Concrete recommendations for future studies and activities related to climate change include strengthening the documentation center at the climate change unit; improving accessibility to various sources of data for scientists; evaluating local perceptions of climate change and adaptation strategies; and studying social conflicts that may arise as a result of climate change impacts. These efforts will build upon the work carried out for this country study on climate impacts and adaptation assessments, and contribute to a greater understanding of the implications of climate change for sustainable development strategies in Cameroon.

4 Estonia

The climate change impact and adaptation assessment for Estonia began in September 1996, and was conducted by a team of national experts coordinated by Andres Tarand of the Ministry of the Environment. Implementation of the study was carried out by the Stockholm Environment Institute (SEI) - Tallinn, under the coordination of Tiit Kallaste. A copy of the full report can be obtained from SEI-Tallinn, Box 160, EE0090 Tallinn, Estonia.

Source:CIA World Factbook (1999)

4.1 Introduction

The Republic of Estonia represents a country in transition from a centrally planned economy to a market economy. The economic and social changes projected for the next decades are likely to dwarf the impacts of climate change in Estonia. As in developing countries, socioeconomic changes are shifting the context within which climate impacts will be felt. However, in Estonia, many of the projected impacts associated with climate change are considered to be positive.

Estonia is located in northeastern Europe, between 57°30'34" and 59°49'12" N. latitude and between 21°45'49" and 28°12'44" E. longitude. Bounded by the Baltic Sea in the north and west, Estonia occupies an area of 45,215.4 km^2, of which about one tenth (4133 km^2) is taken up by some 1500 islands and islets. Estonia shares a land border of 339 km with Latvia and 294 km with Russia.

Estonia has a relatively flat surface topography with undulating plains and small hills. About 40% of the Republic's territory lies between 50 and 100 meters above sea level, while only one tenth has an elevation over 100 meters. Southern Estonia is the country's highest region, with the greatest scenic and topographic variety. In spite of its small area and relatively simple geological structure, Estonia is rich in mineral resources. Estonian oil shale reserves are the largest commercially exploited deposit in the world. Oil shale has low calorific value compared to other fossil fuels, but it is a major source for power generation, and the main resource for the petrochemical industry. Estonia is also rich in peat. The total area of peatlands measures 100,901 ha and makes up 22.3% of Estonia's territory. Peat reserves are presently estimated at 2.37 billion metric tons. A small share of the reserves is suitable for animal litter, and the rest are used as fuel or for soil improvement. .

Estonia has experienced large demographic and economic changes over the past decade, as a result of the reforms initiated at the end of the 1980s. The population of Estonia was estimated at 1,462,130 in 1997. At 32.8 persons per square kilometer, the average population density is relatively low. The population in Estonia has been decreasing since the early 1990s, when restoration of Estonia's independence resulted in the departure of non-Estonian workers. Decreasing birth rates and a negative natural increase of the population has led to an aging trend in the population of Estonia.

Changes in technology and globalization, particularly the rapid development of information technology, have had a strong influence on Estonia’s economy. The share of the traditional industrial and agricultural sectors in the national economy is diminishing, while newer sectors such as financial services, transportation, and information technology are rapidly growing. Drastic reforms took place in the institutional framework of the economy. This resulted in a liberalization of most of the prices that were formerly regulated, and led to increased inflation. Property reform has played an important role in shaping Estonia's economic environment. As a result, the bulk of economic activity is concentrated in the private sector, which now accounts for two thirds of the GDP.

The most important economic sectors, with respect to their contribution to the gross domestic product (GDP), are manufacturing, wholesale and retail trade, transportation, storage and communications, and real estate. The Estonian economy has undergone progressive changes since regaining its independence in 1991. After a period of decreasing GDP (–14% in 1991 and –15% in 1992), the Estonian economy started to revive in April 1993. Stable increases of about 4% have been achieved in recent years (see Table 4.1).

Climatic change could have important implications for Estonia’s national economy. Agriculture and forestry are considered the most vulnerable sectors because climate change could lead to long-term changes in ecosystems, and thus in agricultural yields. Tourism and recreation are also closely related to weather conditions, particularly in coastal areas. Tourism has been a rapidly increasing sector due to Estonia's favorable geographical location. Other sectors of the national economy will not be significantly affected by changes in climate. Dramatic changes in socioeconomic development during the last eight to ten years have had a far greater effect than any other development, including climate change trends.

Table 4.1 Change in the GDP and inflation compared to the previous year

	1990	1991	1992	1993	1994	1995	1996
GDP, million kroons (EEK)	20874	18298	13501	13030	12665	13045	12567
Growth, %	…	-14	-15	-6.7	-1.8	+4.3	+4.0
Inflation, %	60	303	952	35.6	41.7	28.9	23.1

... = Data not available

The government of Estonia has identified the development of the energy sector as a strategic component in the stable development of a market economy. Estonia has substantial domestic primary fuel resources of oil shale, peat, and wood, as well as waste products from forest and secondary fuel resources of shale oil. At the same time, Estonia lacks natural gas, oil, and coal; those fuels have to be purchased at world market prices. The main goal of Estonian energy policy and strategy is to improve the efficiency of production, transmission, distribution, and consumption of energy.

Estonia's energy supply system consists of electric and thermal power plants. The production of electrical energy is concentrated in northeast Estonia. Almost all electricity production (99%) is based on oil-shale. Two thermal power plants, the Eesti and Balti power plants, are together capable of generating 3045 MW. The installed capacity is actually much higher than Estonia's own current demand. The plants were designed and built during the Soviet period to provide electricity for a much larger area. Because export of electricity has diminished, present-day production has dropped by nearly half. Smaller co-generation plants have been installed in Tallinn and in northeast Estonia. Electricity production is still monopolized in Estonia, with all electricity produced by the state-owned enterprise AS Eesti Energia (Estonian Energy).

The economic transition and restructuring of the Estonian economy has caused a remarkable decrease in energy consumption in the industrial and agricultural sectors. Both of these sectors have been negatively affected by the economic transition. Large-scale production has been replaced by significantly fewer enterprises operating at a smaller scale.

4.2 Historical Climate Changes in Estonia

Estonia has a rich historical climate record that provides evidence of past climate change. These past climate changes have been studied and can provide important insights regarding future climate impacts and adaptations.

Climatically, Estonia belongs to the mixed-forest sub-region of the Atlantic continental region of the temperate zone. Cyclonic activity from the Atlantic Ocean and the continental impact of Eurasia are the main factors influencing the climate. Consequently, the west-east gradient is more important in a meteorological sense than the north-south gradient. Local climatic differences in Estonia can be largely attributed to proximity of the Baltic Sea, which warms the coastal zone in winter and cools it in spring. Topography, particularly in the southeastern part of Estonia, plays an important role in the distribution of precipitation and duration of snow-cover. As a result of these factors, Estonia's summers are moderately warm (15 to 16ºC), and winters relatively mild (–5 to –3ºC).

The mean annual precipitation in Estonia is about 550–650 mm, ranging from 500 mm on some islands to almost 750 mm in the uplands. Annual precipitation exceeds evaporation approximately twofold, and the climate is quite damp. The highest precipitation in Estonia occurs in summer, especially in July and August. The maximum precipitation occurs in the middle of the summer in the continental part of the country, and later in the west. On the western coast of the West-Estonian Archipelago, the region with the most maritime climate, the rainiest period occurs in the autumn (October).

Historical climatic changes in Estonia are described here on the basis of modern observational data from a network of meteorological stations and the historical climatology databank in Tallinn Botanical Gardens. This databank has a collection of early weather observations from Estonia and neighboring countries, and a relatively rich collection of historical documents concerning direct and proxy climate and weather data.

The following four measures can be used to characterize historical climate change in Estonia:

- the winter season (December–March);
- the spring dates that air temperature rises above 0ºC (ice-break on rivers);
- the summer season (April–July);
- annual average air temperature.

The average air temperature in winter (December–March) is an important indicator of climate trends because of the significantly greater dispersion of winter mean temperatures (the standard deviation is two-fold compared with summer average). Systematic instrumental observations began in 1858. Winter temperatures for dates prior to the instrumental observation period are reconstructed from ice-break dates in Tallinn Port. As an old Hanseatic port, Tallinn has numerous port journals, custom books, town council minutes, correspondence, and trade company documents that can be used as proxy data sources for climate information. The constructed time series reveals a linear trend and a trend in the 30-year smoothed average, amounting to 1.8ºC for all winters over the period 1500–1997 (see Figure 4.1). After 1850, an almost constant warming occurs in winter, with a linear trend of 1.6ºC.

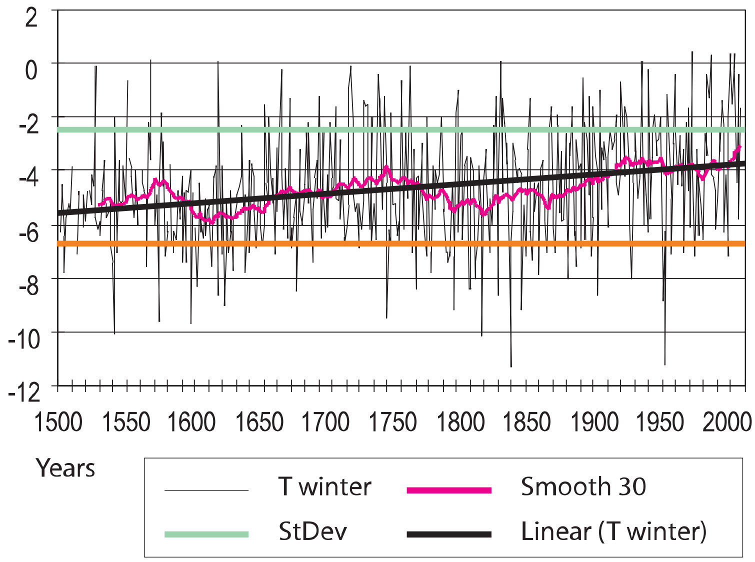

Figure 4.1 Average winter (December-March) air temperature in Tallinn, 1500-1997

The most intensive warming has occurred in the most recent period (1967–1997), with an increase of 0.8ºC in the mean winter air temperature compared to previous period. This has occurred only once before, in the mid-17th century. During the 1967–1997 period, the last ten winters have been the warmest, with an average air temperature of –1.5ºC. This period is likely to be the warmest period in the five hundred year record.

The beginning of spring is generally the time when average air temperatures rise above 0ºC. These dates are calculated from the ice-break dates on rivers (see Table 4.2). There is a strong linear trend in ice-break dates: the ice-break now occurs an average of 15 days earlier than it did over the last three centuries. Seven days of this can be attributed to the most recent period, when for the first time in the observation period Estonia experienced two winters without ice formation on rivers. The vegetation period has been prolonged at least ten days in spring. The ice break and earlier snowmelt cause a change in albedo (the reflective capacity of the surface), which could be a reason for more droughts in spring.

Although the average air temperature for April–July is not a traditional index of summer temperatures for Estonia, it corresponds to the first rye harvesting date, which can be used to reconstruct air temperature data. A comparison of the mean air temperature calculated by degree-days up to the rye harvesting date, and on the basis of early observational data, suggests that the more recent temperature data are incorrect due to the influence of direct solar radiation on the thermometers. The time-series is corrected up to the year 1830 by a negative factor of 1.1ºC (see

Table 4.3). Within the limits of the continuous time series (1737–1995), the linear trend is 1.5ºC. Since the beginning of the 1920s, there has been a positive linear trend. The most intensive warming to date has taken place in March, April, and May, with a gradient of 1.5ºC per 100 years. From October to February the trend has been moderate (0.9ºC per 100 years on average). No significant trend was evident in summer (June–September). An extrapolation of past trends up to the year 2100 results in mean winter air temperatures for Tallinn close to –

2.0ºC. On average, Tallinn will be out of the freezing zone of the Baltic Sea in the second half of the 21st century.

Table 4.2 Average ice-break in Palmse 1706-1996

Period	Years with data	Average (days since 1.03)	STD	Average	Date earliest	Date latest
1706–33	28	40.3	7.5	9.04	18.03	23.04
1734–66	33	38.2	10.1	7.04	15.03	27.04
1767–99	33	38.8	8.7	8.04	18.03	24.04
1800–33	34	39.6	10.1	9.04	10.03	25.04
1834–66	33	40.4	8.6	9.04	20.03	20.04
1867–99	33	37.3	8.7	6.04	18.03	22.04
1900–33	34	31.1	12.0	31.03	8.03	20.04
1934–66	33	32.1	9.5	1.04	10.03	17.04
1967–96	30	16.7	27.5	17.03	0.00	9.04

Table 4.3 Mean summer air temperature in Tallinn 1731–1996 (°C)

Period	Years with data	Mean temp.	STD	Maximum	Minimum
1731–66	34	9.7	0.94	12.1	7.8
1767–99	33	9.5	0.94	11.9	7.7
1800–33	34	9.5	1.03	11.8	7.6
1834–66	33	9.9	1.07	12.4	7.7
1867–99	33	10.1	0.95	12.3	8.1
1900–33	34	10.0	1.21	12.1	7.2
1934–66	33	10.6	0.96	12.9	8.6
1967–96	30	10.9	0.80	12.4	9.6

Precipitation is the most variable climatic characteristic in Estonia and is characterized by a high temporal and spatial variability. Its extreme values cause severe droughts and floods, which have a significant impact on human activity. Precipitation anomalies determine the general character of weather conditions, especially during the warm half-year. A time series for precipitation data is characterized by clearly observed periodical fluctuations, with alternating dry and wet periods in Estonia (Jaagus, 1992; Tarand, 1993).

One objective of the country study was to analyze whether the periodicity of precipitation observed during the last century has occurred over a much longer time scale. Another task was to determine whether there have been any changes in seasonal distribution of precipitation in Estonia. Precipitation measurements on the territory of Estonia have been made since 1866. The first dense network of precipitation stations was established in 1885. Since then, precipitation has been measured at about 100 locations in Estonia. Using proxy data for earlier years, Tarand (1993) composed a reconstructed time series of spatial mean precipitation anomalies in Estonia going back to 1751. The Blackman & Tukey method of spectral analysis was applied, and a periodogram was produced, demonstrating the distribution of total dispersion by different periodical fluctuations (see Figure 4.2). High peaks in the periodogram demonstrate significant periodical fluctuations. A periodicity in annual precipitation anomalies of 25–33 and 6–7 years was observed in Estonia during the period 1751–1995. The fluctuation period is not constant, but varies between 25 and 35 years. The fluctuations are called Brückner cycles and have been identified in precipitation time series in many regions of Europe.

Linear regression analysis was used to analyze long-term changes of precipitation and seasonal shifts. The corrected time series reveals a weak increasing trend. Significant trends were evident for autumn (SON) and winter (DJF), but absent in spring and summer (see Figure 4.3) (Jaggus, 1996). The increasing trend in autumn and winter precipitation indicates a seasonal shift and demonstrates a general tendency of climate change in Estonia from a continental climate towards a more maritime climate.

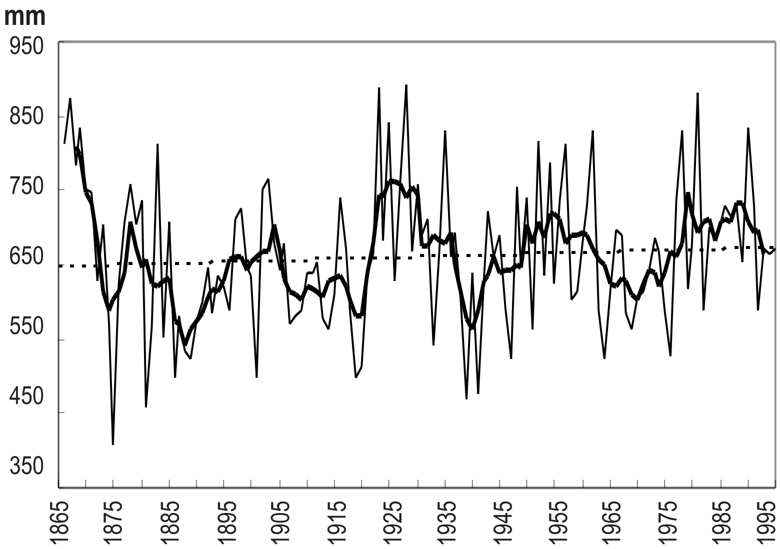

Figure 4.2 Corrected series of spatial mean annual precipitation in Estonia

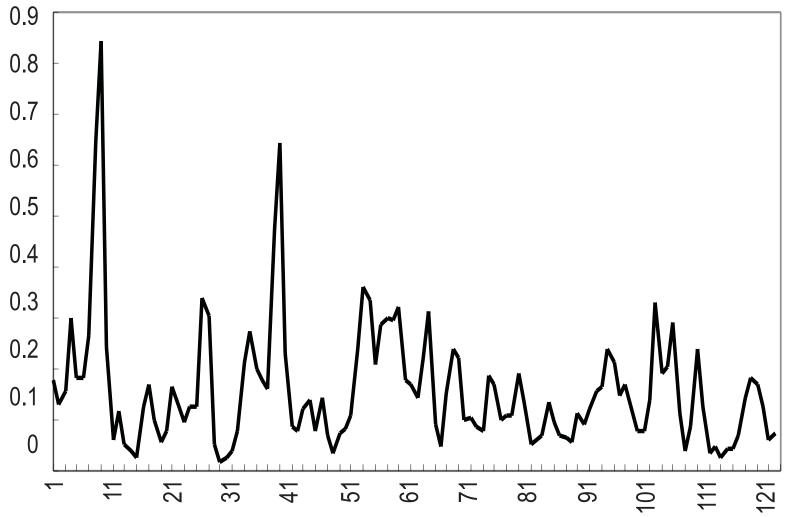

Figure 4.3 Periodogram of annual precipitation anomalies in Estonia. The two peaks correspond to periods of 27.1 and 6.3 years

From the results of time series analysis, it can be hypothesized that any warming associated with climate change will be matched by an increase of precipitation and a decrease in the continentality of climate. It may also mean a shift of the precipitation maximum towards autumn, and an increase in the percentage of winter precipitation.

The country study also involved the analyses of wind measurements, solar radiation measurements, and net long-wave radiation, with the results presented in the full report. In addition, several analyses of long-term phenological time series were carried out. The variation in phenological data represents the impact of climate change in nature, and will help to predict the results of the impact of climatic changes on ecosystems. The Estonian phenological database consists of valuable ornitho-, phyto-, ichthyo- and agrophenological data from 1950–1996. The observation series have been collected by different organizations such as the Estonian Naturalists Society, the Estonian Hydrological and Meteorological Institute, Tartu University, and many other bodies. The study is based on eight common plant, fish, and bird species in three different observation points. Spring phenophases were selected for analysis because of the availability of good observation series and because the effect of climate change is stronger in the spring in Estonia.

The blossoming dates of five common tree species (*Corylus avellana, Acer platanoides, Padus sylvatica, Syringa vulgaris and Sorbus aucuparia*) were studied through a statistical analysis and with a geographic information system (GIS). In the analysis of the general mean values and dispersion, early, normal, and late springs were distinguished, and spatial and temporal variations of phenophases were analyzed separately for each type. The results show that the blossoming of studied plant species has advanced 3–14 days over the 78-year time series.

The studied ichthyophenological time series also exhibit a trend. Over the 44 years included in the study, the beginning of spawning for pike now occurs six days earlier, and for bream 8 days earlier. However, the ichthyophenological observation series are not of the best quality, because of the potential for many errors in the measurements. The statistical confidence of the linear trend (t-statistic) is low for ichthyophenological data. The analysis of a 132-year ornithophenological time series produced opposite results from the phyto- and ichthyophenological time series: The skylark arrived 5 days later, and the white wagtail 6 days later, over a 132 year period.

Key Point: Based on the analysis of historical data, it can be hypothesized that warmer temperatures will be matched by an increase in precipitation, and that climate change will be most evident in the winter season.

The study of phenological time series suggests that Estonian springs have started 3–14 days earlier over the last 78 years. It also shows that the last 40-year period has been warming even faster than the earlier years. It is complicated to find the reasons for those changes based on phenological data series. They may in part be a result of long-term climate oscillations, and in part be attributed to human impacts. The study of phenological calendars of extreme years and reconstruction of longer time series may help to explain the changes that are taking place.

Analyses made on the basis of instrumental weather observations and proxy data going back to the year 1500 demonstrate that climate change is most evident in the winter season in Estonia. A positive air temperature trend could be followed from the mid-19th century, with a notable increase in the last decade (1988–1997). It is also notable that spring appears to be beginning earlier in Estonia, and the ice-break on rivers has occurred up to two weeks earlier in recent decades, compared to past centuries. This was corroborated by an analysis of phenological data.

The analysis of this rich historical climate record shows that there is evidence of climate change in Estonia. The causes of these changes can only be speculated, but anthropogenic-induced increases in greenhouse gases may be contributing to at least part of the change, particularly the strong trends observed over the past decades. There is a likelihood that such trends will continue, and possibly accelerate as a result of ongoing atmospheric emissions of greenhouse gases. To carry out the analysis of climate change impacts and adaptations, the historical results were compared to climate change scenarios generated by GCMs.

4.3 Climate Change Scenarios for Estonia

There is strong evidence that the climate of Estonia has been changing over the past centuries. These changes serve as a background for interpreting future climate changes attributable to increasing atmospheric concentrations of greenhouse gases. As historical records can provide insights to past climate change, computer models can be used to generate scenarios for future climate changes. The country study team used MAGICC, a simple climate model, to generate scenarios of climate change for Estonia.

MAGICC (Model for the Assessment of Greenhouse-gas Induced Climate Change) is a set of coupled gas-cycle, climate and ice-melt models that allows the user to determine the global mean temperature and sea-level consequences of user-specified greenhouse gas and sulphur dioxide emissions. MAGICC is an integrated model constructed from individual components that are highly parameterized, but capture the essential features of more complex models. It was developed in the Climatic Research Unit of the University of East Anglia (Hulme et al., 1995b).

The climate module of MAGICC is a one-dimensional upwelling-diffusion, energy-balance model. The model, elaborated by Wigley (1987; 1992), distinguishes between land and ocean and between hemispheres by treating them as separate boxes, with energy flow between the boxes. Such differentiation is important because there are large radiative forcing differences between different parts of the globe.

MAGICC starts with greenhouse gas emission scenarios. The scenarios cover a wide range of possible future emissions of carbon dioxide, methane, nitrous oxide, halocarbons, and sulphur dioxide, and includes the six IPCC scenarios drawn from the Supplementary Report to the IPCC Scientific Assessment (IPCC, 1992). All IPCC scenarios were updated for the 1995 Second Assessment. IS92a is the central IPCC scenario, while IS92c shows the lowest and IS92e the highest emissions. All IPCC scenarios may be regarded as reference scenarios that describe how future greenhouse gas emissions might evolve in the absence of climate policies beyond those already adopted (IPCC, 1992). Emissions scenarios contain uncertainty because they rely upon estimates of future geopolitical, socioeconomic, and demographic evolution.

MAGICC permits changes to model parameters within the following ranges:

- Land-use CO_2 emissions may range from 0.4 to 1.8 Gt C per year with a medium estimate of 1.1 Gt C per year

- Aerosol indirect forcing may range from 0 to –1.5 W m^{-2}, with a medium estimate of –0.8 W m^{-2}
- Ocean upwelling may be kept constant or depend on global mean temperatures (weakening with warming)
- Climate sensitivity depends on the estimates of climate system feedbacks and can be chosen from anywhere between 1.5 K and 4.5 K, with a best estimate of 2.5 K

Combining the input parameters, two extreme possibilities can be estimated: the maximal and minimal possible changes in the global mean temperature and sea level by the year 2100 with respect to 1990. The maximal warming could be expected if the highest emissions scenario IS92e is chosen; if land use CO_2 emissions are assumed to be 0.4 Gt C per year; if the indirect forcing by aerosols is set at 0; if the ocean upwelling rate is assumed to be constant; and if the climate sensitivity is estimated to be 4.5 K. The minimal warming could be expected if the lowest emissions scenario IS92c is chosen; if land use CO_2 emissions are assumed to be 1.8 Gt C per year; if the indirect forcing by aerosol is set at –1.5 W m^{-2}; if the ocean upwelling rate is considered variable; and if the climate sensitivity is estimated to be 1.5 K.

A moderate estimate of global mean warming can be expected if the medium emissions scenario IS92a ("business-as-usual") is chosen; if land use CO_2 emissions are assumed to be 1.1 Gt C per year; if the indirect forcing by aerosol is set at -0.8 Wm^2; if the ocean upwelling rate is considered variable; and if the climate sensitivity is estimated to be 2.5 K. To provide the most probable scenario of sea level rise, the study team chose the moderate IPCC emissions scenario IS92a (BAU) and the default model parameters for MAGICC.

Key Point: Estonia is located in a region where the negative forcing of aerosols should be considerable. This could offset some of the changes predicted by climate models.

The regional climate change scenario generator SCENGEN is a simple software tool that enables users to extract results from both simple and global climate model experiments, and combine them with observed global and regional climatologies to construct a range of geographically explicit climate change scenarios for the world. SCENGEN includes the results of 14 GCMs that have been stored as patterns of monthly mean changes of different variables per 1ºC of global mean warming. These normalized patterns are scaled up by the transient global mean temperature changes obtained from MAGICC. SCENGEN enables a large number of model outputs to be composed and examined in a short time. SCENGEN creates a global or regional climate change scenario forced by greenhouse gas emissions only, and does not include emissions of sulphate aerosols. The geographical distribution of aerosol emissions is extremely uneven. However, Estonia is located in a region where the negative forcing of aerosols should be considerable.

The combination of MAGICC and SCENGEN uses 1961–1990 baseline climatologies, and permits users to choose between 14 different GCMs. Users then select any 30-year period between 1961 and 2115, any 5 x 5 square, and any month. Changes in the following meteorological parameters can then be calculated: mean temperature, precipitation, cloud cover, minimum temperature, maximum temperature, mean wind speed, vapor pressure, and diurnal range of air temperature.

To choose the most appropriate GCM for Estonia, model results for the point 58ºN, 26ºE were examined with respect to changes in local annual temperature and precipitation by the year 2050. The newest models are HadCM2, CSIRO9M2, and ECHAM3TR. The best resolution is shown by HadCM2, ECHAM3TR, UKTR and UKHI.[1] The best agreement with Estonia's precipitation data is shown by HadCM2, UKTR, UKHI and CSIRO9M2 (Airey, Hulme, & Johns, 1996).

According to the comparative analysis, the best models for Estonia should be HadCM2 and ECHAM3TR. These two models give rather different, but not extreme scenarios for Estonia. HadCM2 represents a moderate scenario and ECHAM3TR represents a warm and wet scenario. These projections for continental Estonia east of 25ºE for the period 2036–2065 (in relation to the period 1961–1990) are shown in Table 4.4. The variability of the obtained results is caused by three factors: the choice of greenhouse gases emissions scenario, the choice of model parameters for MAGICC, and the choice of general circulation model.

Table 4.4 Projected change for continental Estonia from 2036–2065 to 1961–1990

Model	Change of annual temperature, °K	Change of annual precipitation, %
HadCM2	1.3	7.5
ECHAM3TR	2.3	14.9

According to the models, the climate of Estonia will become warmer and wetter. All models show that temperatures will rise more in winter and less in summer. Estimates of precipitation changes are more dispersed: no annual trend can be observed, although some models show a slight decrease during some months.

To generate scenarios for the country study, three alternative greenhouse gas emission scenarios developed by IPCC (IS92a, IS92c, IS92e) were combined with two general circulation models (HadCM2, ECHAM3TR). MAGICC and SCENGEN were used to generate the scenarios (Hulme et al., 1995a; Wigley & Raper, 1992). Six climate change scenarios up to the year 2100 were developed for assessing the impacts of climate change. They were calculated for the case of mean values of MAGICC parameters. The following abbreviations are used:

HAD - HadCM2 model
HAM - ECHAM3TR model
MID - IPCC medium emission scenario (IS92a)
MIN - IPCC minimum emission scenario (IS92c)
MAX - IPCC maximum emission scenario (IS92e)

GCM results are available for 5x5 degree cells. The territory of Estonia is covered by two grid cells. The border between West and East Estonia is, in this case, 25ºE longitude. In general, results of both GCMs are quite similar. They project a higher increase of air temperature during

[1] See Appendix II for an explanation of model acronyms.

the winter half-year (October–March) and a lower increase in the period April–September. However, the HAM model expects higher warming than the HAD model (see Figure 4.4). The increase of air temperature in eastern Estonia should be higher than in western Estonia, especially in winter.

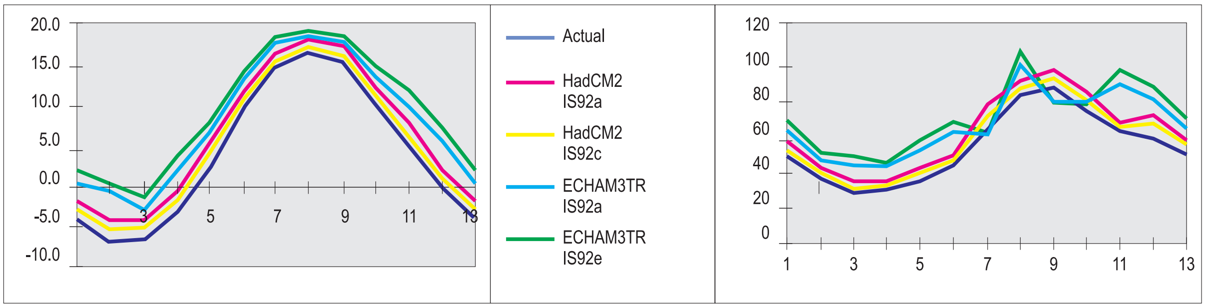

Figure 4.4 Annual variability of monthly mean temperature (left) and precipitation (right) at the Vooremaa spruce forest site according to the four chosen scenarios as compared to the actual data

There is less agreement regarding the precipitation results. The HAD model indicates a rather uniform increase of precipitation in Estonia. It should be higher in western Estonia, especially during the period from April to August. The highest increase is predicted for June. The HAM model projects a greater increase of precipitation in Estonia, primarily during the cold period (October–May). The rainfall rise in summer will be weak. In fact, precipitation changes for East Estonia in June and August are projected to be negative.

The best estimation of winter warming up to the year 2100 is between +2 and +4ºC, which means that winter air temperatures will approach 0ºC in Estonia. Neither climate models nor statistical extrapolation can be regarded as climate predictions, but the probability of warming over the next 50–100 years is greater than that of cooling. One has to keep in mind that the positive trends of climate change in Estonia, both with respect to mean air temperature and precipitation, are in any case expected to occur as a result of the natural fluctuations experienced over the past centuries.

The continentality of the climate will be reduced and the influence of the sea will become more pronounced. Winters will become milder and hibernating conditions will improve. During the winter period, cyclonic activity will become more intensive and the wind speed will increase. In the coastal area, especially for soils with a lighter texture, the danger of spring wind erosion will increase.

The significance of climate change for Estonia can be considered using the method of time analogues. Expected changes in the average annual air temperature are within the range of 1–3ºC in Estonia. An analysis of time series temperature data showed that the lowest annual average air temperatures occurred in 1915, 1942, and 1943 – only 3ºC or below. The warmest years were 1934, 1938, 1949, 1951, and 1975, when the annual average temperature rose to 7ºC. Comparing the predicted air temperature changes with Estonian local observational time series, we see that they stay within the limits of air temperature fluctuations of earlier years.

From this it can be concluded that an increase in average temperatures will not bring about any catastrophic change in Estonia. However, climate changes resulting in changes in the beginning, end, and duration of the season are more important, as are climate extremes and variability. With the rise of annual mean air temperature, the values of main agroclimatological indices – the length of vegetation period, the amount of heat accumulated during this period and the severity of winter – will also change (Kivi, 1981). The length of the vegetation period will increase, whereas the amount of heat needed for plants and the severity of winter will decrease.

4.4 Agricultural Impacts

Agriculture is considered to be the sector that is most vulnerable to climate change in Estonia. The development of agriculture in northern high-latitude regions is largely determined by thermal resources (Carter, 1996). The potential effects of global climate change on agriculture have been discussed in qualitative and quantitative terms in numerous studies (Parry, Carter, & Konijn, 1988; Roostalu, Tamm, Kevvai, & Valgus, 1996). In most cases, these studies are based on natural indicators. It has been shown that the responses to climate change vary for different plant species and agricultural crops. Cereal crops and perennial grasslands have been shown to be most sensitive to climate change.

It can be speculated that the rise in average temperature will bring about a change in the course of annual temperature in Estonia, prolonging the total growing season, thus also lengthening sowing and autumn harvesting periods. At the same time, a greater amount of the warmth necessary for plant growth and development will accumulate during the vegetation period. The development of agricultural varieties will become quicker, and the growing period will shorten. Given these scenarios, it is likely that most crops in the southern region will have a wider distribution than they have today. Such crops include maize, summer wheat, and buckwheat.

In this study, the relationship between crop yields and weather conditions was used as the main indicator of the efficiency of agricultural production. According to the principle of maximum productivity, crop cultivation is considered to be the basic task of agriculture (Tooming, 1977; Tooming, 1984). Crop cultivation should guarantee maximum yields with the available climatic, soil and economic resources. Optimal strategies for plant cultivation can be affected by climate change. Agroclimatic resources must therefore be evaluated regularly. Various indices and complex characteristics have been proposed for the evaluation of agroclimatic potential (Sepp & Tooming, 1991). However, the Estonian country study team employed the method of model or standard yields (Tooming, 1977; Tooming, 1984; Zhukovsky, Sepp, & Tooming, 1990).

In establishing the effect of climate change on agriculture, the relationship between weather and crop production was expressed through a method of mathematical modeling. The method was based on the calculation of maximum yields under given geographical conditions and the effects of certain limiting factors. According to the principle of maximum plant productivity, adaptation and succession processes take place in natural plant communities and are directed at providing the maximum productivity achievable under the given environmental conditions (Tooming & Kallis, 1972; Tooming, 1977). According to this principle, productivity, whether it is very low (deserts) or very high (tropical rain forests, wetlands), is nevertheless maximal under existing environmental conditions. This principle has been applied to the solution of various problems in plant physiology, ecology, and agriculture.

Natural plants and plant communities are systems that have adapted to existing environmental conditions during a long evolutionary process. Field crops have been developed through human activity over a prolonged period. However, some strategies exist for achieving harmony between plants, whole crops, and the environment, including the following:

- improvement of plants through breeding, with the aim of achieving a better response to environmental conditions
- improvement of environmental conditions by means of irrigation and drainage
- optimal distribution of crops, according to the regional climate and field microclimates
- plant protection from pests and disease
- high quality agricultural technologies and yield programming

Ecologically based model yields can be calculated using models with input data on plant parameters and meteorological conditions. By gradually including limiting factors, ecologically-based model yields simplify the modeling of crop productivity. They can be recommended for the estimation of climate change impacts on agroclimatic potential. The ecologically based model yields can be classified as follows:

1. Potential yield (PY) is the yield under ideal soil and meteorological conditions. The PY depends on the biological parameters of species or varieties and the influx of solar radiation.
2. Meteorologically possible yield (MPY) is the maximum yield conceivable under the existing meteorological conditions provided by high soil fertility and appropriate agricultural technologies.
3. Actual possible yield (APY) is the maximum yield achievable under the present level of agricultural technology, and existing meteorological and soil conditions.
4. The real yield (CY) under commercial conditions is the yield in the field.

The objective of this method is to calculate possible yields in different regions to promote the production of calculated yields. Possible changes in ecologically based yields may be calculated for different climate change scenarios. According to this methodology, the estimation of agroclimatic potential starts from the theoretically highest yield level in optimal weather conditions, i.e. from the calculation of the potential yield (PY). The agroclimatic potential of a given region is mainly associated with the mean value of the meteorologically possible yield (MPY) and its statistical distribution, taking into account the most important meteorological factors affecting the yield. The distribution functions determine the interval of the possible yield values (APY) and their frequencies (Sepp & Tooming, 1991; Tooming, 1993). This research method emphasizes both potential possibilities and real opportunities in crop cultivation. It enables resources to be used more effectively through optimization of agricultural techniques, amelioration, fertilization, and the introduction of new varieties.

Potatoes are one of the most important agricultural products in Estonia. The dynamic model POMOD was used for simulating potato model yields (Sepp & Tooming, 1991). POMOD and climate change scenarios were used to calculate meteorologically possible yields (MPY) for potatoes. To calculate local temperature and precipitation changes to the year 2050, the HadCM2 and ECHAM3TR models were selected. Baseline agricultural data from the period 1965–1996 were used for the calculations. These data were modified according to each scenario of projected changes in temperature and precipitation. Optimal sowing and harvesting dates were then determined from the condition of yield maximum.

Calculations based on POMOD show that the meteorologically possible yield using real data is on average 55.3 t/ha for Estonia. The low and medium variants of both scenarios raised the yield by 4–7% (see Table 4.5). The high variant may cause a 3% decrease in the yield in the case of the moderate climate change scenario, and 17% according to the wet and warm scenario.

Table 4.5 Meteorologically possible yields relative to the yields for the period 1965–1996, calculated for the counties of Estonia according to different climate scenarios

County	Moderate scenarios			Warm and wet scenarios		
	Low	*Medium*	*High*	*Low*	*Medium*	*High*
Harju	1.092	1.122	1.052	1.109	1.107	0.941
Lääne-Viru	1.089	1.146	1.089	1.110	1.153	0.958
Ida-Viru	1.076	1.127	1.055	1.095	1.129	0.926
Järva	1.063	1.075	0.974	1.077	1.059	0.831
Lääne	1.066	1.081	1.000	1.090	1.063	0.884
Rapla	1.063	1.086	0.993	1.086	1.072	0.842
Hiiu	1.097	1.165	1.119	1.106	1.132	1.095
Jõgeva	1.074	1.082	0.980	1.094	1.074	0.833
Pärnu	1.033	1.005	0.894	1.041	0.974	0.758
Saare	1.076	1.080	1.008	1.078	1.043	0.934
Viljandi	1.028	0.998	0.880	1.045	0.967	0.726
Tartu	1.042	1.030	0.924	1.062	1.004	0.773
Põlva	1.025	0.996	0.883	1.032	0.961	0.712
Valga	1.020	0.983	0.871	1.025	0.953	0.706
Võru	1.023	0.993	0.872	1.027	0.950	0.695
Estonia as an average	1.058	1.061	0.969	1.072	1.042	0.834

The model scenarios show that the changing rates of MPY are notably different for different regions of Estonia. Meteorologically possible yields for potato will increase about 4–7%. The increase is greater on islands and in northern Estonia by 10–16%. In southern Estonia, meteorologically possible yields for potatoes will not change significantly. In the case of very warm and wet scenarios, a decrease in yield can be expected.

Besides changes in average yields, changes in yield variability are of great importance. The variability of yields can be described by their cumulative statistical distributions. All of the curves have been normalized in relation to the average MPY over the period 1965–1996. Large changes in climate will cause a more substantial decrease in high and low yields under both scenarios. Calculations indicate that the optimum sowing time will on average shift to 4 to 11 days earlier, with the exception of the high change variant of warm and wet scenarios. To obtain maximum yields, the entire cultivation period ought to be prolonged by 10 to 30 days (see Table 4.6).

Potential yields for potatoes will increase with a possible lengthening of the growing season. The potential increment in yields will be accompanied by an increase in the plants' nutrient needs. This means that mineral requirements may be increased. In the case of soil minerals, the need for amelioration will fall, while the soils with lighter texture will need increased artificial irrigation.

Table 4.6 Average dates for the beginning and end of the possible potato vegetation period and the average optimum limits of potato cultivation

	Beginning of vegetation	Optimum sowing time	Optimum harvesting time	End of vegetation
Real data for 1965–1996	08 May	09 May	29 Sept	11 Oct
Moderate scenarios				
Low change	03 May	05 May	05 Oct	18 Oct
Medium change	28 Apr	02 May	15 Oct	29 Oct
High change	18 Apr	28 Apr	18 Oct	14 Nov
Warm and wet scenarios				
Low change	02 May	04 May	08 Oct	21 Oct
Medium change	23 Apr	01 May	20 Oct	12 Nov
High change	08 Mar	14 Apr	02 Oct	13 Dec

Changes in the climate at all spatial scales affect plant growth. To characterize the micro-climatic variability of smaller areas, a classification of geo-complexes was developed (Karing, 1992). Using this classification, values for direct solar radiation, radiation balance, air and soil temperature, soil moisture, wind velocity, and precipitation can be calculated (Karing, 1995). Such a study shows that the microclimatic variations of water resources in southeastern Estonia are significant. The best microclimatic conditions for grassland production are the tops of hills and the valleys between them. In the case of barley cultivation, favorable moisture conditions prevail on the lower parts of south-facing slopes and in flat areas with loamy soils. The yield differences between the foot of north-facing slopes and the lower part of south-facing slopes can be as high as 50%.

The efficiency of manipulating the microclimate varies greatly in different localities (see Table 4.7). It depends notably on the intensity of land cultivation on a particular farm, as well as on the doses of mineral fertilizers applied. The higher the production level, the higher the efficiency of microclimate management.

Climate change is likely to be accompanied by an increasing phytoproductivity of the ecosystem, increasing the amount of dead plant mass deposited in the soil, which is subject to humification, leaching, and mineralization in the decomposition process. If the future climate becomes more arid, one might expect the peat layer to decrease as it did during the Boreal climate stage. If climate change brings about an increase in moisture, the opposite process may take place, i.e. the amount of soil organic matter could rise.

Estonian soils have gone through several periods of climate warming and cooling throughout their evolution, and these fluctuations have had varying effects on soil development. With global warming, the intensity of a number of soil evolution processes will change, and some of these changes will take place in different directions. The extent of decomposition and washing out of $CaCO_3$ may decrease with global warming, as the solubility of gases in water decreases with increasing temperatures. However, with global warming, other conditions will also change, including precipitation. The removal of Ca2+ from the soil depends mostly on precipitation run-off, and can affect the influence of global warming on the decomposition and washing out of $CaCO_3$. The decrease in the decomposition and washing out of carbonates due to global warming should be regarded as undesirable for northern Estonia, where the soils are characterized by a high calcareous content, but favorable for southern Estonia.

Under scenarios of climate change, differentiation of the soil mineral profile (i.e. degradation of soil upper horizons) may become more pronounced if leaching out continues. However, this differentiation could be inhibited if leaching decreases, or cease altogether if the climate becomes drier and the leaching process stops. If coniferous forests are replaced by broad-leaf deciduous forests, there may be a slowing down of soil mineral constituent decomposition, as well as less washing of substances into deeper layers or out of the soil.

Table 4.7 Agroclimatic indicators of the water regime regulation efficiency of soils of barley crops under different microclimate conditions

Position		Y_0 = 3.8 tonnes/ha			Y_0 = 9.3 tonnes/ha			Y0 = 1.0 tonnes/ha		
	ΔE	Y^M	Y^{pi}	ΔY	Y^M	Y^{pi}	ΔY	Y^M	Y^{pi}	ΔY
1. Hilltop	59	3.8	2.5	1.3	9.3	6.0	3.3	1.0	0.6	0.4
2. Northern slope										
Upper part	0	3.4	3.4	0	8.7	8.7	0	1.0	1.0	0
Middle part	0	3.3	3.3	0	8.2	8.2	0	1.0	1.0	0
Lower part	-46	3.3	2.4	0.9	8.2	6.0	2.2	1.0	0.6	0.4
Foot	-71	3.2	1.8	1.4	8.0	4.6	3.4	1.0	0.5	0.5
3. Southern slope										
Upper part	57	3.8	2.5	1.3	9.5	6.3	3.2	1.0	0.7	0.3
Middle part	49	3.8	2.7	1.1	9.4	6.7	1.7	1.0	0.7	0.3
Lower part	0	3.8	3.8	0	9.4	9.4	0	1.0	1.0	0
Foot	-39	3.7	2.8	0.9	9.2	7.1	2.1	1.0	0.8	0.2
4. Lowland										
Temporary										
Excessive moisture	-30	3.5	2.9	0.6	8.6	7.0	1.6	0.9	0.8	0.1
Drained loams	25	3.5	3.0	0.5	8.6	7.3	1.6	0.9	0.8	0.1
Drained sandy loams	0	3.5	0	0	8.6	8.6	0	0.9	0.9	0
5. Hat area loams	17	3.7	3.3	0.4	9.0	8.1	0.9	1.0	0.9	0.1
Sandy loams	0	3.7	3.7	0	9.9	9.0	0	1.0	0.9	0

ΔE is the change in soil moisture (mm) irrigation or drainage; Y^M and Y^{pi} are yield levels after and before the water regime regulation, ΔY is the yield growth rate.

Statistically homogeneous data on productive water reserves in three soil layers were used to study the soil moisture regime. The soil moisture content was characterized according to its availability to plants, using soil hydrological constants. It was found that during the first half of summer (May, June) the soil moisture supply in the 0 to 50 cm layer quickly diminishes, reaching 50–60 mm by the end of June. In overmoist soils, the difference reaches 50–70 mm by the end of June, with an additional 10 mm in July and August. Spatial variations of soil moisture content are conditioned by different soil hydromorphism and varying water-holding capacities.

The climate in Estonia is suitable for growing herbaceous plants (as their assimilation period lasts more than five months) and is not greatly affected by night frosts in spring and autumn. Long-term experimental data on different soils in various Estonian regions have shown that two, three, or almost four cuts are available from meadow plants during their vegetation period. In other words, they are constantly in a vegetative stage, which guarantees a high-intensity growth process.

Natural grasslands are located irregularly throughout Estonia. Typical grasslands in western and northern Estonia are mainly calciphile parkland meadows, which are rich in species. There are fewer natural meadows in southern and eastern Estonia. Natural meadows yield on average 1.0 to 1.2 metric tons of dry matter per hectare. The most productive types of Estonian natural grasslands are found among flood plain meadows. They can yield up to3–4 metric tons of dry matter per hectare.

Before World War II, the total area of natural grasslands was 1,572,357 ha. The total area of cultivated grasslands was only 55,278 ha at that time (Adojaan, 1961). Since then, the area of natural grasslands (hay-meadows and pastures) has decreased by an average of 32,000 ha per year. When the exploitation of natural grasslands ceases, they become overgrown with brushwood and trees. Rare or dense brushwood emerges on the uncut areas after three or four years. Of the 303,117 ha of natural grasslands that had survived to the beginning of the 1980s, only 165,096 hectares (less than 55%) were usable grasslands (Aug & Kokk, 1983).

An analysis of production-climate relationships shows negative relationships between yields from natural dry upland meadows and mean annual temperature. One can conclude that a rise of mean annual temperature without an increase in the rainfall could have a negative effect on the yields of natural dry upland meadows. According to calculations, a rise in mean annual temperature of 1°C can reduce the dry matter yield on average by up to 0.05 metric tons per hectare. In contrast, an analysis of experimental data from flood plain meadows, where overflow occurs briefly and rarely, shows that at a 1°C rise in mean annual temperature can increase the yield from these meadows by up to 0.52 metric tons of dry matter per hectare. In the case where overflowing ceases on flood plain meadows, a temperature increase can bring about a decrease in productivity.

Key Point: Agriculture in Estonia is likely to benefit from climate change.

The yields of cultivated meadows may be positively influenced by the rise of temperature and increase in rainfall. Preliminary research shows that a rise in mean annual temperature by 1°C can increase the average dry matter yield of perennial fodder crops by up to 0.17 metric tons per hectare. In general, climate change is likely to be favorable for grassland husbandry in Estonia. The total growing season will lengthen and a greater number of cuttings will be possible. In the case of higher temperatures and higher rainfall, the growth and development of herbaceous plants will quicken, and harvesting times will shift to an earlier period. Livestock will be better provided with fodder in summer and winter.

In conclusion, agriculture in Estonia will be more effective and competitive compared to the present. It will be possible to cultivate more southern varieties in Estonia with longer growing periods. Grasslands could expand, especially natural grasslands and forest pastures. In enclosed small pastures, the irrigation norms may be increased by about 30 mm. Under different scenarios of climate change, soils with lighter texture will find less application as agricultural land. If possible, these lands should be reforested, especially on islands and in coastal areas.

4.5 Forest Impacts

Approximately 2 million hectares (46% of the total land area) of Estonia is covered by forest (Yearbook, 1995). The forested area in Estonia increased significantly during the 20th century as a result of land ownership restitution and declining agricultural production. In fact, the forest area has tripled over the last 80 years, and more than doubled over the last 50 years. There are presently around 400,000–500,000 hectares of abandoned agricultural lands in Estonia, which will most likely be afforested. This will make forestry more important in the future.

Estonia is a timber-exporting country. Although the forests of Estonia contribute considerably to the national economy, Estonia's forests are currently underutilized. This is partly due to the lack of a market, but the underutilization can also be attributed to institutional and legal factors, including inadequate decision-making rules. Sustained-yield and multiple-use forest management has been the goal of Estonian forestry over 50 years. Since the 1950s, Estonia has been in a situation where the annual cut in forests is less than 50% of the annual growth increment, which has resulted in an increasing growing stock of forests.

Estonia's productive forest area amounts to 1,926 million hectares (Viilup, 1996a). Of this, 62% is state-owned forests and 6% is private forests. As much as 32% of Estonian forests have no owner at the moment or will be returned to the previous (private) owner in accordance with ownership restitution. There are about 224,000 ha (20.3%) of state-owned forest held as preserved forests under strict restrictions for cutting, 115,000 ha (10.4%) held as protected forests under comparatively soft restrictions for cutting, and 765,000 ha (69.3%) classified for use as commercial forests in Estonia (Eltermann, 1996).

The diversity of Estonian forests is remarkable by species composition and by site types. The percentage of stands by dominant tree species is: Scotch pine (38% of the area), Norway spruce (24%) and birch (30%) (Estonian Forest Department, 1995). Most of the stands dominated by spruce, birch, and aspen (and also pine stands on fertile soils) are mixed stands. There have been changes in the species composition of Estonian forests resulting from damage by the human-controlled moose population.

The current species composition of forests is mainly influenced by reforestation and afforestation, thinning, and also draining. Estonian foresters have planted and seeded almost half a million hectares (25% of the present forest area) in the 20th century. All reforestation and afforestation activities have been oriented towards increasing the proportion of conifers, especially pine. Changes in the forest species composition during the last 2000 years cannot be interpreted as primarily the result of natural processes. Instead, they are the result of both changes in climate and human impact in Estonia.

Climate change means not only changes in temperature and precipitation, but also in the composition of air and precipitation. Carbon dioxide is only one of the components affecting forest growth and health. The influence of game, insects, fungi, and forest activity in the largely unpredictable social, economic, and technological environment of 2090 must be taken into consideration. The following approach was adopted in this research:

1. Evaluatation of the impact of climate and atmospheric change on forest growth during the last 30–40 years.
2. Investigation of the long-term changes in upland forest soils affected by atmospheric deposition and climate change using the forest-soil-atmosphere model (RipFor).
3. Prediction of forest stability and possible changes caused by forest pests and damages related to climate change on the basis of analogues.
4. Simulation of growth and harvest of Estonian forests assuming climate and atmosphere changes at the predicted rate, using the MELA model for multi-stage linear planning optimization.
5. Analysis of the genome variability of forest tree species as an adaptation factor.

The study of forest growth trends in eastern Estonia (Tartu County, 43 years), northern Estonia (Vahastu district, 46 years), and central Estonia (Forest Enterprise Suure-Jaani, 30 years) showed increasing growth rates and a distortion of growth functions on temporary sets of sample plots.

During the last 30–46 years, there has been a remarkable shift of sites towards more fertile and drier conditions. This recent change of fertility and character of site types is in full accord with the results from the RipFor model by Arp and Oja (1997). The shift in forest growth over the last three decades has been confirmed by comparing empirical conditional means of stand height, DBH and volume by dominant species, site type, and stand age in Suure-Jaani Forest Enterprise in 1960 and 1990. Both a direct comparison and a comparison of the mean values smoothed by a growth function give similar results. Preliminary estimates indicate an increase in height growth by 1–1.5 m over the last 30 years. A similar trend was found in the growth of DBH and volume of stands. However, for some older stands, the mean values of stand volume were less in 1990 than in 1960.

Significant human-induced changes of dominant species have occurred in Suure-Jaani. This change is mainly evident in stands up to 30 years old, and can be attributed to afforestation and reforestation, the large number of moose, and to some extent nursery diseases. The clear-cut pine stands were most often reforested by spruce to avoid moose damage. As a result, the number of young spruce stands was up to 10 times larger in 1990 than in 1960, while the number of pine stands was considerably less. However, after two to three decades, moose started to debark middle-aged spruce stands, and have destroyed many of them completely. This represents a double failure: afforestation with the wrong species combined with the loss of decades of forest growth and value.

The forest-soil-atmosphere model RipFor was used to analyse the potential influence of climate change on forest biomass production and nutrient cycling in Estonian forests. The objective of this exercise was to estimate the changes in nutrient availability and nutrient fluxes in the soil-vegetation system of Estonian forested areas as possibly occurring under two different climatic change scenarios selected for this project, namely HadCM2 and ECHAM3TR.

RipFor quantifies biomass production and nutrient transfers among major stand compartments – including foliage, wood (which includes branches and medium to coarse roots), fine roots, forest floor, mineral soil, and soil solution (see Arp and Oja, 1997; Oja and Arp, 1997). The compartments were considered to be homogeneous and characteristic for the stand. The basic unit of RipFor is a dominant tree gap for which biomass growth and nutrient cycling is simulated through several tree life cycles. The model does not include precise species composition and does not address species shifts. The main processes addressed are net primary production (proportional to foliage biomass affected by nutrient availability), biomass respiration, litterfall (including throughfall), litter decay (including translocation of nutrients and of photosynthate before foliage fall), nutrient uptake from available nutrient pools within the soil, ion exchange, and replenishment of soil bases (Ca, Mg, K, Na) via soil weathering and atmospheric deposition.

The climatic factors included in the model are radiation, CO_2 concentrations in the atmosphere and soil, atmospheric deposition of the nutrients, air temperature, and precipitation. Temperature and precipitation affect soil conditions (soil moisture, rate of organic matter decomposition, nutrient mineralization, and transformations and weathering of soil minerals). In the model, air temperature, precipitation and leaf area affect the rate of evapotranspiration. In turn, rates of evapotranspiration and nutrient availability affect productivity and water use efficiency. The rates of evapotranspiration and soil moisture availability were calculated separately with the ForHyM model (Arp & Yin, 1992), and can serve also as a precalculator for nutrient cycling.

The RipFor model was applied to major forest communities in both eastern and western Estonia. More detailed model analyses were carried out for a spruce stand in Vooremaa (eastern Estonia), which has been thoroughly studied in the field and thus provides most of the data needed for fine-tuning the model. Two scenarios, HadCM2 IS92a and ECHAM3TR IS92a were used as basic climate change scenarios. In addition, calculations were made for the extreme versions of scenarios (HadCM2 IS92c and ECHAM3TR IS92e) to estimate the variability of results. This variability turned out to be moderate.

Key Point: Although climate change is likely to stimulate forest growth in Estonia, it could also lead to increased damages by pests and game.

The model results for the Vooremaa spruce stand and other similar sites show very clear and obvious trends: snowpacks will decrease and snowmelt will occur earlier with increased climate warming. Reduced influence of snowmelt on stream discharge will increase the synchronization between precipitation and stream discharge. In the growing season, soils will become slightly drier than is currently the case. Increased drought stress may occur because the scenarios lead to a drier spring as well as slightly drier summer conditions. This could increase the danger of forest fire, which in turn could accelerate species shifts from the current vegetation to vegetation that is better adapted to drier conditions and fire disturbances. In this exercise, it was assumed that this does not occur, as the decrease in soil moisture content is relatively low for Estonia. A major species shift, anticipated or not, would make the RipFor calculations unreliable. In this analysis, it is assumed that the climate for all scenarios will change linearly over a period of 100 years.

Model simulations imply increased productivity resulting from (1) increased CO_2 concentrations in the atmosphere, (2) increased rates of evapotranspiration, (3) increased allocation of photosynthate to foliage, (4) and increased rates of nutrient cycling (increased amounts of net primary production imply increased amounts of nutrient uptake, litterfall, litter decomposition and mineralization. The calculations can be considered somewhat conservative, as the effects of increased temperature on soil weathering and nutrient mineralization are probably underestimated.

Due to Estonia's geographical position, the main forest tree species – pine, spruce and birch – are growing in close-to-optimal conditions. To date, there have been no signs of forest disturbances caused by minimum winter temperatures or other weather conditions. The last serious storm damages occurred in the end of the 1960s and the early 1970s. As the climate is rather cool with sufficient precipitation, the area damaged by forest fire is relatively stable. The damaged stands have been cleaned, therefore potential forest pest multiplication after fires has been avoided. Relatively cool weather in the vegetation period and high mortality in winter do not provide favorable reproduction conditions for needle and leaf pests. Trunk pests – bark and pulp beetles and weevils – have mainly a secondary role in pine and spruce groves. They have accelerated the death of trees damaged by disease, human activity, storms, and fires.

In Estonia, the most numerous and dangerous trunk pest has been spruce bark beetle (*Ips typographus*). Mortality due to low winter temperatures has regulated its numbers, although this pest has shown higher survival rates in recent winters. Another factor important in its development is weather conditions during the flying period (late April to early May). Even a short period of dry and warm weather is a good precondition for the spruce bark beetle's successful development. An analysis of changes in spruce grove areas caused by spruce bark beetles reveals an increase in activity from this pest. In the 1970s and the 1980s such damaged area made up 200 to 250 ha in Estonia. After the 1992 drought, the damaged area has increased 7 to 8 times, making up 1863 ha. This change is directly caused by warm and dry weather and indirectly caused by draught stress on trees. With climate change, trunk pests may have not one but two generations per year.

Damages caused by game have also played a great role in forest health and productivity over the last decades. The most numerous cervines in Estonia are roe deer (*Capreolus capreolus L.*), moose (*Alces alces L.*), and red deer (*Cervus elaphus L.*). The first two have been the main inhabitants in Estonian forests. Red deer were introduced to Estonia in the end of the 19^{th} century. The population of this species has increased due to the migration from the northern parts of Latvia. Essential preconditions for the migration can be thin snow cover and relatively mild winters. The number of roe deer and red deer are likely to increase with climate change.

While from the 1960s until the 1980s moose caused damage in young pine stands, their damage has become more varying. A sudden expansion of damages occurred in spruce stands in the second half of the 1970s. This was followed by a drop in the first half of the 1980s. A new rise began in the end of the 1980s and was followed by a drop in the beginning of the 1990s. Although hunting has reduced the damage to spruce stands by moose, the damaged stands are in poor condition. Besides the damages to "middle-aged" spruce woods, young stands suffer as well and normal reforestation is hindered. In many forested districts, one cannot find any undamaged broad-leaved reforested area.

Although the population of cervines can be regulated by hunting, weather conditions play an important role. As a well-adapted species, moose can tolerate cold winter weather, but not the roe deer and red deer. Future warming, especially in winter months, can have a positive influence on the population of roe deer and red deer. Consequently, it can be projected that increasing damages by cervines will occur, mainly in young forest stands.

Root rot (*Heterobasidion annosum*), with its widespread distribution, can be regarded as the most dangerous fungal disease in Estonian forests. Nearly 20% of the 1989–1994 clear cuttings involved urgent cutting of stands damaged by root rot. The data indicate an increasing role of this disease (see Table 4.8). Climate change and an increase in average temperatures will make environmental conditions for the spread of root rot more favorable. More damaged areas and hence heavier economic loss may occur in coniferous stands. Such a situation will not be realistic for broad-leaved stands in the near future.

Table 4.8 Dynamics of urgent clear cutting areas as a consequence of damage by root rot (hectares/percent)

Year	Spruce stands	Pine stands	Total
1989	32.8/91.1	4.0/8.9	36.8/100.0
1990	17.1/59.6	11.6/40.4	28.7/100.0
1991	14.1/88.7	1.8/11.3	15.9/100.0
1992	20.9/77.7	6.0/22.3	29.6/100.0
1993	162.1/95.0	8.5/ 5.0	170.6/100.0
1994	383.1/91.2	37.1/ 8.8	420.2/100.0

With further climate warming in Estonia, changes in the dynamics of forest pests and damages caused by them are likely. The damaged forest area, which has increased in the last decades, is likely to further increase in the future. Reproduction outbreaks of pests that feed on coniferous and broad-leaved trees will occur more often. The preconditions for the immigration of southern dendrofagous insects will improve. Tree-resistance to trunk pests will decrease due to droughts, especially in the best spruce sites. There will be displacements in forest insect phenology.

Climate change is also likely to alter forest growth and the shape of growth functions. It is likely to result in faster forest growth because of the air pollution, higher CO_2 concentrations and additional nutrients in the air (Nilson & Kiviste, 1984; Spieker, Mielikäinen, Köhl, & Skovsgaard, 1996). Climate change is not the only factor that could affect forest growth rates. Most factors influencing forests and forestry are related directly or indirectly to human actions, especially drainage, intensity of forest management, market changes, and game management. Climate change should be considered within the context of other factors that are changing at different speeds and to different extents.

Although during the last 12,000 years there have been many remarkable changes in the Estonian climate, no Estonian tree species (Scotch pine, Norway spruce, birches, alders, aspen) have disappeared in Estonian territory. The main tree species represented in Estonian forests cover a large area and are growing in a variety of climatic and soil conditions. This indicates a great variability of their genome and adaptability. It is unlikely that climate change over the next 100–200 years will be more drastic than the changes that have already occurred during the last 10,000 years. Consequently, one cannot expect drastic changes in the species composition of Estonian forests over the next 100–200 years. Nevertheless, the predicted climate change can affect forest management practices.

4.6 Water Resources

Understanding the sensitivity of water resources is one of the most important steps in the assessment of climate change impacts. The first estimates of climate change impact on water resources in Estonia were obtained in 1995–1996, through the U.S. Country Studies Program (Järvet & Jaagus, 1996). This study involved three river basins in different landscape regions (Pärnu, Kunda and Väike-Emajõgi). The results showed that regional differences in runoff are strongly influenced by local conditions. Consequently, as many river basins as possible were used in this study.

Estonia is located in a humid zone, where precipitation usually exceeds evaporation. However, due to very high variability of precipitation, drought periods as well as excessive wet periods do occur in Estonia. Climate change can cause significant changes in the hydrological regime and water resources. There are a number of uncertainties that should be carefully studied. A key concern is how precipitation amounts and snow cover will change. River runoff and water resources directly depend upon these parameters. One main goal of the UNEP country study was to estimate the impact of possible climate change on river runoff in Estonia using different climate change scenarios.

The land surface of Estonia is located within the Baltic Sea drainage basin. Estonia can be divided into three main watersheds (Lake Peipsi, the Gulf of Finland, and the Gulf of Riga) and 27 main river basins. Most of the basins have an area of less than 1000 km^2. Despite the small area of the country, there is a remarkable variability of hydrological parameters both in space and in time. There are 7000 rivers, brooks, and canals in Estonia. Those are divided between three basins: the Gulf of Finland, Väinameri and the Gulf of Riga, and Lake Peipsi. As many as 90% of the rivers are up to 10 km long and only 1% are over 50 km in length. The longest river is the Pärnu River in West Estonia. There are over 1400 natural and man-made lakes, covering 6.1% of the territory.

The following information and data sources were used for climate change impact assessment:

- Borders and areas of each river basin unit (catchment) from Department of Geography, University of Tartu
- Daily and monthly mean streamflow values for each river basin from the Estonian Meteorological and Hydrological Institute, and Information Centre of the Ministry of the Environment
- Monthly mean values of temperature and precipitation covering the watershed of each river basin unit from the Estonian Meteorological and Hydrological Institute
- Groundwater level and estimated resources data of different aquifers from the Estonian Geological Survey
- Current water use for different sectors for each river basin unit from the Information Centre of the Ministry of the Environment
- Data and digitized maps of land use from the Estonian Mapping Survey
- Climate change scenarios generated by MAGICC and SCENGEN programs

The longest continuous water level records in Estonia date back to 1867, when the recording of the Emajõgi River in Tartu was initiated. The first information on river runoff on the present territory of Estonia dates from 1902 at the Narva River. However, systematic hydrological observation of rivers did not begin until 1921. In 1990, Estonia's national hydrometric network included about 90 water level measurement stations, covering 28,734 km2, or 65.8% of the total area of Estonia (see Table 4.9).

Table 4.9 Measured runoff area in Estonia (km²)

Basin	Total area	Measured area	Measured area %	Ungauged area
Lake Peipsi-Narva River	15609	12289	78.7	3320
Gulf of Finland	9379	6680	71.2	2699
Gulf of Riga	14551	9712	66.7	4839
West-Estonia Archipelango	4140	383	9.3	3757
Total	*43679*	*29064*	*66.5*	*14615*

River runoff in Estonia is characterized by a very high temporal variability caused by precipitation fluctuations. The 7-year moving average demonstrates periodical fluctuations both of water level and river discharge, with maxima in the 1920s and the 1980s. Fluctuations of water level are caused by natural variations of precipitation (Behrendt & Stellmacher, 1987). Two kinds of periodical fluctuations were observed over a 126-year period for Lake Võrtsjärv: short-term fluctuations of 4–6 years, and long-term fluctuations of about 30 years.

Evapotranspiration is one of the main components of a water balance. Precipitation and discharge in a river are directly measurable, whereas the measurement of evapotranspiration is quite complicated. For the assessment of climate change impacts on evapotranspiration (ET), historical weather data was used as a baseline, along with increased temperature scenarios obtained from various GCMs. The estimation of ET includes climatic parameters not available from GCM results (e.g. relative humidity, duration of sunshine, vapor pressure deficit, wind velocity). In this study, the Penman-Monteith model was used to estimate ET. The climatic parameters commonly altered in GCM models were then varied individually to determine the sensitivity of the Penman-Monteith model. Sunshine duration, relative humidity and wind velocity were taken into consideration. The Penman-Monteith model does not directly include precipitation, but it is evident that changes in precipitation influence plant growth, causing changes in leaf area index (LAI) value, which is included in the model. The Väike-Emajõgi watershed was used as an example. Monthly mean and yearly average ET rates were compared against the baseline 1961–1990 study period.

The Väike-Emajõgi River basin, located in southern Estonia, is characterized by a hilly moraine relief and a sandstone plain covered by Quaternary sediments. Forests are the dominant land cover (about 60%), followed by agricultural land (29%). The most variable component in the watershed's water balance is precipitation. Runoff is less variable, and evapotranspiration is the least variable component. The catchment water balance depends on the state of the catchment's water storage.

Evapotranspiration shows a rather linear trend with increasing temperature, whereby a 1°C change causes about a 4% increase or decrease in annual average ET values. Temperature has a greater influence in the cold season, reaching up to 6.8% per 1°C in February. However, if the actual vapor pressure remains the same, then an increase in temperature will cause a higher vapor pressure deficit, and therefore higher ET. It has been suggested that with increased precipitation, the actual vapor pressure will also increase. Potential evapotranspiration is also very sensitive to changes in relative humidity; a 1% increase in RH produces about 1.6% lower ET values.

For the present study, six different IPCC 1992 scenarios (see Table 4.10) were analyzed. All scenarios have altered precipitation and temperatures. As Figure 4.5 shows, the predicted changes in ET will affect the cold season more than the growing season. However, the change in the magnitude is much smaller on an annual scale because the cold season ET constitutes only 10–13% of the annual ET. The biggest changes occur with the ECHAM3TR IS92e scenario. This scenario predicts a 16 mm increase in June, and about a 4 mm increase in January.

Table 4.10 Relative changes in yearly, vegetation-period, and cold-season evapotranspiration rates in different GCM scenarios for the watershed of the Väike-Emajõgi

Scenario	I-XII, %	IV-IX, %	X-III, %
HadCM2 IS92a	8.6	7.5	18.2
HadCM2 IS92c	4.5	3.9	9.5
HadCM2 IS92e	11.3	9.8	24.5
ECHAM3TR IS92a	13.4	11.0	34.7
ECHAM3TR IS92c	7.0	5.8	17.8
ECHAM3TR IS92e	17.9	14.6	47.1

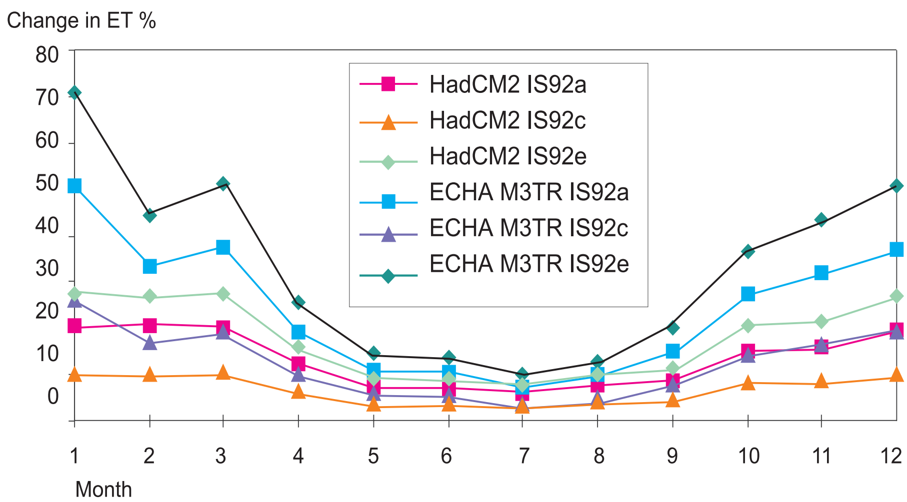

Figure 4.5 Relative changes in potential evapotranspiration by six IPCC 1992 alternative scenarios in the watershed of the Väike-Emajõgi

River runoff is one of the main characteristics describing available water resources. Possible changes in precipitation and air temperature should be reflected in runoff data. The aim of this study was to estimate the impacts of climate change on river runoff in different regions of Estonia using a water balance model. The point model WatBal (Yates, 1994) was used, as it is considered to be a suitable tool for climate change assessments of river basin runoff (Yates & Strzepek, 1994). WatBal is a lumped-integral conceptual model. A river basin is aggregated to a 'bucket,' for which the continuous balance function (1) describes water movement into and out of it. The main water input for the model is effective precipitation (Peff), and the main output, aside from runoff (R), is evapotranspiration (Ev). WatBal includes three models for PET calculated on a monthly time step: Priestly-Taylor, Thornthwaite, and Modified Penman.

Sensitivity analyses with the WatBal model were made using data from the period 1961-1990 for three river basins: Pärnu (gauge Oreküla), Väike-Emajõgi (Tõlliste) and Kunda (Sämi)

(Järvet & Jaagus, 1996). The results confirm that the model is stable; the correlation between the observed and modelled runoff was 0.8–0.9 for a variety of years and parameters. It was also found that runoff is significantly determined by effective precipitation. The results of model calibration show a remarkable variability of model parameters on the territory of Estonia, mostly caused by landscape differences.

The climate change scenarios described earlier were used for modeling the impact of climate change on river runoff. Using the WatBal model, changes in river runoff in the case of six climate scenarios were calculated for all the studied river basins. Percent changes in annual runoff are presented in Table 4.11. The Hadley Centre model shows lower increase in runoff, while the Max Planck Institute model indicates a higher increase. The emission scenarios reveal rather linear differences. The lowest increase in annual river runoff is projected by the HADmin scenario, the highest one by HAMmax. In general, an increase of annual runoff by 20–30% (HADmid) or by 40–50% (HAMmid) is modelled for the year 2100. These changes can be considered significant.

Key Point: River runoff and groundwater recharge is projected to increase significantly by 2100, but with dramatic geographical and seasonal differences.

Not only is the total increase of annual runoff important, but also its annual distribution. In most impact studies, the seasonal patterns of runoff have received less attention, especially concerning their regularity (Krasovskaia & Saeltun, 1997). However, modeling results demonstrate the possibility of enormous changes in seasonal runoff in Estonia. The results below illustrate geographical differences in the sensitivity of runoff to climate change. Runoff maximum is more sensitive than runoff minimum.

Possible changes in the annual course of runoff should be more substantial in the western part of Estonia, in regions with a maritime climate. In southern and eastern Estonia, the modeled annual curve of runoff is similar to the baseline. A decrease of modeled runoff in spring and its increase in autumn are typical of the western part of Estonia, especially of the West-Estonian Archipelago. Instead of four hydrological periods in a year, only two periods occur in this region: maximum runoff in autumn and winter, and minimum runoff from May to August. The Lõve River basin in the island of Saaremaa is the only basin from the West-Estonian Archipelago and coastal region included into this study. In the Lõve basin, the discharge reduction in the summer is greater than in other regions of Estonia. A shift in the spring runoff maximum to an earlier time will result in a longer duration of the summer low-water period and in a decrease of total runoff during the vegetation period (April–September) in many river basins of Estonia.

Climate warming is likely to lead to milder winters in Estonia, with a decrease in the duration of snow and ice cover. Mild winters lead to a more rapid snow melt and an earlier beginning of the spring season. Frequent melting periods in winter prevent accumulation of snow. The mean maximum runoff will move from April to March, and spring runoff will consequently decrease. There may, on the other hand, be an increase in river runoff in autumn caused by a significant increase in autumn precipitation. In some watersheds in West Estonia, autumn runoff maximum (in November) will exceed the spring maximum. The period of minimum runoff in summer will be lengthened, as the dry period will begin earlier. During this period, rivers receive the majority of water from groundwater. This could cause a severe water deficit in some small river basins in West-Estonia. However, it is important to note that all modeled changes in river runoff can be considered to be within the observed natural variation during the baseline period.

Table 4.11 Per cent change in annual runoff according to the climate change scenario

Watershed	Station	Sector	HAD-MID	HAD-MIN	HADMAX	HAMMID	HAMMIN	HAMMAX
Ahja_025	Ahja	E	26	13	31	39	21	51
Ahja_062	Koorvere	E	36	24	40	48	32	59
Avijo005	Mulgi	E	24	11	30	41	21	54
Emajo043	Tartu	E	46	33	51	60	42	72
Halli005	Riisa	E	26	13	32	41	23	53
Jägal026	Kehra	E	35	21	41	52	32	63
Kääpa011	Kääpa	E	30	16	36	48	27	61
Kasar017	Kasari	W	23	12	31	42	22	55
Kasar041	Teenuse	W	27	15	35	46	26	59
Keila019	Küla	W	27	16	35	46	26	58
Kunda025	Sämi	E	15	5	19	27	13	36
Leiva002	Pajula	W	35	21	43	54	32	68
Lõve_004	Uue-Lõve	W	9	-1	15	26	9	38
Mustj001	Mustjõgi	E	38	22	44	57	34	71
Naves015	Aesoo	E	24	10	27	37	20	48
Ohne_036	Tõrva	E	33	19	37	47	29	59
Pärnu026	Oore	E	22	10	26	37	20	47
Pärnu042	Tahkuse	E	20	8	25	35	18	45
Pedja046	Tõrve	E	30	16	36	48	27	60
Piiga009	Piigatsi	E	18	7	22	31	15	41
Põlts047	Pajusi	E	23	11	28	37	19	46
Pöögl002	Kuustle	E	40	26	46	57	37	71
Prand005	Tori	E	18	6	23	32	16	42
Pudis003	Pudisoo	E	36	21	42	54	32	68
Punge013	Roostoja	E	22	10	28	38	20	49
Purts008	Lüganuse	E	18	6	23	33	15	43
Reiu_022	Surju	W	39	25	47	59	37	74
Tagaj004	Tudulinna	E	22	9	28	40	20	52
Vääna028	Hüüru	W	22	11	29	40	21	51
Vemaj036	Tõlliste	E	35	21	40	50	30	62
Vigal024	Konovere	W	31	19	39	51	30	64
Vihte002	Vihterpalu	W	26	14	33	45	25	57
Võhan012	Räpina	E	26	14	31	40	22	51
Võhan057	Himmiste	E	29	16	33	42	24	54
Valge026	Vanaküla	E	31	17	36	47	27	58
Vändr007	Kiisa	E	43	30	49	61	41	74

For Estonia, a detailed groundwater budget has been completed on the basis of long-term observations, experimental measuring, and basin-wide groundwater flow modeling (Vallner, 1980). The total groundwater discharge to the channel network is approximately 7,700,000 m^3/d, but its intensity is spatially variable (see Figure 4.6). The spatial variation for the annual groundwater level fluctuations is controlled by the recharge-discharge mechanism, which mainly depends on climate. Direct groundwater seepage into the sea averages 800,000 m^3/d, and the exchange of subsurface fluxes between Estonia and adjacent territories does not exceed 10,000 m^3/d. The total net infiltration calculated by water budget investigations and groundwater flow simulations is 9,000,000 m^3/d. Average pumpage from wells and mines reaches 1,000,000 m^3/d. All these data should be considered as long-term mean values.

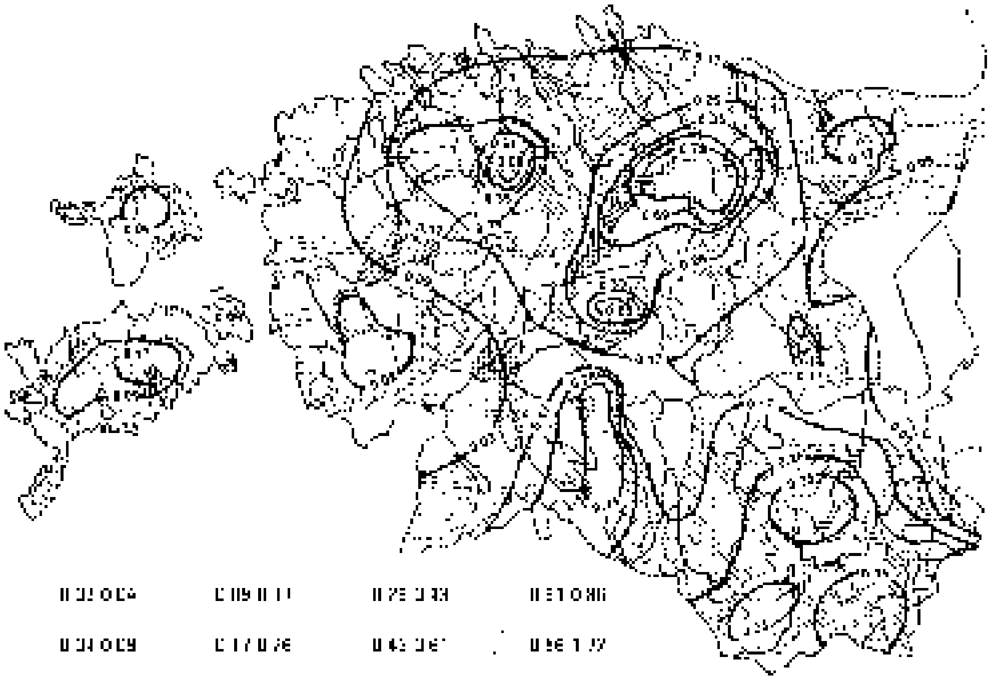

Figure 4.6 Long-term mean groundwater discharge to channel network (hatching, mm/d) and recharge (isolines, mm/d)

The aquifer system of north-eastern Estonia has been modeled by means of the computer simulation MODFLOW, elaborated by the U.S. Geological Survey (Vallner, 1996). The time step used for transient simulations was 10 days. The impact of climate change on the groundwater recharge was determined by substituting the increment of the surface runoff modelled into the equation, using the values of HADmid, HAMmid, HAMmax, and HADmax. The calculations show that as a result of climatic change, the expected increment of groundwater recharge will be from 0.007 to 0.186 mm/d, depending on the hydrogeological conditions of catchments. The relative increment of the groundwater recharge will vary from 6 to 75%. The most intensive accretion of the groundwater recharge occurs in Upper Estonia and especially in the Pandivere Upland. Infiltration rates will decrease towards the lowlands.

Regression analysis indicates that change in groundwater recharge is positively correlated with the change in surface runoff. According to transient simulations, realized by a time step equal to 10 days, an additional groundwater recharge will mostly take place in late winter and autumn. In these periods, contemporary infiltration is usually restricted because of low air temperatures, which prevent snowmelt. If the climate warms, precipitation will mostly reach the ground surface as rain, capable of instant percolation into the unfrozen soil. As a result, groundwater recharge will significantly increase during warm autumn and winter.

Groundwater recharge may be expected to increase by 20-40% as a result of climate change. If the scenarios HAMmax and HADmax are run, the accession of the groundwater recharge may reach even 75% in comparison with the present time. In the catchment of the Emajõgi River, groundwater recharge will be high under every climate scenario. Groundwater will be intensively recharged in catchments of most significant rivers of western Estonia (Kasari, Halliste, Keila) as well of the Jägala River under the HAMmid scenario. The HADmax scenario results in increased infiltration in catchments of the main rivers of southern Estonia (Väike-

Emajõgi, Võhandu), and also in the catchments of the Valgejõgi and Vigala rivers. Despite the differences in infiltration rates, the areal distribution of groundwater recharge is almost the same according to both scenarios. Owing to climate change, the ratio of the groundwater recharge to the total surface runoff will increase from 30 to 40%.

The predicted increase of groundwater recharge and the rise of the groundwater table will simultaneously be conducive to and complicate water management in Estonia. The rising of the groundwater table will benefit water supply. In Estonia, a large portion of the rural population gets their domestic water from shallow wells. They are commonly only a half-meter deeper than the mean low groundwater table under natural conditions. In hot summers and in cold winters, many of these wells become unfit for water supply, or even run dry. Such a situation is quite common in the limestone plateau of northern Estonia and especially in the region of oil shale mines. To guarantee an adequate yield, the deepening of shallow wells has been recommended up until now. A rise in the groundwater table will significantly improve both the productivity and reliability of shallow wells.

Key Point: Increases in groundwater resources resulting from climate change will have both positive and negative effects on water resource management.

As a result of the general increment of groundwater recharge, the safe yield of bored wells mentioned will augment by some 20% or even more. Thus groundwater can be obtained by means of fewer wells and reduced drawdown at pumping. Consequently, the extraction of groundwater from upper confined aquifers will become cheaper as a result of projected climate changes. However, many towns and villages in northern Estonia along the coast of the Gulf of Finland get their drinking water from deep aquifers that belong to the zone of passive water exchange. Pumping conditions of deep groundwater aquifers will not be altered on account of climate change.

On the negative side, the increase of groundwater circulation may favor the transport of pollutants in the water-bearing formation. The movement of pollutants may gather speed and the pollution plumes enfold greater areas than today. As a result, a portion of wells kept pure so far may become polluted. Therefore, the isolation and liquidation of groundwater point-pollution sources will be more expensive in the future. An intensive water circulation may lead to the formation of new sinkholes in the karsted carbonate bedrock, which may promote spreading of pollutants in groundwater. The rising of the groundwater table and thinning of the aeration zone will ultimately make it more difficult to cultivate arable lands suffering from overmoisture. Therefore, it will be necessary to reconstruct almost drainage systems for wet agricultural lands. If intensive mining of oil shale or phosphorite is undertaken in Estonia still at the time of the expected climate change, then it must be taken into account that the water inflow will increase into goafs or quarries by some 30% in comparison with the present time. It will complicate the dewatering of mines and make mining of mineral resources more expensive. Finally the basements of existing buildings may suffer from intruding subsurface flows due to the rising groundwater table. The foundations of new buildings and the isolation of their basements from groundwater will probably be more complicated and expensive.

Tallinn is the only big city in Estonia that consumes a large quantity of surface water (50-60 million m^3 per year). To collect such an amount of water, a water supply system has been built up, the intake structure of which embraces a territory of 2000 km^2 and includes several reservoirs, regulators, channels, and pump works. It gathers surface water from two big catchment areas: Pirita and Jägala. The latter is part of the Gulf of Riga drainage basin (upper course of the Pärnu River). Tallinn Water Supply System (TAWASS) was developed step by step during 1959-1986. At present it is the only surface water resource management system of national importance, therefore it was chosen for a case study on climate change impacts.

The aim of the case study was to estimate the sensitivity of TAWASS to different system parameters, water policies and consumption rates, how weather variability (affecting river runoff regime) influences the TAWASS, and how climate changes (according to selected scenarios) influence the TAWASS. TAWASS was modelled by the Interactive River-Aquifer Simulation program (IRAS). IRAS was developed by Cornell University and Resources Planning Associates, Inc. IRAS simulates, over time and space, water flows, storage volumes, water quality (concentration of substances) and hydroelectric power and energy in a variety of surface water or interdependent surface and groundwater systems (Loucks, French, & Marshall, 1995).

Among many parameters of the model, the water storage of Lake Ülemiste (total volume $26.0x10^6m^3$, minimum storage volume $10.0x10^6m^3$) is most suitable for a brief presentation of results because the model tries to satisfy Tallinn's water consumption need. If water shortages occur, the storage volume of Lake Ülemiste equals the accepted minimum. Using the most probable water demand for the period 2075-2100, one can see that all scenarios based on averaged flow data are very similar and water storage of Lake Ülemiste does not undergo stress periods. Changes induced by climate changes are small. To examine the system's behavior if Tallinn needed more water, a demand of $80x10^6m^3$ was prescribed. Results for comparison are presented in Figure 4.7. One can see that stress is possible during a dry spring when the runoff peak is not high enough to fill the reservoirs of the TAWASS. Consequently, some slight changes in water management policy (e.g. in reservoir release rules) may be necessary, but this requires more experiments with flow data in possible extreme years. In conclusion, changes of surface water resources, induced by possible climate change are in general favorable for the TAWASS, and will not lead to considerable changes in the system's behavior.

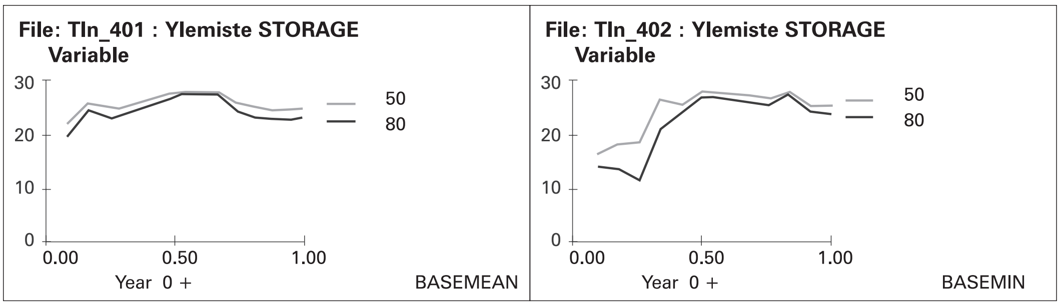

Figure 4.7 Influence of changes in water demand (50 → 80 10^6m^3) using two types of flow data: monthly averages for the baseline period (left) and monthly runoff of a specific year (right)

4.7 Land Drainage

The aim of drainage in agriculture and forestry is to reduce the level of the soil water table, which improves soil water conditions for cultivation and plant growth. In spring, a high water table is harmful and may lead to a late sowing time. In autumn, the crop may remain unharvested due to waterlogged soil. In general, almost 2/3 of the arable land of Estonia needs artificial drainage and predicted climate change will increase the importance of proper drainage activities. The analysis presented here is based on statistical data from an FAO study on "Sustainable Water Management Strategies for the Land Drainage and Irrigation Sector" carried out by the Institute of Water Management of the Estonian Agricultural University and Amelioration Bureau of the Ministry of Agriculture of Estonia.

In Estonia, the total drained area is currently 732,000 ha, including 650,000 ha with sub-surface drainage and 82,000 ha with open ditch drainage. About 561,000 ha of forested land is drained as well. It has been estimated that the potential drained area of Estonia can reach up to 880,000 ha. This means that almost 83% of the potential drained area has been already drained. The drainage work carried out in agricultural land (composed by arable land and cultivated grassland) is distributed unevenly by counties (see Table 4.12).

Table 4.12 Main characteristics of drained areas (01.01.1996) by counties (thousand ha)

County	Agricultural land	Sub-drainage	Open ditch drainage	Total drained area
Harjumaa	88.8	52.9	8.5	61.3
Hiiumaa	14.0	12.3	1.4	13.7
Ida-Virumaa	43.5	18.5	4.2	22.7
Järvamaa	84.5	37.0	9.9	46.9
Jõgevamaa	89.0	53.6	6.0	59.6
Läänemaa	46.5	30.6	6.3	37.0
Lääne-Virumaa	110.3	24.7	4.5	29.2
Põlvamaa	70.6	36.3	2.3	38.5
Pärnumaa	100.4	85.7	3.3	89.0
Raplamaa	78.1	50.5	9.1	59.5
Saaremaa	56.9	19.6	7.0	26.6
Tartumaa	104.1	80.7	6.5	87.2
Valgamaa	57.4	38.0	3.5	41.5
Viljandimaa	98.5	75.3	6.1	81.4
Võrumaa	68.7	35.2	3.1	38.3
Total	*1111.3*	*650.8*	*81.5*	*732.4*

The peak period of drainage construction was in the late 1960s and the early 1970s, when drainage on up to 40,000 ha was constructed annually. The construction of new drainage more or less ended in 1991. Under conditions of decreased agricultural production and economic difficulties, there are insufficient resources for the operation and maintenance of the whole drained area, thus some areas will be abandoned. After around 20 years without any maintenance, most of these abandoned areas can be treated as "natural" (i.e. undrained).

An inventory of drainage systems conducted in 1994 concluded that 37% of all sub-surface drainage systems were in good condition, 52% in satisfactory and 11% in unsatisfactory condition. The situation was worst in peat soils, where inadequate drainage was found in almost 30% of the drainage systems, or about 12,000 ha. Fortunately peat soil drainage constitutes only

6% of the total sub-surface drained area, In case of clay soils the total area of inadequate drainage was 20,000 ha, which makes up more than 17% of the drained clay soils. The highest percentage of inadequate drainage was found in Harjumaa, Lääne-Virumaa and Pärnumaa with 22%, 18.7% and 18.2% respectively. In absolute terms, the worst situation is found in Pärnumaa (15,000 ha) and Harjumaa (12,000 ha).

There are two aspects that should be considered in assessing the impact of climate change on drained agricultural land: 1) the magnitude of changes in water regime; and 2) seasonal variability within a year. The first aspect raises the question "do present drainage systems have the capacity to remove increased amount of water?" The sub-surface drainage systems in Estonia have been designed to remove excess water to a level of 0.25 m from surface within 1-3 days, from 0.25 m to 0.5 m within 2-5 days. This is mainly determined by drainage spacing. If drainage systems are working properly, then an increase in precipitation of about 30% will not cause significant damages to crop growth and permeability of soils.

This conclusion is not valid for peat and clay soils, where infiltration is slow and the main removal of water occurs as surface runoff. These soils will experience waterlogging after heavy rainfall, also there will be ponded water in the fields. The total amount of drainage in clay and peat soils is 115,000 and 41,000 ha, respectively. There is also a regional aspect, because the relative importance of soils of this type is higher in Western-Estonia: Pärnu, Lääne and Rapla counties.

The seasonal changes in the yearly runoff pattern show that in spring the maximum runoff will appear earlier and autumn runoff will increase. While increased precipitation raises the danger of waterlogging, increased temperatures will hinder this process. Especially important is the effect of the melting of snowpack and decreases in the frozen soil layer, which prevents the downward movement of infiltrated water. Temperature increases imply that the excess water will be removed earlier, and that sowing time can begin earlier. While springtime may become more favorable for agriculture, the increased precipitation in autumn (from the end of August until October) will seriously affect harvesting conditions. That will occur more likely in heavy soils (clay and peat soils) as well as in fields with inadequate drainage, especially in the western part of Estonia.

4.8 Adaptation

A large number of political, social, technological and other factors are changing at an increasing rate, particularly in countries undergoing the transition to a market economy. The most important of those changing factors are directly or indirectly caused by humans, and many of them are changing more rapidly and have a stronger impact on Estonian economy than the impact of climate change.

Adaptation is the key issue for mankind's welfare, starting from the personal level and extending to the level of human society as a whole. Adaptation is based on information, on the knowledge about the environment in the widest sense, and on "cause-effect" models. The terms adaptation and decision making are synonyms in general. There is a tendency in impact assessments to use increasingly sophisticated models. The more sophisticated a model, the more know-how is needed to adjust and run it and the higher is the risk of failure. The reliability of climate prediction, as the key model for this study, is quite low. Social, economic and technologic predictions are even more unreliable. Against such background it seems important to ask the question: to what extent does the uncertainty in Estonian agriculture, forestry, fishery and hunting in 2090 depends on climate change and to what extent on political, economic, technological and other man-made changes? Based on present knowledge, the impact of the man-made changes is likely to overshadow the impact of climate change in Estonia.

Forestry is a good example of adaptive decision-making in the case of climate change because of its long planning period. Bearing in mind the poor competence to predict political, economic, technological and other man-made changes in forestry, one has to conclude that the most efficient way to promote adaptation is through strategies based on permanent monitoring of the present situation and a flexible decision-making system. The general idea of adaptation is to accommodate the changing needs and wishes of the final consumer (e.g. mankind) on one hand and the changing possibilities of nature and man-made environments (e.g. infrastructure) on the other hand, in the most efficient manner. Every inefficiency in this process leads to waste of potential values and consequently to loss of real benefits.

Flexible adaptation has been indispensable in Estonian forestry. The forest area has tripled during the last 80 years and more than doubled in Estonia during the last 50 years. Drastic changes in the species composition of Estonian forests have occurred due to the damage by the human controlled moose population, but to some extent also due to diseases. The changes in Estonian forestry due to the direct influence of a possible climate change can be predicted to be at least an order weaker than the changes mentioned above.

The implementation of sustainability into the development of Estonia was planned in the Ministry of the Environment during 1993-1994. The process of long-term planning is nothing new for developed democracies, but for countries in transition like Estonia it meets serious obstacles, mainly among politicians because of associations with 5-year planning in the Soviet Union. In 1997, an amendment was adopted obligating the Government of Estonia to elaborate long term development plans for energy, transport, agriculture, forestry, tourism, and chemical and construction industries. The plan for development relies on projections for the utilization of natural resources and the state of the environment. If the development plan is passed, parliament has an obligation to finance mitigation and adaptation measures.

Adaptation to climate change fits into long-term development plans for the corresponding sectors. As much as possible these plans will consider cost-effectiveness, thus allowing rational decisions for shorter periods within the planning time. This type of master plan is already under elaboration for energy planning as a result of an effective political campaign in winter 1996/97. However, one has to be extremely careful with long-term plans and their implementation schemes based on models of climate change, given their uncertainties. Despite the relatively good possibilities of legislative intervention, there seem to be three groups of obstacles hindering effective implementation of countermeasures to climate change.

First, as Estonia is situated in the temperate zone, catastrophic impacts of weather and climate have not been as important in historical memory as the recent changes in political and social life. In fact, great catastrophes connected with climate (e.g. hurricanes) are relatively rare. Historically, economic and social issues have been much more significant than climate variability. However, sometimes climate has had a triggering effect for big historical events.

Second, in all post-socialist countries the change of paradigm in society from totalitarianism to democracy and from a centrally planned to market economy caused deep changes in every field of human activities, and in state structures as well. However, the speed and ways of reforms have been different, resulting in a variety of states at different stages of transition. In Estonia, it is evident that the rapidly changing situation in practical life and in legislation makes it difficult to discern both short-term and long-term trends. Subjective reasons like gaps in the collection of data for statistics and incomplete exchange of information between ministries complicate the situation even further. Estimations of sectoral developments are now more or less the opinions of experts, sometimes influenced by internal policy deliberation.

Third, the individual's knowledge about global ecology is not of primary interest in Estonia. In a country in transition with a rapid increase of income differences, a great proportion of the population has more problems in everyday life to solve relative to populations in more stable democracies. This leads to at least two reflections. First, politicians, counting potential votes, are not speaking very much about global issues, even if they are concerned. Second, mass media, ruled by the profit calculations, are more interested in "creating news" than in process analyses.

The degree to which climate change impacts and adaptation strategies are taken into account in Estonia is likely to be conditioned by the nature of the impacts and the ongoing changes in social and economic institutions. The country study recognized a number of strategies for adapting agriculture, forestry, and water resources to climate change. However, the constraints to adaptation discussed above must be addressed. Given the many positive impacts of climate change in Estonia, climate adaptation may appear trivial in relation to other, more pressing needs.

5 Pakistan

The climate change impact and adaptation assessment for Pakistan began in September 1996, and was conducted by a team of national experts under the coordination of Mahboob Elahi, the Director General of the Ministry of Environment. A copy of the full report can be obtained from the Ministry of Environment, Local Government and Rural Development, Islamabad, Pakistan.

5.1 Introduction

Pakistan is a developing country located in southern Asia, between latitudes 24ºN and 37ºN and longitudes 61ºE and 76ºE. It has an area of over 88 million hectares, and included within this area are a variety of landscapes, ranging from high mountain ranges to stark deserts. The Indus River and its tributaries dissect the country, providing a source of the world's largest contiguous irrigation network.

The population of Pakistan was estimated at 140 million in 1997. This population is unevenly distributed among four provinces: Sindh, Punjab, North West Frontier Province (NWFP), and Balochistan. More than half of the total population lives in the fertile Punjab province, whereas the largest province, Balochistan, has the least number of people.

Pakistan is divided into five physiographic regions, each with a number of sub-regions: 1) the Himalayas, 2) the Hindukush and the Western Mountains, 3) the Pothwar Plateau and the Salt Range, 4) the Indus Plain, and 5) the Balochistan Plateau. In addition, the coastal zone and the offshore Exclusive Economic Zone in the Arabian Sea can be considered physiographic regions.

The climate of Pakistan varies widely, from temperate climates in the north to hot and dry tropical climates in the south. The country is characterized by wide variations in both temperatures and precipitation. Temperatures reach as low as –26ºC over the northern mountains, and as high as 52ºC over the central arid plains. The mountainous and sub-mountainous areas of the northeast receive over 1700 mm of precipitation annually, in contrast to the arid plains of southwest Balochistan, which receive an average of only 30mm. Pakistan receives rainfall in both the summer and winter. In general, the Punjab and Sindh provinces receive more rainfall in the summer, whereas Balochistan and NWFP receive more rain in the winter.

During the summer, monsoon depressions dominate the weather. These depressions are associated with a surface pressure trough that develops over the sub-continent in a northwest-southwest orientation, roughly parallel to the Himalayas. The western edge of the trough merges into the seasonal heat low over Balochistan, and the eastern end extends over the northern Bay of Bengal. Monsoon depressions form in this eastern part and normally move as tropical cyclones in a roughly west-northwesterly direction. After crossing the central part of India, the depressions generally weaken in intensity because the moisture supply is cut off. Subsequently, they move further west-northwest and merge with the heat low over Balochistan. Once in about ten years, a still-active depression recurves towards the north or northeast, resulting in heavy rains over Kashmir.

The frequency and movement of monsoon depressions is varied. However, it usually covers most of the country by the middle of July and starts receding in the beginning of September. By November, low pressure waves or "Western Disturbances" approach Pakistan from the west. The structure of a western disturbance is similar to that of an extra-tropical disturbance. These disturbances contribute to winter rainfall in many parts of the country.

Interactions between physiographic characteristics, climate, water resources, and human activities have resulted in a number of distinct agro-ecological zones in Pakistan. These include the northern mountains, the rain-fed (*barani*) lands, the irrigated plains, the sandy deserts, the hill torrents (*sulaiman rod kohi*), the western dry mountains, and coastal areas. Only about one-fourth of Pakistan's total land area is arable. Irrigated agriculture is practiced on 16 million hectares, while the remaining 4 million are dedicated to rainfed agriculture.

The water resources sector is both the engine and the gear of development in Pakistan. However, per capita surface water availability is progressively decreasing as population increases. As a result, Pakistan has moved from being a water-affluent country towards being a water-scarce country. Such a situation merits more efficient water management practices, both at macro and micro levels. This includes the construction of additional reservoirs on the Indus River, as well as the adoption of water conservation measures.

About 14% of Pakistan is covered by deserts, including Thar, Chyolistan, Thal, Chagei, and Kharan. Rainwater is the primary source of fresh water in these areas. Human activities in desert areas are primarily dependent upon the availability of rainwater. Temperature conditions in most parts of Pakistan's deserts are severe. As such, a small increase in temperature is unlikely to have a significant effect on current hydrological conditions. However, any change in precipitation will have significant effects. Already, almost three quarters of the land area of Pakistan is subject to some degree of desertification. The extent and severity varies with the type of ecosystem. It has been speculated that the shifting of sand dunes along the Makran coast in Balochistan, and the denuding of rangelands by livestock, are both contributing to desertification. Rangelands support an estimated 8.5 million livestock units, which is considered to be twice the estimated sustainable carrying capacity.

Natural processes as well as anthropogenic activities have been responsible for large-scale land degradation in Pakistan. Wind and water erosion, waterlogging, salinity/sodicity, flooding, and loss of organic matter and biodiversity are major problems in Pakistan.

Pakistan, like many other Third World countries, is a society in transition from an agricultural-based economy to a modern industrial economy. This transformation of Pakistan's economy has been accompanied by high population growth, a rapid rate of urbanization, urban infrastructure degradation, environmentally damaging agricultural and industrial practices, inefficient energy use, high biomass consumption, and deforestation. These factors are also likely to increase Pakistan's vulnerability to climate change.

Key Point: Rapid socioeconomic changes accompanied by a variety of environmental stresses are likely to increase Pakistan's vulnerability to climate change.

However, it is important to distinguish the impacts generated by socioeconomic processes from those attributed exclusively to climate change. In particular, there is a need to develop a sense of the relative importance of climatic and non-climatic factors. This is especially important when considering adaptation strategies. It can be presumed that such vulnerability will establish the pattern of adaptive responses, and that climate change will either reinforce or mitigate the intensity of such adaptations, without altering the basic patterns.

Low levels of human resource development can exacerbate vulnerability to climate change impacts. Unchecked population growth, for example, exerts additional pressure on physical infrastructure and the environment. Low levels of literacy are associated with high fertility levels and a neglect of health and nutrition at the household level. The absence of health care facilities and education increases the population's vulnerability to climate-induced changes in vector and water-borne diseases, to respiratory illnesses, and to heat-related morbidity and mortality. The socioeconomic situation alone in Pakistan places the country in a vulnerable position. Climate change is likely to influence and exacerbate the situation.

For example, an increase in temperature could raise the incidence of mortality and morbidity in Pakistan. Heat-stroke deaths are closely correlated with high temperature extremes. Every year, newspapers report scores of deaths from heat stroke. Heat-stroke deaths are probably underreported in rural areas. Increased precipitation could create more stagnant ponds, and result in an increase in the number of water-borne diseases, unless control measures are strengthened. Currently in Pakistan, the spread of water-borne diseases causes nearly 40% of all deaths. Typical water borne diseases in Pakistan include typhoid, cholera, gastro-enteritis, dysentery, and infectious hepatitis. Controlled disposal of municipal wastes is limited to sections of a few major cities and industrial sites.

The impacts of climate change in Pakistan can be categorized in terms of the major economic sectors, significant cross-sectoral resources, and vulnerable areas. Areas considered in this report include agriculture, water resources, forestry, human health, industry, and energy. The time frame used in the study was determined by the limits of predictability, the availability of data, the nature of climate chance, and sector specificities. The time frame for the impact studies extended to the year 2100, with recognition that the distant future is surrounded by much greater uncertainty. Sectorally, climate change impacts are expected to occur relatively early in the water resources and agriculture sectors, while forest ecosystems are likely to be affected much later.

5.2 Socioeconomic Characteristics of Pakistan

Pakistan is described by the World Bank as a low-income developing country. Between 1972 and 1995, the country maintained an annual growth rate of 5.4%. However, over a shorter period (1991–1995) this growth rate fell to 3.7%. This recent decline reflects both structural and transient constraints. The structural constraints are evidenced in a continuation of an inward-looking industrialization strategy, a deteriorating infrastructure base, fiscal imbalances, social sector neglect, and institutional weaknesses.

The service sector accounts for the largest share of GDP (49%), whereas the manufacturing and commodity sectors contribute 18% and 33%, respectively. The low share for manufacturing is an outcome of protectionist policies that have generated inefficiency and resulted in low added value to agro-based industries.

Agro-processing based industries dominate Pakistan's industrial sector. Key industries include sugar, vegetable ghee, cotton spinning, weaving, leather, carpets, fish and fish by-products, paper, chemicals, petroleum refining, and basic metals. Large-scale industries contribute to about 12% of GDP, whereas small-scale industries contribute only about 6%.

Agriculture presently contributes 25% of Pakistan's national income, and provides employment to 50% of the labor force. Approximately 60% of the country's exports are directly or indirectly based on agriculture. The soils, topography, and climates of Pakistan are generally suitable for year-round agriculture. The major agricultural areas lie within the basin formed by the Indus River and its tributaries, which run in a general northeast-southwest direction. Low organic content of soils, water and wind erosion, waterlogging, salinity/sodicity, and flooding are causes of land degradation that affect agricultural productivity. An estimated 17% of the land surveyed is affected by water erosion, 7.6% by wind erosion, 8.6% by salinity and sodicity, and 5.1% by waterlogging. Furthermore, 96% of the arable soil suffers from less than adequate organic matter.

Agricultural production has also been constrained by problems of a technical, institutional, and policy nature. Technical constraints are evident in poor agronomic and post-harvest management practices. Institutional deficiencies include capital scarcity for small farmers, inadequate research, and weak extension programs. Policy problems relate to input and output price distortions. In recent years, structural problems have emerged, precluding production increases in agriculture. These structural constraints include land use limits, non-availability of water, land degradation, and land fragmentation accompanied by a reduction in land holdings.

In comparison to other low-income countries, Pakistan ranks poorly in terms of its social indicators. The adult literacy rate in Pakistan is very low (39%), and the female literacy rate is among the lowest in the world (26%). Primary and secondary school enrollment rates are only 44% and 21%, respectively, and there are large gender gaps in education. Health care in Pakistan remains under-funded, with total annual expenditures as a percentage of GDP at 3.4%. A political commitment to social sector development has been historically weak in Pakistan.[2] However, the situation has improved in recent years with the initiation of the Social Action Program (SAP) and various other joint government-donor initiatives.

The annual population growth rate in Pakistan is estimated at 2.5%. This raises concerns about future resource requirements and the growing demand for health, nutrition, and education. A combination of population growth and per capita income growth, along with urbanization and modernization of Pakistan's economy, have resulted in large and unmet demands for power, telecommunications, transportation, and water. Budgetary constraints have impeded the expansion of the infrastructure base, placing additional pressures on existing facilities at the expense of rehabilitation and maintenance. For example, capacity shortages in power and telecommunication are estimated at 20%.

The principal indicators of health in Pakistan are not encouraging: Life-expectancy at birth is low (55 years), infant mortality rates are high (106 per 1000 live births), and overall mortality is high (the crude death rate is 12 per 1000 people). About 64% of all deaths in Pakistan are due to infective and parasitic diseases. The incidence is higher in urban areas (68%) compared to rural areas (62%).

The incidence of cancer in Pakistan is also ranked very high. Air and water pollution have reached alarming proportions, and the effects of toxic, industrial, and vehicle emissions, as well as noise and dust pollution on human health are alarming. Unlike water pollution, air pollution is more of an urban problem in Pakistan. In fact, morbidity is worst near the industrial centers of Karachi, Lahore, Faisalabad, Hyderabad, Rawalpindi, and Peshawar. Almost every type of industrial chemical is either produced or imported for use in Pakistan. However, both their use and disposal are largely unregulated. Excessive use of pesticides is a problem in both rural and urban areas.

5.3 Baseline Scenarios

To understand the future impacts of climate change, the Pakistan country study team focused on developing long-term socioeconomic scenarios. Two baseline socioeconomic scenarios were developed up to the year 2020. For the later period (2020–2050), the scenarios become more speculative. The interdependence among various socioeconomic and environmental indicators precludes stand-alone forecasts. Table 5.1 presents a synthesis of both a "business as usual" scenario, as well as an optimistic scenario.

[2] There are strong rural-urban, regional and gender differences with regard to health and nutrition in Pakistan. There are also strong differences related to income and educational level. Pakistan, like many other countries, maintains a bias towards urban-based curative care, as opposed to preventative care.

Table 5.1 Integrated scenarios

Scenarios	Year					
	1992	2000	2010	2020	2030	2050
"Business as Usual" case						
Population growth (%)	3.0	2.6	2.3	1.9	1.9	0.0
Urbanization (% of population)	33	37	42	45	47	50
GDP growth (%)	5.4	5.4		5.4		5.4
Sectoral share (%)						
Manufacturing	18	19	20	22	23	25
Agriculture	27	24	22	20	18	16
Trade (Average tariff rate)	70	30	25	20	18	15
Physical infrastructure development (%)						
Private investment share	20	30	50	70	75	80
Social sector development (%)						
Education – literacy rate	35			60		
Health expenditure	3.4			4.9		
Fiscal deficit (%)	6.0	7.0	6.5	5.5	4.8	4.0
CO2 emission (000Gg)- without mitigation	123	140	241	405	560	700
Optimistic case						
Population growth (%)	3.0	2.4	2.0	1.5	0.0	0.0
Urbanisation (% of population)	33	37	42	45	47	50
GDP growth (%)	5.4	7.0		7.0		7.0
Sectoral share (%)						
Manufacturing	18	20	25	30	35	35
Agriculture	27	22	18	15	10	10
Trade (Average tariff rate)	70	25	20	15	10	10
Physical infrastructure development (%)						
Private investment share	20	30	40	50	60	70
Social sector development (%)						
Education – literacy rate	35		60	75		
Health expenditure	3.4		4.9	6.0		
Fiscal deficit (%)	6.0	8.0	7.0	4.0	4.0	4.0
CO2 emission (000Gg)- without mitigation	123	160	300	500	700	1000

The "business as usual" (BAU) scenario combines long-term trends with recent structural reforms. The optimistic scenario is based on sanguine assumptions about economic policy, institutional governance, and political developments. Some of the assumptions included in the table are listed below:

- Higher industry shares reflect higher GDP growth rates
- Higher GDP growth rates are associated with lower tariff rates, a proxy for export promotion
- Relatively higher industry shares correspond with higher CO_2 emissions
- GDP growth is correlated with expenditures on health and education
- The fiscal deficit is reduced at a slower rate in the high case scenario, reflecting public sector expenditures on physical and social infrastructure development

Urbanization rates are scenario-neutral. This is because the potentially higher rate of urbanization associated with industrialization will be offset by social and infrastructure development in the rural sector.

Population Growth: Pakistan's current population is estimated at 131 million, growing annually at a rate of 2.5%. Pakistan is expected to become the tenth most populous country in the world by 2010. Under the BAU scenario, population projections will follow the bounds represented by current demographic and socioeconomic trends. The growth rate is projected to decrease to 2.1% in 2010, and to 1.9% in 2020. These decreases are based on the following premises:

- reduced fertility levels associated with female education
- greater availability and acceptance of family planning services
- better delivery of these services through community-based programs
- integration of family planning with basic health services
- distribution of contraceptives through commercial and social marketing channels
- improvements in maternal and child health care

The optimistic scenario envisages a growth rate of 2% in 2010, and 0% or replacement levels in 2030. To achieve these rates, a political consensus on the need to curb population growth is needed, followed by an acceleration of initiatives under the Social Action Program, particularly those that directly and indirectly affect fertility.

The population structure of Pakistan is made up of a disproportionate number of youth. Development of Pakistan's social sector is likely to be influenced by two opposing tendencies. On the one hand, political and budgetary constraints and institutional inadequacies have given low financial priority to the social sectors, making it difficult to maintain present levels of service. On the other hand, the government's Social Action Program (SAP) is wide-ranging and ambitious. It seeks to reduce gender disparities among implementers and beneficiaries, introduce cost-recovery mechanisms, and create incentive-based systems to reward efforts. The SAP also aims to decentralize operations to the district level, involve local communities in the design, planning and implementation of social services, and encourage private sector participation. Under the optimistic scenario, if strategic initiatives and policy reforms are fully implemented, Pakistan's total literacy rate could reach as high as 60% in 2010, and 75% in 2020. Female literacy rates would increase as well, to 45% in 2010 and 60% in 2020.

Urbanization Trends: Under the BAU scenario, the urban population is expected to grow at about 4% over the projected period. It will triple in size over a 25-year period, and include half of the total population by 2020. The underlying factors contributing to this scenario include natural increases, in-migration, and place transformation (i.e. the amalgamation of areas). In-migration partly reflects growing urban prosperity, stemming from industrial and service sector growth and increased employment opportunities. It also reflects limits to extensive cultivation in agriculture, continuing mechanization and land consolidation, the displacement of people on marginalized land, and the relative neglect of the rural sector in terms of social services and infrastructure.

Economic Growth: The BAU scenario includes the effects of wide-ranging economic, social and regulatory reforms instituted in recent years. However, it assumes only modest efforts to address the implementation constraints associated with these reforms. The optimistic, or high growth scenario, assumes strengthening of the democratic process, sustained economic and fiscal restructuring, institutional strengthening, and improvements in governments. A low growth scenario was also considered, whereby there is stagnation in industry and agriculture, further infrastructure degradation, growing fiscal imbalances, and continued law and order problems in Karachi and Punjab. The BAU scenario projects past trends into the future in the case of agriculture and industry.

In the optimistic scenario, manufacturing is seen as the driving variable behind economic growth. The key to sustained industrial growth of over 10% includes outward-looking industrial policies, sound economic management institutions, improvement in infrastructure and services, and political stability. Pre-2020 growth rates of 7% will create a foundation for even higher growth rates after 2020. Under such an optimistic scenario, industry's share of GDP could reach 35–40%, while the share of agriculture could decline to about 10%. Industry and service sector synergisms would also generate intra-sectoral shifts within the services sector, whereby those activities servicing would increase while commercial and construction activities would decrease.

In terms of industrial development, projections for manufacturing value added were based on growth rates derived from regression equations using Census of Manufacturing Industries (CMI) data from 1975–76 to 1990–91. Agricultural land constraints were factored into the analysis, such that growth in agro-based products such as sugar and cotton were dampened. In addition, upward adjustments of 1% were made for industries concentrated in Karachi, premised on improvements in the law and order situation. As seen in Table 5.2, the share of agro-based industries is projected to decline from 58% in 1991 to 40% in 2030. This is reflected in as structural shift towards non-agricultural based products.

Table 5.2 Growth in manufacturing (value added)

Medium case projections (Million PKR)					
Industries	**1991**	**2000**	**2005**	**2010**	**2020**
Sugar	8.75	20.00	40.00	80.00	150.00
Edible oil	1.66	2.19	2.65	3.21	4.70
Cotton spinning	16.71	50.00	100.00	200.00	800.00
Cotton weaving	3.49	5.93	8.55	12.33	25.64
Paper	1.74	5.37	10.02	18.70	65.20
Chemicals	8.90	36.90	84.05	191.48	993.70
Petroleum products	2.16	6.45	12.25	23.28	84.07
Cement	6.8	25.36	52.35	108.08	460.58
Basic metals	5.93	13.41	21.12	33.24	82.38
Total:	*56.22*	*165.61*	*330.99*	*670.32*	*2583.89*
Total agro-based	*32.35*	*83.49*	*161.22*	*314.24*	*1045.54*
B as % of A	*57.5*	*50.4*	*48.7*	*46.9*	*40.5*

Source: Projections are driven from regression equations using historical data from the Census of Manufacturing Industries.

A more optimistic scenario, with industrial growth of more than 10% and a higher value added among product groups such as leather and cotton, is premised on a policy and institutional climate based on low protection, a level playing field for foreign and domestic investment, and a strong infrastructure support. Under such a scenario, the share of agro-processing industries is expected to decline to 25% by 2020. This decrease will be offset by an increasing share of engineering, electronic and other tertiary products. After 2020, industry will be the lead growth sector, with agro-based products declining to 15–20%.

Large amounts of capital are required to expand and maintain the infrastructure base. To sustain GDP growth rates of 5% and above, it is estimated that investments of about USD 65 billion are needed over the next 15 years. Because this is beyond the capacity of the public sector, at least 75% of the required investment will need to be generated in the private sector. The scope for such private-sector financing is tied to organizational restructuring, backed by regulatory and administrative reforms. This might involve the privatization and regulation of natural monopolies, such as railways, roads and ports, water and sewage, and electrical power and gas transmission and distribution. It could also include corporatizing and decentralizing activities that are currently under public sector control and management, such as hydroelectric power generation and irrigation. Finally, organizational restructuring could emerge as a result of increased competition in fields such as telecommunications and thermal power generation.

Energy: Per capita energy consumption in Pakistan is considered to be quite low. Total final energy consumption in Pakistan was 46.81 million tons of oil-equivalent (TOE) in 1995–1996, or about 0.35 TOE per capita. If conversion and transportation losses are included, the total amount increases to 62.42 million TOE. Although this can be attributed to low overall development, it also reflects the absence of energy infrastructure in rural areas and a heavy reliance on biomass consumption. Despite low per capita energy consumption, energy intensity has been increasing over time. In other words, Pakistan uses its commercial energy in an extremely inefficient manner.

The energy system in Pakistan has traditionally been demand-based, with commercial demand in excess of supply met through imports. Oil products accounted for over 42.5% of the commercial supply, followed by natural gas (36.3%), hydro and nuclear electricity (14.6%), coal (6%), and liquid petroleum gas (LPG) (0.5%). Commercial sources contributed about 49% of these supplies, and non-commercial sources about 51%. Fuelwood dominates traditional fuel supplies (60%), followed by dung (19%) and crop residues (21%).

The energy demand scenario is driven by macroeconomics, demographic trends, and sectoral variables. The rate of population growth and urbanization is correlated with household energy consumption, as well consumption in the transport sector. The rate of industrial and agricultural growth is correlated with the respective energy needs of these sectors. Fuel-use economy resulting from various demand-side management measures is also factored into the forecasts. Although biomass consumption is not explicitly addressed, the switch from traditional to modern fuels is implicit in the household sector projections. This reflects a depletion of fuelwood stocks and the expansion of modern energy infrastructure in rural areas. Finally, it is anticipated that the power sector will rely increasingly on dirty fuels, such as oil and coal, as natural gas reserves are depleted.

Energy consumption is forecast to increase almost five-fold by the year 2020. The fuel consumption needs of the power sector are likely to be twice the needs of the industry and transport sectors by 2020, whereas they are roughly equal in the base year. The relative share of non-commercial or traditional fuels in overall energy consumption is expected to decline in relative terms. In absolute terms, however, the consumption of biomass is expected to grow to the year 2020 and beyond. Fuelwood consumption is expected to rise to over 14.5 million TOE from a 1996 level of 12.6 million TOE, and other biomass fuels such as dung or crop residues to over 23 million TOE from the current level of 11 million TOE.

After 2020, fuel consumption needs in the power sector are likely to taper off, as earlier investments in thermal power generation come on-stream and additional hydroelectric power is developed as an alternative energy source. The main contributors to increased energy consumption in the post-2020 period will be the industrial sector, the domestic sector, and the transport sector.

In terms of distribution, future energy scenarios will have positive impacts. Planned increases in power generation capacity and supply of natural gas are based on the government's objective to intensify its rural electrification drive and expand natural gas connections to rural areas. This should reduce reliance on biomass fuels, which in 1995 was greater than the collective consumption of all other fuels. Consumption of fuelwood at present rates is unsustainable, given Pakistan's diminishing forest cover.

The impacts of energy demand scenarios were considered in relation to public health, distribution, economic growth, infrastructure, and the environment. The growing use of oil-based fuels and coal will lead to higher concentrations of hydrocarbons, aldehydes, carbon monoxide, sulfur dioxide, nitrogen oxides, and lead in the atmosphere. The direct health problems related to such emissions include bronchial, lung, and eye irritation, accelerated asthma attacks, reduction in the blood's oxygen carrying capacity, inhibited growth, and mental debilitation.

Agriculture: Approximately 20 mha of Pakistan’s land area is used for agricultural production. There is little land available in Pakistan for the expansion of arable agriculture. Nevertheless, agricultural production remains far below its potential because of undercropping on available land. An increase in double-cropping since 1973–1977 has been directly associated with the increase in private tube wells. Abundant quantities of Class I and II soils suggest the possibility for an additional three-fold intensification. However, limits to water availability precludes such intensive land use, particularly in view of competing demands for drinking water and sanitation services. In view of water supply constraints, the challenge for Pakistan is to use existing supplies more efficiently to improve crop yields.

The agricultural growth scenario considers an overall growth rate that increases with projected population growth in order to meet basic food needs, as well as a 2% increase over this growth in order to satisfy demands arising from increased incomes and to sustain export growth. The agricultural growth rate includes a structural transformation within the sector, whereby the crop component declines from 70% in 1992 to 60% by 2050, whereas the livestock component increases from 28 to 39%. The fisheries component, currently small, is expected to drop, while the percentage of forestry GDP is expected to double by 2050.

The scope for increased agricultural production at the extensive and intensive margins has been substantively exhausted by land and water limitations. Agricultural growth is premised on productivity increases associated with improved water use efficiency, rationalization of input and output prices, and agronomic improvements such as new seeds, crop rotation, and incorporation of agricultural residues and green manuring. In addition, better post-harvest management and marketing improvements could increase agricultural productivity. Improved animal husbandry practices could also be implemented. Finally, increased institutional support could benefit production, including input credits for small farmers and intensification of research. From an environmental perspective, the lining of canals, improvement of drainage, rehabilitation of saline and waterlogged soils, water conservation, and flood control would contribute to production increases.

The demand for agricultural commodities in Pakistan has been calculated by the National Commission on Agriculture and the Water Sector Investment Policy Study. For this study, demand estimates were made for the medium case socioeconomic scenario, which assumes population growth rates of 1.9% and 0.0 % by the years 2020 and 2050, respectively. The year 1995 was selected as the baseline, and population growth rates of 2.4% and 0.95% were used for the periods 1995–2020 and 2021–2050, respectively. The projected requirements for various agricultural commodities are presented in Table 5.3. Per capita demand as estimated by the National Commission on Agriculture (NCA, 1988) was used for the projections.

Production projections for major agricultural commodities in Pakistan were made for the years 2020 and 2050 (see Table 5.4). The projections take into consideration improvements in water management, rationalization of input and output prices in line with water prices, improvements in agronomic practices, improved post-harvest management, institutional support, and so on. Production projections are less than the future demand requirements for wheat, rice and sugarcane, but higher for fruits, vegetables, meat, and milk. This means that Pakistan could face problems of food grain shortages in the years 2020 and 2050, even if the agricultural growth rate is equivalent to the population growth rate.

Table 5.3 Demand for selected agricultural commodities in Pakistan (1000 tons)

Commodities	Baseline requirement 1995	Projected requirement 2020	Projected requirement 2050
Wheat	17.9	32.4	43.0
Rice	5.1	9.2	12.2
Sugarcane	41.6	75.3	100.0
Cotton*	1.8	3.3	4.4
Fruits	5.1	13.8	18.3
Vegetables	4.5	12.2	16.2
Meat	2.1	5.7	7.6
Milk	15.3	41.5	55.0

*Represents 10.6, 19.4 and 25.9 million bales respectively

Table 5.4 Production projections of major agricultural commodities in Pakistan (1000 tons)

Commodities	2020	2050
Wheat	27.46	35.70
Rice	6.21	7.89
Maize	1.89	2.40
Cotton	18.00*	25.00*
Sugarcane	50.0	60.0
Fruits and vegetables	20.0	50.0
Livestock		
Meat	5.0	14.0
Milk	50.0	125.0

* million bales

In order to achieve self-sufficiency in major crops and commodities, the suggested growth rates shown in Table 5.5 would have to be achieved. In general, the agriculture sector would have to grow at a rate of about 4% per year to meet the country's growing demand for food.

Table 5.5 Suggested agricultural growth rates for various commodities to achieve self-sufficiency

Commodity	Annual growth rate (%)	
	1997-2020	2021-2050
Wheat	2.6	1.0
Rice	4.0	1.0
Sugarcane	1.9	1.0
Cotton	3.3	1.0
Fruits	4.1	1.0
Vegetables	4.0	1.0
Meat	4.1	1.0
Milk	4.1	1.0

Water Resources: The future water needs of Pakistan depend upon assumptions about population growth. Population estimates for the year 2050 vary widely, depending on whether exponential or linear growth is assumed. To estimate urban water demands, provision of service to 50% and 75% of the population was considered for the years 2020 and 2050. For the industrial sector, water consumption was considered to be five times higher than the estimates for 1990. Agricultural demands were based on per capita food requirements for the year 2000 and beyond, as well as on current water usage and acreage.

Key Point: Water resources are critical to development in Pakistan. However, prospects for future water availability are limited, even if storage capacity is increased and resources are distributed more efficiently.

About 30% of the water diverted for agriculture actually reaches the crops. The remainder is lost between canals and watercourse heads, within the watercourses themselves, and in farmer's fields. However, a significant proportion of the losses constitutes secondary water resources, through groundwater recharge. This is estimated at 46 million acre–feet (maf) annually, of which 41 maf is pumped up through tubewells. In short, the possibilities for making additional groundwater available to farmers are limited. Diverting additional flows from the Indus River system is likely to result in major environmental problems by inducing seawater encroachment in coastal areas.

A baseline scenario for the water resources sector shows prospects for future water availability to be limited to an additional 5–15 maf at best. This could be achieved by increasing the efficiency of the distribution system, increasing water storage capacity, and exploiting groundwater. With the construction of additional storage capacity, water releases would be better regulated, and more water would be available for *rabi* crops. Flood management would also be improved. However, if capacity increases also lead to reduced water outflows to the sea, coastal resources and fisheries could be threatened. According to the baseline scenario, existing levels of waterlogging and salinity are likely to remain unchanged. Continual water scarcity and rotational, supply-based distribution will constrain productivity. Improved irrigation measures can enhance water use efficiency, and the availability of groundwater can ensure a better match between water demand and supply.

Forestry: As little as 5% of Pakistan's total area is under forest cover. Of this, 30% is economically utilized, while the remainder is under protective cover. Both economic and environmental considerations suggest that the desirable range of forest cover is 25–30%. An area ranging from 7,000 to 9,000 hectares is deforested each year, which corresponds to about a 2% decline in forest cover annually. The factors contributing to deforestation include logging for timber, cutting of fuel wood, land-use changes such as crop cultivation, and overgrazing of livestock. There are numerous socioeconomic consequences of deforestation. For example, many rural communities in the Northern Areas have been displaced by soil erosion and degradation. From a biological perspective, the clearing of mangroves in coastal areas has resulted in sea encroachment and the loss of habitat for many marine species.

Financial, institutional and foreign exchange constraints, regulatory loopholes, and increasing commercial returns from fuelwood and timber contribute to a fairly pessimistic outlook with regard to the future of forests in Pakistan. Afforestation efforts in Pakistan have yielded relatively small gross gains, not more than 23,000 ha annually. The key constraints to reforestation are financial and institutional, pressure from humans and livestock, reluctance of farmers to participate, and lack of community involvement. Regardless of reforestation efforts, the existing and potential pressure on forests suggests that the present trends towards deforestation are unlikely to be reversed.

The two major factors leading to forest depletion are logging and the cutting of trees for fuelwood. Privately owned farmlands supply 50% of the demand for timber, while imports contribute 36%, and state forests make up the remainder. Based on per capita income increases, it was projected that demand for timber would reach 4.11 m^3 by the year 2000. Population pressure is expected to raise the demand for fuelwood by 55% by the year 2000. Unless alternative fuels can be provided, such as kerosene and natural gas, the growing demand for fuelwood is likely to contribute to soil erosion, damage watersheds, reservoir silting, desertification, and sea encroachment. Such changes could exacerbate the impacts of climate change.

5.4 Climate Change Scenarios

The socioeconomic scenarios described above provide the context for examining the impacts of climate change. To consider climate impacts and adaptation strategies, the Pakistan team created synthetic scenarios of climate change. Temperature and precipitation were used to study the impacts of climate change up to the year 2020, and for some aspects, up to the year 2050. In order to ensure consistency across sectoral studies, scenarios of +0.3°C per decade temperature changes and +1% precipitation changes per decade were used. An alternative scenario of a +0.3°C per decade temperature increase and a -1% precipitation change per decade were used, as well as one scenario that assumed no change in precipitation.

By 2020, the temperature in Pakistan is expected to increase by 0.9ºC, doubling to 1.8ºC by 2050. Precipitation scenarios include increases or decreases of 3% by 2020, and 6% by 2050. Scenarios for sea level rise included 20 cm by 2020 and 30 cm by 2050. Given that computer models project an increased frequency of extreme events, it was considered that the average summer monsoon rainfall in South Asia might increase by 17%–59%, driven largely by a doubling in the frequency of high magnitude rainfall events. Variable monsoons could also generate more droughts, but this effect would be mitigated by higher snowmelt in the mountains.

Scenarios of increased flood frequency have potentially serious consequences for Pakistan, particularly since a significant proportion of the population lives on low-lying flood plains of the Punjab and Sindh provinces. Population growth is likely to aggravate the effects of seasonal flooding, which includes damage to infrastructure and crops and loss of human life. From a historical perspective, there seems to be an increase in the frequency of heavy floods on the Indus plain. Records from the past 100 years indicate that seven of the ten highest peak floods in the ravi season have occurred over the last 25 years. Climate change may account for the increase, but it would be premature to draw a simple causal relationship, given the likelihood of an increase in runoff due to erosion in the Himalayan foothills.

These synthetic scenarios are somewhat conservative, but they do not contradict the results from climate models. The CSIRO 9 model predicts a 17% increase in wet (summer) season rainfall in South Asia associated with a doubling of atmospheric CO_2. When scaled to correspond to the low, medium, and high emissions scenarios of the IPCC, the range is between 5% and 50%. These results are supported by numerous other models, including CCC, UKMOH, and GFDLH, which predict 20%, 24%, and 59% increases, respectively. Moreover, the CSIRO model projects that the average time period between heavy rainfall events will be reduced by more than one half (Watson et al., 1998).

The impacts of climate change are considered in the light of the differences between the socioeconomic conditions projected to exist without climate change (the reference case) and those that are projected with climate change. A preliminary examination of current conditions and projected future trends suggests that the presently large supply and demand imbalances are likely to increase over time. This suggests that vulnerability to climate change may increase in Pakistan.

The socioeconomic impacts generated by climate change can be wide-ranging. They can be direct or indirect. The first-order impacts of climate change occur on what are referred to as primary sectors. The cascading effects of these changes on other sectors are referred to as second-order effects. First-order impacts include plant growth, natural aquatic and terrestrial ecosystems (i.e. forests, grasslands, marine and coastal environments, etc.), water resources, sea-level rise and others. Second-order impacts encompass a wide spectrum of socioeconomic variables: agricultural enterprises and human settlements, human health, air quality, and transportation, energy, industrial, and service sectors. Within this category are primary, secondary, and tertiary sectors, reflecting the intensity of induced impacts generated by first-order effects.

5.5 Water Resources

The main source of water in Pakistan is the Indus River system. The system resembles a funnel, with a number of water sources at the top that converge into a single river that flows into the Arabian Sea east of Karachi. The average annual inflow of the western and eastern rivers and their tributaries at the rim stations is 146.01 million acre-feet (maf.)

The Indus River and its five major tributaries form one of the world's largest contiguous irrigation systems. The Indus basin irrigation network in Pakistan stretches over an area of 14 mha. Based on the 1960 Indus Basin Treaty with India, Pakistan was allocated the flow of three western rivers (Indus, Jhelum and Chenab), with occasional spills from the Sutlej and Ravi rivers. The network has three major reservoirs: the Tarbela, Mangla, and Chashma. It also includes 19 barrages or headworks, 12 link canals, 43 canal commands, and over 107,000 watercourses. Irrigation developments over the past 150 years have resulted in very large diversions of water. The three reservoirs are losing their storage capacity due to sedimentation.

Water is delivered to farms through outlets (*mogas*). Within a watercourse command (an area ranging from 200 to 700 acres), farmers receive water in proportion to their land holding. The entire discharge of the watercourse is given to one farm for a specified period, on a seven-day rotation schedule called *warabandi*. Due to its age, overuse, and deferred maintenance, the delivery efficiency of the canal system is low. On average, delivery efficiency ranges from 35 to 40% from the canal head to the root zone, with maximum losses occurring in the watercourses. As a result, less water is available for crops, and problems of waterlogging and salinity can result. It is estimated that more than 5.6 mha of irrigated land on the Indus plain is affected by waterlogging and salinization.

The surface irrigation supply system is extremely rigid, providing water on a rotational (*warabandi*) basis and limiting intensive cultivation to 75%. As a result, under-irrigation is quite normal. Nonetheless, farmers tend to make rational choices at the farm level, opting for allocative efficiency across crops, rather than yield enhancements. At the field level, there is considerable scope for improving irrigation methods. Improved irrigation notwithstanding, the timeliness of water supply is key to maximizing efficiency. Water should be available to farmers during tillering, jointing, sprouting, and grain development. The warabandi system precludes such timeliness.

Over time, the canal irrigation system has caused the water table in the Indus basin to rise by an average of 15 m. This has raised concern over waterlogging. Watterlogging is a condition whereby the soil is saturated to the extent that common plants fail to grow, or their growth and yields are adversely affected by poor aeration of the root zone. It is estimated that as much as 10–15% of the irrigated areas of the Indus basin may suffer from excessive wetness and ponding as a result of high intensity monsoon rains, low infiltration rates of soils, and blockage of natural drainage by infrastructure. However, an analysis of trends in waterlogging shows that overall for Pakistan, the waterlogged areas actually declined between 1979 and 1986. This suggests that a balance may have been achieved between groundwater recharge and utilization.

There has also been great concern over the salt balance in the Indus basin. In the absence of good drainage, surface evaporation occurs and results in salt deposition. In fact, some 10.8 million tons of salt are added to the system each year. However, as long as they remain below the reach of crops and trees, they do little harm. When salts are mobilized, either through a rising water table or pumping of saline groundwater, they become a problem.

The scope for finding additional water in Pakistan is limited. Surface water supplies are fixed, whereas additional groundwater potential is limited from 5–15 maf. The country's groundwater resources include a vast aquifer underlying the Indus plains that gets recharged through natural precipitation and from river flows. More recently, seepage from the canal systems has added to groundwater recharge. Outside the Indus plains, small aquifers have been identified in the inter-mountain valleys.Groundwater resources have been heavily exploited in Pakistan. Groundwater has made increased acreage under crops and higher cropping intensities possible. The exploitation of groundwater can be attributed to the inadequacy of canal water resources, as well as the variability of rainfall and high runoff during the monsoon season.

Although the quality of groundwater in the Indus basin aquifer is highly variable, there are large areas that are underlain by usable groundwater. Within the gross area of 16.45 mha of the canal commands, it is estimated that about 8.14 mha is underlain by groundwater with salt concentrations of less than 1500 ppm. Outside the canal commands, along the riverine areas and just below the Himalayan foothills, the groundwater is of useful quality (this amounts to 2 mha). About 25,000 public and 350,000 private tube wells are located throughout various irrigated parts of the country. These tube wells pump about 65 bm^3 of groundwater annually.

Hilly torrent irrigation is practiced in the uplands of Pakistan. This involves the diversion of flood water for direct irrigation or storage. Although agricultural productivity is low in these areas, the livelihood of a large number of people depends upon this system. There is high potential for improving this mode of irrigation.

The impact of climate change on water resources must be seen within the context of new infrastructure that is designed to respond or adapt to an increasing demand for water for drinking, sanitation purposes, and power generation. For example, consider Karachi, the only major coastal city in Pakistan, and a metropolitan area with a population of over seven million. The salinity in Karachi and the Indus delta is already very high. With a rise in sea level, there is likely to be an increase in the frequency and intensity of monsoon storm flooding. This will cause damage to infrastructure and create unhygienic living conditions in some parts of Karachi.

In 1991, 45% of the rural population and 80% of the urban population had access to safe drinking water (UNDP, 1994). In the future, there is likely to be decreased access for both rural and urban populations because rates of urbanization exceed the capability of services to cope with the growing demand, at the same time that the quality of groundwater is deteriorating. Increasing water deficits will cause intersectoral competition and tensions among productive sectors. Higher pricing or rationing options are likely to generate cost increases or production losses. Such problems are likely to be exacerbated by provincial water allocation decisions, which will be politically driven and thus not lead to optimal water utilization.

5.6 Impacts on the Indus Basin

A comprehensive reevaluation of the Indus basin system was undertaken in order to maximize its capacity for meeting irrigation and energy requirements under all possible conditions, with or without global warming. The current total water storage in the Indus River system remains insufficient, and it is likely that the problem will become more acute in the future under various climatic scenarios, particularly if temperature increases are coupled with a decrease in precipitation. Even if there is an increase in precipitation, the benefits will not be realized unless the storage capacity of the system is increased.

An analysis was carried out to estimate the capacity of the Indus system to divert, deliver, and use water in space and time with respect to inflows. Historical water withdrawals, losses and outflows to sea were plotted against inflows. The irrigation distribution system has a capacity of 199 maf, and releases from the system are between 99 maf and 109 maf. Annual inflows range from approximately 100 maf to 180 maf. Both the outflows and losses from the system increase with increased inflows. The analysis showed that the increase in inflows does not necessarily result in increased water use, because the increased amount cannot be controlled in both time and space. In other words, the capacity of the system is constrained by storage spaces.

Key Point: Increased precipitation will not necessarily lead to increased water use if water cannot be controlled in both space and time. The capacity of the Indus River system is constrained by storage space.

The hydrological impacts in the Indus basin system were examined on the basis of historical data from the past 30 years. Scenarios were developed using a runoff-rainfall model for the upper basin. This model, known as the UBC-Mangla watershed model, was developed by the University of British Colombia to forecast inflows to the Mangla reservoir (Masood and Ullah, 1991). It is a precipitation-runoff model that uses daily temperature and precipitation data to forecast river discharges.

To develop hydrological scenarios of climate impacts on average inflows, the UBC model was used to calculate inflows for all three climatic change scenarios. A comparison of inflows and the percentage change in the years 2020 and 2050 is provided in Table 5.6 for the scenario with no precipitation change. The base flows for the study were calculated as the averages of historical discharges at rim stations from 1960 to 1990. From this table, it can be seen that negative changes occur in the kharif season, and positive changes occur in the rabi season. Nevertheless, without a change in precipitation, the net effect of changing inflows is negative in both 2020 and 2050.

Estimates of total water availability for the base scenario and for the three climate change scenarios are provided in Table 5.8. Given the water requirements for crops at current yields, it is clear that the efficiency of both water and land usage has to at least double by 2020. It was estimated that about 46 maf of water is currently lost through evaporation from the system as a whole. This includes evaporation from reservoirs, lakes, ponds, groundwater, flowing water, and water supply systems. Evaporation rates from these sources are expected to increase as a result of temperature increases (see Table 5.9). It is estimated that an additional 12 maf and 15 maf must be added to the system by the years 2020 and 2050, in order to meet the increasing water demand of the population and industrial and agricultural sectors.

Table 5.6 Summary of regional, seasonal and monthly inflows and variations

Main scenario – 2020 (0.3 °C and 0% PPT per decade)												
Area	**Main**		**Eastern**		**Others**		**Rabi**		**Kharif**		**Total**	
Inflow maf	130.43		10.03		4.76		24.32		120.91		145.23	
Change maf	-0.444		-0.223		-0.116		0.115		-0.898		-0.783	
With base %	-0.339		-2.171		-2.375		0.477		-0.737		-0.54	
Month	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Inflow maf	5.440	3.284	3.112	3.044	3.286	6.151	9.078	13.597	21.772	30.422	31.312	14.727
Change maf	-0.039	-0.077	-0.062	0.027	0.077	0.187	0.178	-0.023	-0.486	-0.889	0.188	0.134
With base %	-0.70	-2.28	-1.94	0.91	2.41	3.14	2.00	-0.17	-2.18	-2.84	0.60	0.92

Main scenario – 2050 (0.3 °C and 0% PPT per decade)												
Area	**Main**		**Eastern**		**Others**		**Rabi**		**Kharif**		**Total**	
Inflow maf	129.99		9.81		4.64		24.43		120.01		144.44	
Change maf	-0.888		-0.445		-0.231		0.231		-1.796		-1.57	
With base %	-0.679		-4.341		-4.750		0.954		-1.474		-1.07	
Month	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Inflow maf	5.402	3.208	3.050	3.071	3.364	6.338	9.256	13.574	21.286	29.533	31,500	14.861
Change maf	-0.077	-0.153	-0.123	0.055	0.155	0.375	0.356	-0.047	-0.972	-1.778	0.377	0.268
With base %	-1.41	-4.56	-3.88	1.81	4.83	6.29	4.00	-0.34	-4.37	-5.68	1.21	1.84

Table 5.7 Monthly change from baseline (%)

Year	**2020**			**2050**		
Month	0.3°C & 0%PPT	0.3°C & +1%PPT	0.3°C & -1%PPT	0.3°C & 0%PPT	0.3°C & +1%PPT	0.3°C & -1%PPT
Jan	0.91	6.19	-2.25	1.81	15.29	-4.50
Feb	2.41	10.27	-1.88	4.83	24.11	-3.75
Mar	3.14	6.03	-0.78	6.29	18.03	-1.56
Apr	2.00	5.85	-1.92	4.00	22.76	-3.85
May	-0.17	3.63	-2.95	-0.34	9.91	-5.89
Jun	-2.18	0.25	-4.71	-4.37	0.64	-9.42
Jul	-2.84	0.82	-5.49	-5.68	2.00	-10.98
Aug	0.60	4.68	-1.99	1.21	11.05	-3.98
Sep	0.92	-4.58	-1.90	1.84	12.28	-3.80
Oct	-0.70	3.15	-3.12	-1.41	7.82	-6.24
Nov	-2.28	-0.30	-4.68	-4.56	0.87	-9.35
Dec	-1.94	2.42	-4.59	-3.88	7.14	-9.18
Total	*-0.54*	*2.21*	*-3.35*	*-1.07*	*8.47*	*-6.69*

The results from the UBC model show that temperature increases lead to increasing inflows during the rabi season and decreasing inflows during the kharif season. This means that the net effects of temperature change are positive, even with a decreased annual inflow. The results suggest that the precipitation increase leads to relatively less change in the rabi season than in the kharif season.

Over the long run, increased temperatures with or without any change in precipitation will cause glacial melting in the upper watershed, leading to higher rates of sliding and sediment loads. In the lower rainfed watershed, the effects will be the opposite, with less likelihood of sliding and sediment loading. However, warmer temperatures and increased precipitation in the upper watershed can lead to increased snowfall, which may offset the effects of temperatures on the stability of the glaciated areas.

Table 5.8 Total water availability

	Base		
Source	**Total**	**Rabi**	**Kharif**
Available at rim stations	146.01	24.20	121.81
Rainfall in the canal command	25.0	4.75	20.25
Total inflow	171.01	28.95	142.06
Required below Kotri**	10.0	5.0	5.0
Evaporation@ 10%	16.10	2.4	13.71
Seepage losses @30%***	43.47	6.47	37.01
Total surface water	101.44	15.09	86.35
Ground water****	44	11	33
Total available	145.44	26.09	119.35
Total water availability in 2020*			
0.3°C and 0% ppt/decade	141.73	25.46	116.40
0.3°C and 1% ppt/decade	146.62	26.40	120.22
0.3°C and -1% ppt/decade	138.81	24.88	113.93
Total water availability in 2050*			
0.3°C and 0% ppt/decade	138.43	24.85	113.50
0.3°C and 1% ppt/decade	148.04	26.75	121.29
0.3°C and -1% ppt/decade	132.39	23.72	108.67

Nazir (1993), **water accord, ***assumed 30% safe potential by Tarar 1997, **** evaporation from ground, @ general mean evaporation.

Table 5.9 System evaporation

	Base	**0.9°C**		**1.8°C**	
Year	1990	2020**		2050**	
Growth rate		**High**	**Low**	**High**	**Low**
Dams	2.7*	2.9	2.9	3.0	3.0
Lakes/ponds	4.2	4.4	4.4	4.7	4.7
From ground	10.0*	10.6	10.6	11.2	11.2
From flowing water	30.0*	31.5	31.5	33.1	33.1
Water supply @ 15%		1.6	1.6	2.5	3.1
Net losses	46.9	51.0	51.1	54.5	55.1

*Based on existing rate of evaporation in the system (Nazir, 1993), ** mean evaporation changes for climatic scenarios. Water supply served to 50% of the population in 2020 and 75% in 2050. 10 maf storage added to the system in 2020.

Water availability for irrigation would be increased under a scenario of increased precipitation. If the increase in precipitation is reliable, more small dams could be constructed in these areas. However, higher precipitation may also result in higher silt loads, which may affect the structural stability of the system. A decrease in precipitation would increase evaporation losses, and shallow ponds would dry more quickly.

An increase in precipitation in the barani areas would have a great impact on agriculture. Even a small increase in precipitation, such as 3% in the year 2020 or 6% in 2050, is likely to lower the pressure of meeting crop water demands from reservoirs. Such a change in precipitation would change not only the demand for water, but also overall patterns of agriculture in Pakistan, as more areas would be likely to be brought under cultivation.

Computer modeling tools can be used to provide information to optimally coordinate the many facets of an integrated system such as the Indus River Basin. A generalized interactive model called MODSIM, developed at the Colorado State University, was used to model water resource systems in the basin. The model uses a network approach, where a network consists of two types of components, nodes and links (or arcs). The nodes are reservoirs and demand and transition nodes. The Indus basin was divided into 57 nodes and 70 links, including 30 demand nodes representing the canal system in the region. All major contributors of water to the Indus basin, from Tarbela and Manga downward, were included in the network. The input files for the model include the maximum, minimum, and beginning capacities of each reservoir.

Key Point: A combination of increased river flows and increased flood plain pressures suggests that flood hazards could be one of the most serious problems associated with climate change.

Nine storage reservoirs are represented in the model, but six of these have zero capacity. There are only three reservoirs in the system, and their capacities are declining because of sedimentation. The system cannot deliver demand above the average of 104.87 maf. As a result, demand was held steady throughout the study period. In some simulations, the Kalabagh dam was added in the year 2010, and average demands were increased from 104.87 maf to 110.31 maf. Four scenarios were then considered: 1) no global warming; 2) a 0.3ºC increase in temperature with no changes in precipitation; 3) a 0.3ºC increase in temperature with a +1% change in precipitation per decade; 4) and a 0.3ºC increase in temperature with a -1% change in precipitation per decade.

Inflows were calculated for each decade between 2000 and 2050. These inflows were then used as inputs to the system, both with the change in reservoir capacities and with no new reservoir added to the system. The results were analyzed in relation to irrigation demands and the production of hydropower (see Table 5.10).

Under the scenario of no global warming, the decreasing capacities of the Tarbela and Mangla reservoirs due to sedimentation create supply shortages of 2.57 maf by 2020, and 3.90 maf by 2050. In 2020, there are shortages at 13 nodes, and in 2050 there are shortages at 14 nodes. The shortages are most pronounced in the months of October, November, and January.

Under the scenario of increased temperatures with no change in precipitation, the decrease in reservoir capacity is coupled with a decrease in inflows. Releases from the system to meet user demands decline from 102.22 maf in 2020 to 100.68 maf in 2050. Water shortages increase in comparison to the base run, reaching 2.66 maf in 2020 and 4.20 maf in 2050.

Under the scenario of increased temperatures with an increase in precipitation, the situation is almost identical to the base run. This is because the increase in precipitation compensates for the temperature impacts. Although there is a notable increase in inflows, the system does not redistribute them in time, thus demands are not met. The outflows to sump increase with time, reaching 61.46 maf in the year 2050. This suggests that there is potential to develop water resources. The overall impact of this scenario is significantly positive, despite the fact that shortages can be found at 14 nodes.

Under the scenario of increased temperatures with a decrease in precipitation, the reduction in inflows affects both the releases and outflows to sump. The releases decrease from 101.90 maf in 2020 to 99.72 maf in 2050. This amounts to a decrease of 1.7 % and 1.8 % in the respective years, as compared to the base scenario. Shortages increase from 3.0 % in 2020 to 7.8 % in 2050. This scenario has a negative effect over a large number of nodes.

Table 5.10 System operation with and without climate change

WITHOUT GLOBAL WARMING					
Year	**Inflow MAF**	**Demand MAF**	**Release MAF**	**Out flow to sump MAF**	**Shortage MAF**
1990	146.01	104.87	104.87	40.42	0.00
2000	146.01	104.87	104.87	40.44	0.32
2010	146.01	104.87	103.64	41.68	1.24
2020	146.01	104.87	102.30	43.02	2.57
2030	146.01	104.87	102.17	43.15	2.70
2040	146.01	104.87	101.60	43.76	3.28
2050	146.01	104.87	100.97	44.37	3.90

WITH GLOBAL WARMING								
Year	**Inflow MAF**	**Demand MAF**	**Release**		**Out flow to sump**		**Shortage**	
			MAF	**% change**	**MAF**	**% change**	**MAF**	**% change**
With 0.3 °C increase and no PPT change								
2000	145.75	104.87	104.55	-0.00	40.19	-0.63	0.32	0.00
2010	145.49	104.87	103.63	-0.01	41.17	-1.22	1.25	0.01
2020	145.23	104.87	102.22	-0.08	42.31	-1.63	2.66	0.08
2030	144.97	104.87	101.97	-0.19	42.31	-1.97	2.90	0.19
2040	144.70	104.87	101.42	-0.18	42.63	-2.58	3.45	0.18
2050	144.43	104.87	100.68	-0.29	43.10	-2.86	4.20	0.29
With 0.3 °C increase and 1% PPT increase								
2000	148.01	104.87	104.65	0.09	42.35	4.71	0.23	-0.09
2010	150.04	104.87	103.81	0.17	45.3	9.26	1.06	-0.17
2020	152.10	104.87	102.76	0.45	48.65	13.09	2.12	-0.45
2030	154.18	104.87	102.69	0.51	51.61	19.60	2.19	-0.51
2040	156.26	104.87	102.66	1.04	55.86	27.64	2.22	-1.04
2050	158.38	104.87	101.72	0.74	61.98	39.70	3.16	-0.74
With 0.3 °C increase and 1% PPT decrease								
2000	144.38	104.87	104.48	-0.08	38.89	-3.84	0.40	0.08
2010	142.75	104.87	103.46	-0.17	38.59	-7.40	1.41	0.17
2020	141.12	104.87	101.90	-0.39	38.53	-10.44	2.97	0.39
2030	139.49	104.87	101.43	-0.73	37.38	-13.37	3.45	0.73
2040	137.86	104.87	100.72	-0.86	36.50	-16.60	4.15	0.86
2050	136.27	104.87	99.72	-1.24	35.86	-19.19	5.16	1.24

To address various rehabilitation and development activities taking place in different provinces of Pakistan, new storage capacity was considered in the model. The base demands were increased to 110.31 maf, and the model was run using this higher demand (see Table 5.11). The analysis showed that the various climate change scenarios would have an insignificant impact on hydropower generation.

Historical climatological data indicate a warming in the upper snow-covered part of the Indus basin, as well as some increase in the annual rainfall in the flood-generating part of the basin. The increase in peak discharges that is evident in the historic record may be attributed to an increase in rainfall, changes in land use in the upper basin, and flood protection activity upstream, which may increase flood discharges downstream.

Historically, floods have caused heavy losses, both monetary and of life. At the times of flooding, most agricultural areas are covered by cash crops, such as cotton or rice. Floods also cause extensive damages to infrastructure, such as roads, bridges, irrigation protection embankments, and electricity or telephone installations. The magnitude and duration of floods are expected to be marginally affected by temperature increases and a +1% increase in precipitation per decade. Although a lack of data in the watersheds of the main rivers makes it difficult to quantify the impacts, it is likely that increased precipitation will increase the magnitude of the floods and affect the urban areas that are located along river banks. Small towns located at the edges of flood plains are clearly vulnerable to extreme flood events. There have been increasing pressures on the flood plains, including land use intensification tied to population pressure, and pressure for economic growth. A combination of increased river flows and increased flood plain pressures suggests that flood hazards may be one of the most serious problems associated with climate change.

Table 5.11 System operation of the Kalabagh Reservoir

Year	Inflow maf	Demand maf	Release maf	Outflow to sump maf	Shortage maf
Business as usual					
2010	146.01	110.04	110.04	34.98	0.00
2020	146.01	110.04	109.76	35.26	0.28
2030	146.01	110.04	108.56	36.46	1.48
2040	146.01	110.04	107.42	37.62	2.63
2050	146.01	110.04	106.52	38.52	3.52

Year	Inflow maf	Demand maf	Release maf %		Outflow to sump maf %		Shortage maf %	
0.3 °C, no PPT change								
2010	145.49	110.04	110.03	-0.01	34.47	-1.46	0.01	0.01
2020	145.23	110.04	109.70	-0.05	34.53	-2.06	0.34	0.05
2030	144.97	110.04	108.46	-0.09	35.52	-2.59	1.58	0.09
2040	144.70	110.04	107.20	-0.20	36.52	-2.90	2.84	0.20
2050	144.43	110.04	106.25	-0.25	37.23	-3.36	3.79	0.25
0.3°C and 1% PPT increase per decade								
2010	150.04	110.04	110.04	0.00	39.01	11.54	0.00	0.00
2020	152.10	110.04	109.97	0.19	41.13	16.66	0.07	-0.19
2030	154.18	110.04	108.85	0.26	44.35	21.63	1.19	-0.26
2040	156.26	110.04	107.80	0.36	47.49	26.25	2.24	-0.36
2050	158.38	110.04	106.98	0.43	50.43	30.92	3.07	-0.43
0.3 °C and 1% PPT decrease per decade								
2010	142.75	110.04	109.88	-0.15	31.88	8.84	0.16	0.15
2020	141.12	110.04	109.38	-0.35	30.76	12.75	0.67	0.35
2030	139.49	110.04	107.93	-0.58	30.58	16.11	2.12	0.58
2040	137.86	110.04	106.46	-0.89	30.43	19.10	3.58	0.89
2050	136.24	110.04	105.30	-1.15	29.98	22.18	4.74	1.15

5.7 Agricultural Impacts

Changes in climate, particularly an increase in temperature coupled with a decrease in precipitation, would have a negative impact on the future production of major agricultural commodities in Pakistan. In agriculture, first order effects are associated with the biophysical responses at the organism and field level. They relate to changes in crop and livestock productivity. In turn, these induce second-order socioeconomic effects, such as changes in food supply, production profitability, employment potential, etc. Such impacts are generally difficult to quantify, and rely primarily on expert qualitative judgment.

In the absence of climate change, demand and supply projections suggest that the existing deficit will become larger in the case of wheat, and fall in the case of cotton. There is expected to be a shortfall in sugar production, and rice surpluses can be expected to turn into deficits. Projected demand for milk, meat, and fruit reflects population increases as well as changes in tastes and lifestyles associated with rising incomes. Increases in the supply of livestock products and fruits are premised on structural changes in agriculture and higher productivity.

Shifts in crop boundaries will have enormous social and economic impacts on the lives of millions of people who are directly or indirectly associated with cultivating these crops. Farmers will have to adjust to the new crop production environment. Such adjustments and resource allocation decisions will be based on relatively limited information, thus it is likely that resource use efficiency will be adversely affected.

Landless families in villages generally earn their living by working on farms as casual laborers. Women from landless families are often involved in harvesting rice and picking cotton. Women earn enough from cotton picking and rice harvesting to secure food for their families. Consequently, locational shifts of these crops will adversely affect the livelihoods of these families. Also, such shifts may require farmers to buy new machinery for growing new crops.

An increase in temperature and a decline in rainfall would make crop production more dependent on groundwater. The investment costs of new tubewells translate into higher production costs, eroding profitability, and decreasing incentives for producers to maintain or increase production. Increased pumping of groundwater may cause severe problems in areas where the water table is already very low and where recharge is slow due to low rainfall.

Considering the potential impacts of climate change on agriculture in Pakistan, potential shifts in the spatial boundaries of crop areas were examined, along with the impacts of climate change on growth and yield. Analyses were carried out for wheat, rice and maize.

Wheat. The existing potential zone for wheat lies in humid, sub-humid, semi-arid, and arid climates. Growing degree days for wheat were calculated using a base temperature of 5°C for 15 selected locations in four climatic zones of Pakistan. A growing season of 181 days was selected for the multi-locational analysis. A planting date of November 1st and harvest date of April 30th were used in the analysis. Optimal growing degree days (gdd) of 1800 are assumed for medium duration cultivars. An operating range of 1200–2750 gdd was defined because cultivars can adapt to a growing season length ranging from 120–240 days. An increase in gdd in arid regions shortens the growing season length to even less than 120 days, with yield potentials limited to short duration varieties.

A temperature increase of 0.9ºC by the year 2020 shifts the boundary of the potential zone for wheat to some extent within the arid zone. A temperature increase of 1.8ºC by the year 2050 could reduce the potential zone of wheat, as some arid areas might fall out of the potential zone. The highest change in gdd occurs in humid regions and the lowest in arid regions.

Islamabad was selected as a case study representing the humid zone for wheat production. In this area, the growing season was reduced by 3 days with an increase of 0.9ºC, and 8 days with an increase of 1.8ºC. A temperature increase of 0.9ºC increased the number of grains and grain weight, which resulted in a yield increase of 8.2%. Biomass also increased by 35.3%, contributing to a 58% increase in the straw yield of wheat. Although the 1.8ºC increase resulted in a higher grain yield in comparison to the baseline run, it was less than the yield observed under a 0.9ºC increase. An increase of atmospheric CO_2 from 360 ppm to 500 ppm does not affect the length of the growing season for wheat. However, it does contribute to an increase in grain yield and biomass production.

Key Point: The fertilization effect of CO_2 has a positive impact on wheat yields in Pakistan.

Faisalabad was selected as a case study to represent the semi-arid zone for wheat production. The increase in temperatures of 0.9 and 1.8ºC resulted in a reduction in the length of the growing season, by 4 and 8 days, respectively. The temperature increase in this zone reduced the number of grains, but increased the grain weight. As a result, grain yield increased by 2.5% with a temperature increase of 0.9ºC. The grain yield decreased by about 4.0% with temperature increases of 1.8ºC. Straw yields increased by 37.3% in the lower temperature scenario, and by 36.3% in the higher temperature scenario. In general, the increase in temperature resulted in an increase of straw. Again, the increase of CO_2 concentration did not show any effect on the length of the growing season, but did have a positive impact on grain yields.

Multan was selected as a case study to represent the arid zone for wheat production. In this region, the increase in temperature does not have any significant effect on grain yield, whereas it reduces straw yield. Reductions of 7% and 12% in wheat straw yields were observed with temperature increases of 0.9 ºC and 1.8ºC.

In general, the simulations indicated that temperature increases in major parts of the wheat producing areas might result in minor reductions in grain yields. However, the increase in CO_2 concentrations would result in significant increases in grain yields, even with the increase in temperature. Furthermore, the increase of CO_2 concentrations might compensate for the reduction in grain yields through an increased production of straw. Consequently, no considerable changes in wheat growth and yields are expected, assuming that water is not limited. However, temperature increases would require more water in order to meet increased evapotranspiration demands.

Rice: Growing degree days for rice were computed using a base temperature of 10°C for 15 locations in three climatic zones. The zones for rice cultivation include sub-humid, semi-arid and arid climates. A growing season of 123 days was selected for the multi-locational analysis, with a planting date on July 1 and a harvesting date on October 31. Optimal growing degree days (gdd) of 2200 were assumed for the medium duration cultivars. However, cultivars can adapt to a growing season ranging from 92 to 154 days, therefore a range of gdd between 1650 and 2750 was considered. The increase in gdd in the arid regions shortens the length of the growing season to around 92 days. Like wheat, yield potentials are limited to short duration varieties.

A temperature increase of 0.9°C by the year 2020 does not affect the boundaries of the potential zone for rice. However, an increase of 1.8°C by 2050 shifts the boundaries within the arid zone, as the region becomes hotter than the operative range of gdd. The length of the growing season is affected more in the arid regions because rice cultivation in these areas already experiences heat stress. A further increase in temperature would aggravate the heat stress.

Maize: Maize is grown in both cool and hot climates in Pakistan. Growing degree days for the kharif maize crop were computed using a base temperature of 10°C for 15 locations in four climatic zones. The zones for kharif maize production include cool humid, cool hyper-arid, hot humid and hot semi-arid climates. A growing season length of 123 was selected for the multi-locational analysis, along with a planting date of June 15 and a harvesting date of October 15 in both the cool and the hot regions. Optimal growing degree days of 2000 are assumed for medium duration cultivars. Cultivars can adapt to a growing season length ranging from 92–154 days, therefore the operative range of gdd was defined as 1500-2550. The increase in growing degree days in the hot semi-arid regions shortens the length of the growing season to as little as 90 days, thus short duration varieties are used with less yield potentials.

A temperature increase of 0.9°C for the year 2020 shifts the boundary of the potential zone of kharif maize from hot semi-arid to hot humid. The growing season length in the hot semi-arid region will be reduced, with reduced productivity. Furthermore, the temperature in certain regions will exceed the optimum range. A temperature increase of 1.8°C by 2050 further shifts the boundary of the maize potential zone. The major maize producing areas of the Indus basin are outside the potential zone, primarily due to an increase in gdd. As a result, the country's production of maize might be adversely affected by climate change. On the other hand, favorable impacts are observed in the cool regions. Change was more pronounced in cool regions than in hot regions.

An increase in temperature would thus result in reduced canal supplies. The production of major crops such as wheat, rice, cotton, and sugarcane would have to be doubled by 2020 to meet the requirements of the country's growing population. Such an increase in production could be achieved through improvements in irrigation efficiency and productivity.

The existing efficiency can be increased from 34% to 50% through improved water conveyance and application. This would provide an additional 47% water at the field level for crop consumptive requirements. Improved agronomic practices coupled with improved irrigation efficiency can lead Pakistan towards achieving continued self-sufficiency in food. Nonetheless, by the end of 2020, most of the useable groundwater resources will have been exploited. Agricultural production will have to increase by over 36% from that of 2020 to meet the demands in 2050. This increase would only be possible through adoption of very high-efficiency irrigation systems and improved agronomic practices, such as sprinkler and drip irrigation, coupled with chemigation.

5.8 Irrigation Systems

Water shortages are a common problem in Pakistan. The increase in net irrigation water requirements as a result of temperature increases and precipitation decreases would have serious impacts on water availability for crops. Irrigation water requirements for wheat were calculated using a temperature increase of 0.3ºC per decade and a 1% increase or decrease in precipitation per decade. The irrigation water requirements for wheat are different in each climatic zone. As a result, four climatic zones representing humid, sub-humid, semi-arid, and arid regions were selected for prediction of the net irrigation water requirements for wheat (Table 5.12). Temperature increases of 0.9 ºC and 1.8ºC and rainfall changes of +/- 3% and 6% increased the net irrigation water requirements in sub-humid, semi-arid, and arid regions, but had no effect in humid regions. The greatest change in net irrigation requirements (+28.6%) was observed in the sub-humid zone, under a scenario of 1.8ºC temperature increase and a 6% decrease in precipitation.

The net irrigation water requirements for rice and maize were also calculated. A temperature increase of 0.9ºC and 1.8ºC with a change in rainfall of +/- 3% and 6% increased the net irrigation requirements for rice. The highest percentage change (27.9%) was observed with a reduction of rainfall by 6% and a temperature increase of 1.8 ºC. An increase in precipitation balances the increase in water requirement, and the percentage change is zero or less. For maize, an increase in temperature and change in precipitation does not affect the net irrigation water requirements for kharif maize in the cool humid and hot humid zones because rainfall is greater than actual evapotranspiration.

Table 5.12 Net irrigation water requirements of wheat for four climatic zones under climate change scenarios in Pakistan

Climate change scenarios	**Net irrigation water requirement (mm)**				**Percent change in net irrigation water requirement**			
	Humid	*Sub-humid*	*Semi-arid*	*Arid*	*Humid*	*Sub-humid*	*Semi-arid*	*Arid*
Existing	0	105	271	404	-	-	-	-
0.9°C, NCR*	0	111	281	415	0	+5.7	+3.7	+2.7
0.9°C, +3%PPT	0	104	277	414	0	-1.0	+2.2	+2.5
0.9°C, -3%PPT	0	118	284	417	0	+12.4	+4.8	+3.2
1.8°C, NCR	0	121	291	427	0	+15.2	+7.4	+5.7
1.8°C, +6%PPT	0	107	284	425	0	+2.0	+4.8	+5.2
1.8°C, -6%PPT	0	135	297	429	0	+28.6	+9.6	+6.2

* NCR – No change in rainfall.

Changes in land use as a result of climate change can be analyzed by considering the resulting scenarios for wheat, rice, and maize. Two cropping systems are represented: rice-wheat and maize-wheat. Although an increase in temperature of 1.8 ºC reduces the length of the growing season and the productivity under both cropping systems, it does provide more time for the preparation of land for the next crop. Moreover, changes in varieties and agronomic interventions could also be undertaken as adjustment strategies. The increase in temperature could result in sterility problems, particularly for rice in arid areas, due to less grain and more straw yields. Furthermore, the wheat growing season will shorten, and the sustainability of the rice-wheat system in arid zones under increased temperatures would become a problem. An increase in temperature and a reduction in precipitation might also increase soil salinity, which would also affect the productivity of the rice-wheat system. The most serious concern is the increase in net irrigation water requirements in arid areas, especially in the Sindh province, where the quality of groundwater is either marginal or brackish.

Net irrigation water requirements vary considerably with variations in rainfall. For comparison purposes, a semi-arid climate was selected for both cropping systems. The increase in temperature of 0.9 ºC and 1.8 ºC increased the net irrigation water requirements by 3.1% and 6.3% for rice-wheat systems and 3.4% and 6.9% for maize-wheat systems.

5.9 Forestry

Different aspects of climate, including elevated atmospheric CO_2 concentrations, changes in temperature and precipitation, and the frequency and intensity of extreme events, may have different effects on forests. Most studies carried out so far have suggested an enhanced growth rate of trees due to the fertilizer effect of increased CO_2 concentrations, in combination with temperature increases. Temperature and precipitation are the two most important elements of climate, and together they have a number of first-order effects on forest distribution, composition and growth.

The first order effects of climate change and an increase in temperature on Pakistan's forest could be many, including the timberline moving up the Himalayan mountain slopes, the disappearance of alpine grasslands in those areas where mountain tops are just above the timberline, and changes in plant composition, cover, and location. The future area of different biomes could be significantly different than at present. An increased frequency and intensity of drought, storms, erosion, and landslides, could have the greatest impact over the next century. Increased temperature could affect plant distribution, photosynthetic rates, plant growth, soil organic decomposition rates, incidence of fires, pest outbreaks, diseases and ultimately regeneration success, mortality and growth/yield of trees (Deshingkar, 1996).

The impact of future climate change on the forests of Pakistan was determined with the use of the BIOME3 model. The BIOME3 model, developed by (Haxeltine, 1996), is based on ecophysiological constraints (cold tolerance and seasonality requirements), resource availability (water, nutrients, CO_2, and light) and competition among plant functional types on vegetation structure by mechanistically modeling the performance of different plant types. Model inputs consist of latitude, soil texture class, and monthly climate data (temperature, precipitation, and sunshine) on a 0.5º grid. Model output consists of a quantitative description of vegetation in terms of dominant plant types, secondary plant types, present and total leaf area index, net primary production, as well as large-scale vegetation patterns.

Of the 18 biomes identified worldwide by this model, only nine are relevant to Pakistan. The biomes were selected according to the nine forest types identified by (Champion, Seth, & Khattak, 1965), whereby some of the original biomes were combined. The expected changes in distribution of biomes and parameters of growth were determined for the years 2020, 2050, and 2080, using the 30-year average data for the period 1961–1990 as the baseline. Temperature data were extrapolated to the mean elevation of each cell, assuming an environmental lapse rate of

0.6ºC/100 m elevation. Climate scenarios were produced by assuming a rate of change in temperature of +0.3ºC/decade, and a rate of change of precipitation of 0% per decade, +1% and -1% per decade, again with 1990 as the base year. Current atmospheric concentrations of CO_2 were taken as 350 ppm, which was increased to 425 in 2020, 500 in 2050, and 575 in 2080. The results of the analysis are shown in Table 5.13.

The combined effects of increased temperature and CO_2 concentrations results in northwards and upwards movement of cold and temperate conifer forests. Cold conifer forests displace cold conifer/mixed woodlands, and alpine tundra in areas that currently do not support forest cover. The temperate conifer forest belt moves northwards, initially displacing areas occupied by cold conifer forests. In turn, the temperate conifer forests are displaced in lower and warmer areas by warm conifer forests. This warm conifer forest is not displaced by another forest type to any significant extent.

Under scenarios of increased precipitation, there is an increase in the forested area of Pakistan as forests expand into more arid areas. This increase is especially high for the warm conifer forest biome. Increasing precipitation causes a reduction in the area occupied by cold conifer woodland, which is more open and has a lower canopy cover and stand density than cold conifer forests.

Table 5.13 Areas of biomes under current and changing precipitation (mha)

Biomes	Current	2020			2050			2080		
	1961-90	-P*	0P	+P	-P*	0P	+P	-P*	0P	+P
Alpine tundra	5.9	4.9	4.9	4.0	4.0	4.0	4.0	3.6	3.6	3.6
Cold conifer/mixed woodlands	1.0	1.2	1.2	1.1	1.5	1.4	1.2	1.4	1.3	
Cold conifer/mixed forests	3.1	3.5	3.5	3.6	3.6	3.8	3.9	3.3	3.5	
Temperate conifer/mixed forests	3.8	4.1	4.1	4.1	4.0	4.1	4.1	4.5	4.6	
Warm conifer/mixed forests	4.3	5.4	5.9	5.9	6.4	6.9	7.2	6.7	7.4	
Xerophytic woods/scrubs	6.0	6.0	5.8	6.0	5.9	5.8	5.9	6.0	6.0	
Grasslands/arid woodlands	0.7	0.4	0.5	0.5	0.3	0.3	0.3	0.3	0.3	
Steppe/arid woodlands	33.3	34.9	35.8	36.7	36.1	37.4	39.0	36.5	38.7	
Deserts	28.6	26.3	25.0	23.8	24.8	23.0	21.0	24.4	21.3	
Total	*86.7*	*86.7*	*86.8*	*86.7*	*86.7*	*86.8*	*86.7*	*86.8*	*86.8*	*86.5*

The boundary between forest or woodland vegetation and tundra corresponds to the tree line. The polar and alpine tree lines correlate with growing degree days (gdd). In areas where the annual sum of gdd is less than 350 (on the basis of 5ºC average annual temperatures), trees are excluded and the alpine tundra biome is instead assigned to them by the model.

For the changed climate scenarios, there is a considerable decrease in the extent of alpine tundra as cold coniferous forests and woodlands move northward and to higher elevations. Alpine tundra decreases by about 17% by the year 2020, independent of changes in precipitation. Its area decreases by 32% by 2050, and by 39% by 2080.

Cold coniferous forests and mixed woodlands are predicted where cold trees are dominant but where the climate is too cold and/or dry to support a forest cover. Under the current climate, only about 1.1% of the total area of Pakistan is potentially covered by this biome. It expands northwards into the alpine tundra zone as the climate warms. At the same time, cold coniferous/mixed forests encroach upon its southern limit. The area of woodland is reduced to 1.5 mha in 2050 under conditions of reduced precipitation, or to 1.2 mha in the case of increased precipitation.

A cold coniferous/mixed forest biome is predicted where cold trees are dominant and the foliage cover is 76%. As the climate warms, this biome moves northwards. However, temperate conifers tend to move simultaneously into areas previously occupied by the cold conifers. Over a period of 90 years, the area under cold coniferous/mixed forests increases by about 20%, from 3.1 mha to 3.9 mha in 2050, under a scenario of precipitation increases of 6%.

A temperate coniferous/mixed forest biome is predicted where temperate trees are dominant and the foliage cover is 60%. This biome expands northwards as the climate warms. At the same time, warm coniferous forests also expand into areas occupied by temperate coniferous forests. Not all species in the biome may be able to migrate to new locations at equal rates because of physical barriers or physiological constraints. This may result in changes of species composition in this biome. This biome is also vulnerable to increasing socioeconomic pressure due to increases in population, which results in conversion of forests into cropland, orchards, and grazing land. An increase of 4–6% is expected with climate change. This might increase to about 20% by the year 2080, given a 9% increase in precipitation.

Key Point: The forest model considers land that has the *potential* for expansion into forest areas under climate change. The reality in Pakistan is that forests are being deforested and degraded rapidly.

Warm coniferous/mixed forests, also known as sub-tropical chir pine forests, have 60% foliage cover. As the climate warms, these trees move northwards. The southern boundary of these conifers does not contract, but expands southwards into areas currently too arid to support forests. The net result of this is a large expansion of warm coniferous/mixed forests from about 22% with a decrease in precipitation to more than 85% in the year 2080 with increased precipitation.

As precipitation increases, the area of grasslands and arid woodlands decreases as it is replaced by forests. The total area of xerophytic woods and scrubs does not change, although it does shift southwards. Under climate change, there is a considerable increase in the extent of steppe/arid shrublands, largely because of its expansion into areas that are currently simulated as deserts. Its extent increases from about 5% in 2020 to 20% by 2080. The existing irrigated tree plantations and riverine forests lie in this tract.

Any increase in precipitation decreases the area of desert biome. On the other hand, increases in temperature tend to increase the extent of desert. Increasing CO_2 increases water-use efficiency, thus may offset the increase due to a temperature rise. Consequently, desert may decrease by about one third by the year 2080, regardless of changes in precipitation. The climate warming is not large enough for tropical biomes to appear in northern Pakistan.

Simulated changes in net primary productivity (NPP) are due to changes in precipitation, temperature, and atmospheric CO_2 concentrations. If the area occupied by a certain biome retreats to less productive areas under the changed climate, then the NPP per unit area may decrease. NPP per unit area of cold coniferous/mixed woodland biome usually decreases as precipitation increases. As precipitation increases, areas occupied by woodlands are able to produce a more closed canopy with a higher simulated leaf area. They are then classified as forests, rather than woodlands, which are left on the dry sites. Dry woodland sites have a lower productivity. Table 5.14 shows some positive responses in relation to percentage changes in the NPP of forest biomes.The warm conifers are dominant. If an increase in NPP is any yardstick to measure cover density of a forest type, then warm conifers show a change of 16.4% for decreased precipitation in 2020, and more than 50% by 2080.

The simulations also indicate how the optimal tree species for different areas might change with climate change, and how areas currently unsuitable for forestry might become suitable as climate changes. The model projects that by 2050, about half of the areas where the natural vegetation is currently cold conifers would change to a new dominant vegetation type, especially to temperate coniferous biomes. In many areas where fir and spruce are currently dominant, there would be an increase in the predominance of more temperate coniferous species, such as deodar and blue pine.

Table 5.14 Changes in average net primary productivity (NPP) of different biomes under scenarios of precipitation change (%)

Biomes	2020			2050			2080		
	-P*	***0P***	***+P***	***-P****	***0P***	***+P***	***-P****	***0P***	***+P***
Alpine tundra	9.6	10.6	10.6	22.3	24.4	25.5	38.3	41.5	44.7
Cold conifer/mixed woodlands	9.3	10.6	9.3	14.3	11.8	9.9	21.7	22.4	18.4
Cold conifer/mixed forests	6.9	7.3	6.6	14.8	15.1	15.1	19.0	20.8	21.5
Temperate conifer/mixed forests	13.1	13.0	15.0	22.7	24.7	25.6	28.2	29.8	32.3
Warm conifer/mixed forests	16.4	16.9	18.9	31.3	34.1	37.5	43.7	48.9	53.1
Xerophytic woods/scrubs	12.6	10.5	11.7	22.6	22.6	24.3	32.2	33.4	32.7
Grasslands/arid woodlands	5.8	-1.1	-0.5	13.7	8.0	13.0	9.0	5.9	3.9
Steppe/arid woodlands	16.7	18.0	19.7	30.5	35.4	40.0	42.5	50.4	58.6
Deserts	14.5	14.7	14.9	26.9	28.5	30.0	37.7	40.7	45.7

About 18% of the area currently occupied by temperate coniferous trees would be replaced by warm conifers. Chir pine would move into the areas currently occupied by fir, blue pine, and deodar. Virtually none of the areas currently occupied by chir pine would change to a new biome. In other words, there would be little change in the species composition in areas currently occupied by chir pine forests. Almost three-quarters of the area currently occupied by grasslands and arid woodlands would change to a biome of higher order.

Some of the biomes are more sensitive to climate changes than others. These sensitive biomes tend to be at the extreme ends of the spectrum. For example, alpine tundra loses almost 32% of its area to other biomes. Grasslands/arid woodlands exhibit tremendous sensitivity to climate changes. Although they occupy a small area (700,000 ha), they lose about 43% of their area by 2020 if precipitation decreases. Deserts are also very sensitive to precipitation changes: an increase may cause it to lose as much as 26% of its area by the year 2050, and another 7% by the year 2080. Warm conifers are not very sensitive to either decreased or increased precipitation, and thus do not change much in their extent. However, they gain tremendously when there is an increase in precipitation coupled with an increase in temperature.

A large part of the area simulated as forest in the model is actually land degraded by human interference or land being used for agriculture, orchards, or grazing. The model simulations predict only the potential natural vegetation patterns. Further, the model predictions only indicate that there will be potential for an expansion in the forested area under climate change scenarios. The actual change in forest area depends mostly on the ability of species to migrate to new areas, as well as on the activities of humans in forested areas.

A greater number of fire outbreaks, erratic rainfall, and the pressure of human activities may not allow some species to move to new locations. Physical barriers such as croplands, orchards, and topographic features may also hinder migration. Some economically important species, such as deodar and fir, will almost certainly decline in area and number due the interaction of climate change and socioeconomic pressures. Other species, like chir pine and blue pine, which are tolerant of water stress, fire and grazing pressure, may increase due to reduced competition from associated species.

The impacts of climate change on forests can have implications for related activities, including construction, furniture and paper production, and fuelwood availability. Biodiversity and environmental services (clean air, water) and recreational opportunities are also likely to be affected. It is unlikely that the positive climatic impacts on forests will offset the negative trends arising from a host of socioeconomic pressures. Such pressures increase the vulnerability to climate change, and counter the purely biophysical impacts.

Fuelwood demand was expected to rise by 55% by 2000, as a result of population pressure. Unless alternative fuels can be provided, this will lead to further exploitation of forests. Deforestation has led to serious erosion problems and soil degradation. Rural communities in the northern areas of Pakistan have been displaced by such land degradation, and have been forced to migrate to crowded "road towns," thereby exacerbating problems of sanitation, air pollution, and water pollution.

5.10 Adaptation to Climate Change

The analysis of climate change impacts shows that they would generally be negative, particularly for the water and agriculture sectors. The projected impacts vary from unremarkable to alarming, as in the case of water scarcity. Although the impacts on the forestry sector are encouraging based on computer model predictions, the increase in potential area is neither realistic nor likely to be achieved because of human impacts.

The single most important adaptation measure is the conservation of water and the development of sustainable water projects. Because a large number of human, institutional, and economic factors influence the adaptation process, an interdisciplinary approach is essential. Furthermore, any development or change in one sub-sector has a chain effect on other sub-sectors.

Key Point: Adaptation strategies to climate change will have to be part of a more comprehensive strategy to overcome environmental problems of today, as well as of the future.

The impacts of climate change on water resources are part of a much broader environmental problem. Adaptations to climate change will therefore have to be a part of a more comprehensive strategy to overcome the environmental problems of today, as well as of the future. The strategy can be summed up as "the conservation and efficient use of water in an informed and efficient manner." Three types of adaptation strategies can be identified: 1) those that are a direct result of the water resources management models; 2) those that are not model inspired, but are required for specific scenarios; and 3) general guidelines to enhance the overall efficiency of water resources management.

Nevertheless, planning is difficult without adequate and reliable data, including demographic variations and an understanding of the phenomenological response of the ecosystem to climatic changes. Some examples of potential adaptation strategies follow:

- *Small dams can contribute to Pakistan's water storage capacity.* Rigorous efforts in the construction of small dams appear to be imperative to mitigate the adverse impacts of climate change. The Jhelum River would be an ideal location to begin dam construction, as it is non-controversial and involves relatively small investments. A reservoir on the Chenabb at Chiniot is also an option, as it can also provide extra space for flood control. The WAPDA is already actively considering dams at Sehwan, Mancher, Hammal, and Chitiari, and their construction gains importance if scenarios of increased temperature and decreased rainfall are considered.
- *The village pond system can help in the reduction of expected shortages in the water distribution system.* Enough rainwater is available in the monsoon season for storage, but these ponds have been degraded due to silting and weed growth. It is necessary to revive, extend and expand this system of water conservation by regular cleaning and maintenance of existing depressions. It is also necessary to find more ditches and depressions for increased water storage. There is also a need to revive the old system of rainwater harvesting in the northern Punjab, where rainfall intensities are high.
- *In order to increase cropping intensities, it may be necessary to alter current operating procedures.* Rapid improvements in communications and increased mass education may facilitate improvements in the water distribution system, with much greater responsibilities for operations resting with the farmers themselves.
- *There is a strong need to devise policies that promote water conservation in urban areas to reduce the rising pressure on the drainage and supply systems.* Studies are necessary to find out the optimal methods adapted to local environments. Currently, urban water supplies are short due to the limited capacity of the supply system. At the same time, a large amount of water is wasted. The net usage of water in urban areas is about 2%, as most of it is recycled to the distribution network. Not all urban areas are served with good, clean water. Urban water use is projected to increase, as more people are covered under new schemes of the Social Action Plan. Increases in standards of living will also increase the use of water in urban areas. At present, water is largely pumped from the ground to supply urban areas. If precipitation decreases, water supplies will decline in certain areas, particularly the barani areas.

These examples illustrate the close relationship between addressing present-day problems and adapting to climate change. While the impacts of climate change may be potentially serious for Pakistan, there are a number of measures that can be taken to decrease present-day and future vulnerability, while at the same time increasing adaptation options.

6 Conclusions

The four country studies presented in this report illustrate the importance of adopting a flexible approach to the assessment of climate change impacts and adaptations. While the UNEP Handbook on Methods served as a common reference for the study teams, each team found it necessary to adapt these methods – sometimes to a considerable extent – to meet the specific needs of the country. Moreover, two of the country studies (Estonia and Pakistan) were able to build on previous work on climate impacts, while the other two (Antigua and Barbuda and Cameroon) broke new ground.

The variation in approaches also resulted in variations in how the findings were presented – making it difficult to generalize about either the impacts of climate change on developing countries and economies in transition or adaptation strategies. Nevertheless, three general observations may be made:

1. The most serious impacts of climate change will occur in regions or sectors that are already under stress as a result of human activities.

2. Instead of promoting resiliency, many present-day activities increase the environment's vulnerability to climate change.

3. Most adaptation strategies for climate change can be considered "no regrets" or "win-win" strategies in that they promote sustainable development regardless of actual or potential changes in the climate.

These observations underscore the importance of addressing current environmental stresses and problems as a way to prepare for a future change in climate. Indeed, resolving current socioeconomic and environmental issues may be the most important means of addressing climate impacts and facilitating the adaptation to long-term climate change. This means that there is no need to devise an entirely new institutional framework to deal with climate change: the principle means for adaptation are already in place. However, considerable improvements need to be made in the institutional capacity to administer and regulate environmental issues, including allotting more resources to support existing policies.

Perhaps the most important lesson to be drawn from this study is that adaptation to climate change must be addressed on a country-by-country basis, one that takes into account each country's particular environmental and socioeconomic conditions, and how these conditions respond to political, economic, and environmental changes. Indeed, the wealth of important detail included in each of these reports is a testimony to just how much developing countries and economies in transition can differ from one another. Estonia may well benefit from some aspects of climate change, while Pakistan is likely to lose out. The lack of data in countries such as Cameroon and Antigua and Barbuda underscore the need for long-term studies of climate impacts and adaptations. In general, the country studies show that economic changes – along with political, social, and demographic changes – make some regions and sectors more vulnerable to climate change, and others more resilient. Current environmental problems are also shaping the context for climate impacts and adaptation strategies.

The UNEP Country Studies on Climate Change Impacts and Adaptation Assessments provided the four country teams with an opportunity to evaluate a draft version of the UNEP Handbook on Methods for Climate Change Impact Assessment and Adaptation Strategies. While formal evaluations were not carried out as part of the project, the practical experience of the country study teams and experts involved in providing technical assistance contributed to the refinement of the draft handbook. Recommendations from the country study teams, particularly regarding aspects that were lacking, have been incorporated into an advanced draft of the handbook. The UNEP Handbook serves as a valuable technical resource for other countries interested in carrying out similar national assessments.

In conclusion, the UNEP Country Studies provide a basic foundation for understanding the potential impacts of climate change and the adaptation measures necessary to address them. They indicate the scope of the problems in each of the countries studied, as well as the direction adaptation studies should take. Most importantly, they demonstrate that while each country has a unique set of problems and strategies, all countries will benefit from long-term sustainable development.

References

Adger, W. N., & Kelly, P. M. (1999). Social Vulnerability to Climate Change and the Architecture of Entitlements. *Mitigation and Adaptation Strategies for Global Change, 4*, 253-266.

Adojaan, A. (1961). *Rohumaaviljelus Eestis (Grassland husbandry in Estonia).* Tallinn: Eesti Riiklik Kirjastus.

Airey, M. J., Hulme, M., & Johns, T. C. (1996). Evaluation of simulations of terrestrial precipitation in UK Met. Office/Hadley Centre climate change experiments. *Geophys. Res. Letters, 23*, 1657-1660.

Alleng, G. P. (1993). Review of the role of coastal habitats as nursery areas for coral reef fishes. (WP 23): CFRAMP.

Appeldoorn, R. S., Dennis, G. D., & Monterrosa Lopez, O. (Eds.). (1987). *Review of shared demersal resources of Puerto Rico and the lesser Antilles region.* (Vol. Fish. Rep.): FAO.

Arp, P. A., & Oja, T. (1997). A forest soil vegetation atmosphere model (ForSVA), I: concepts. *Econ. Modelling, 95*, 211-224.

Arp, P. A., & Yin, X. (1992). Predicting water fluxes through forests from monthly precipitation and mean monthly air temperature records. *Can. J. For. Res., 22*, 864-877.

Aug, H., & Kokk, R. (1983). Eesti NSV looduslike rohumaade tüübid ja produktsioon (Distribution and productiveness of the natural grasslands of the Estonian S.S.R.). Tallinn: Valgus.

Behrendt, H., & Stellmacher, R. (1987). Long-term changes in water quality parameters of a shallow eutrophic lake and their relations to meteorologic and hydrologic elements, *The Influence of CLimate Change and Climate Variability on the Hydrologic Regime and Water Resources* (Vol. 168, pp. 535-544): IAHS Publ.

Berry, A. J., & Chew, E. (1973). Reproductive systems and cyclic release of eggs in Littorina melanostoma from Malayan mangrove swamps (Mollusca : Gastropoda). *Journal of Zoology London, 171*, 333-344.

Bohle, H. G., Downing, T. E., & Watts, M. J. (1994). Climate Change and Social Vulnerability. *Global Environmental Change, 4*(1), 37-48.

Boulon, R. H. J. (1992). Use of mangrove prop root habitats by fish in the northern U.S. Virgin Islans. *Proc. Gulf. Caribb. Fish. Instit., 41*, 189-204.

Cambers, G. (Ed.). (1993). Assessment of the Vulnerability of Coastal Areas in Antigua and Nevis to Sea Level Rise: UNDP.

Cambers, G. (1996). Hurricane Impacts on Beaches in the Eastern Caribbean Islands, 1989-1995. COSALC Coast and Beach Stability in the Lesser Antilles . Mayaguez, Puerto Rico: UNESCO Coast and Small Island and the University of Puerto Rico Sea Grant College Programme.

Carter, T. R. (1996). Global climate change and agriculture in the North. *Agriculture and Food Science in Finland, 5*(3), 222-385.

Carter, T. R., Parry, M. L., Harasawa, H., & Nishioka, S. (1994). *IPCC Technical Guidelines for Assessing Climate Change Impacts and Adaptations*. Department of Geography, University College London, UK and Center for Global Environmental Research, National Institute for Environmental Studies, Tsukuba, Japan.

Champion, H. G., Seth, S. K., & Khattak, G. M. (1965). *Manual of silviculture*. Peshawar: Pakistan Forest Institute.

CIA World Factbook. (1999). Country Maps. In *The Perry-Castañeda Library Map Collection & T. U. o. T. a. Austin* (Eds.). http://www.lib.utexas.edu/Libs/PCL/Map_collection/cia99.html.

COLSALC. (1996). *Hurricane Impact on Beach Changes in the Eadtern Carribean Islands 1989-1995* . Mayaguez, Puerto Rico: Coastal and Beach Stability in the Lesser Antilles, University of Puerto Rico, Sea Grant College Program.

Dennis, G. D. (1992). Island mangrove habitats as spawning and nursery areas for commercially imported fishes in the Carribean (Vol. 41, pp. 205-226): Proc. Gulf. Caribb. Fish. Instit.

Deshingkar, P. e. a. (1996). Adapting to climate change in a forest based land use system. A case study of Himachal Pradesh, India: Stockholm Environment Institute and Tata Energy Institute.

Donfack, L., & Boukar, L. S. (1997). Les grande caracteristiques du miliey physique.

EFDP. (1997). *Estonian Forest Policy* : Estonian Forestry Development Programme.

Ellison, J. C. (1992). *Mangrove retreat with rising sea level.* Unpublished Ph.D. dissertation, University of California at Berkeley.

Eltermann, V. (1996). Eesti metsade maksimaalse võimaliku puidukasutuse prognoos (The prediction of the maximum allowable cut in Estonian forests (Manuscript). Tallinn: Eesti Metsakorralduskeskus.

Estonian Forest Department. (1995). *Estonian Forests and Forestry*. Tallinn.

FAO. (1994). Mangrove forest management guidelines. *FAO forestry paper, 117*.

Focks, D. A., Haile, D. G., Daniels, E., & Mount, G. A. (1993a). Dynamic life table model for Aedes aegypti - Analysis of the litterature and model development. *J Med Entomol, 30*, 1003-1017.

Focks, D. A., Haile, D. G., Daniels, E., & Mount, G. A. (1993b). Dynamic life table model for Aedes aegypti - Simulation results and validation. *J Med Entomol, 30*, 1018-1028.

Frich, P. (1996). *Application of the North Atlantic Climatological Dataset (NACD) - an overview.* Paper presented at the European Conference on Applied Climatology.

Gallegos, A. S., Czitrom, S., Zavala, J., & Fernandez, A. (1993). Scenario Modeling of Climate Change on the Ocean Circulation of the Intra-Americas Sea. In G. A. Maul (Ed.), *Climate Change in the Intra-Americas Sea* (pp. 55-74).

Glynn, P. W. (1996). Coral reef bleaching: facts hypothese and implications. *Global Change Biology, 2*, 495-509.

Harmelin-Vivien, M. L., & Laboute, P. (1986). Catastrophic impact of hurricanes on atoll outer reef slopes in the Tuamotu (French Polynesia). *Coral reefs, 5*, 55-62.

Haxeltine, A. (1996). *Modelling the vegetation of the Earth* . Sweden: Department of Ecology, Plant Ecology, Lund Univ.

Hendry, M. (Ed.). (1993). Sea-Level Movements and Shoreline Changes: UNDP.

Hong, W. K., & Chin, E. (1983). Thermal effects of some mangrove moouscs. *The Veliger, 26*, 119-123.

Hulme, M., Jiang, T., & Wigley, T. (1995a). *SCENGEN: A Climate Change SCENario GENerator. Software User Manual, Version 1.0* . Norwich: Climatic Research Unit, University of East Anglia.

Hulme, M., Raper, S. C. B., & Wigley, T. M. L. (1995b). An integrated framework to address climate change (ESCAPE) and further developments of the global and regional climate modules (MAGICC). *Energy Policy, 23*, 347-355.

IPCC. (1992). *Climate Change*: Intergovernmental Panel on Climate Change.

IPCC. (1998). Regional Impacts of Climate Change.

Jaggus, J. (1996). Climatic trends in Estonia during the period of instrumental observations and climate change scenarios. In J.-M. Punning (Ed.), *Estonia in the System of the Global Climate Change* (Vol. 4, pp. 35-48). Tallinn: Institute of Ecology.

Järvet, A., & Jaagus, J. (1996). The impact of climate change on hydrological regime and water resources in Estonia. In J.-M. Punning (Ed.), *Estonia in the System of the Global Climate Change* (Vol. 4, pp. 84-103). Tallinn: Institute of Ecology.

Jaagus, J. (1992). Periodicity of precipitation in Estonia. In T. e. a. Kaare (Ed.), *Man and Nature* (pp. 43-53). Tallinn.

Kallis, A., & Tooming, H. (1974). Estimation of the Influence of Leaf Photosynthetic Parameters, Specific Leaf Weight and Growth Functions on Yield. *Photosynthetica, 8*(2), 91-108.

Karing, P. H. (1992). Õhutemperatuur Eestis (Air temperature in Estonia). Tallinn: Valgus.

Karing, P. H. (1995). Practical applications of microclimatic knowledge and information to agriculture (C AgM report 726). Geneva: WMO/TD.

Karing, P. H., Vartseva, S. E., & Tooming, H. G. (1987). Regulation Efficiency of Barley Crops Productivity, *Proc. of All-Union Inst. Agric. Meteorol.* (pp. 73-81 (In Russian)).

Keita, e. a. (1990, 2-7 Decembre, 1990). *Courantologie et quelques paramètres phèsiques dans l' estuaire de la Bimbia, Cameroun.* Paper presented at the Rapport technique COMARAF sur l'ètude plurdisciplinaire de l'ècosystème de l'estuaire de la Bimbia., Limbe, Cameroun.

Kivi, K. (1981). About spatial and temporal variability of drought in spring. *All-Union Inst. og Agric. Meteorol., 2*, 128-141.

Krasovskaia, I., & Saeltun, N. R. (1997). Sensitivity of the stability of Scandinavian river flow regimes to the predicted temperature rise. *Hydrological Sciences-Journal des Sciences Hydrologiques, 42*(5), 693-711.

Lewis, J. B. (1963). Environmental and tissue temperatures of some tropical intertidal marine animals. *Biological Bulletin, 124*, 277-284.

Liverman, D. M. (1994). Vulnerability to Global Environmental Change. In S. L. Cutter (Ed.), *Environmental Risks and Hazards*. New Jersey: Prentice Hall.

Loucks, D., French, P. N., & Marshall, R. T. (1995). *Interactive river-aquifer simulation (IRAS)* (Program description and operation). NY: Ithaca.

Masood, T. and S. Ullah. (1991). *Draft Report on the UBC Modelling of Jhelum*. Lahore

Maul, G. A. (Ed.). (1993). Implications of the Future CLimate on the Ecosystems and Socio-Economic Structure in the Marine and costal Regions of the Intra-Americas Sea: UNEP.

Nazir, A. (1993). *Water resources of Pakistan*. Lahore: Gulberg.

NCA. (1988). *National Commission on Agriculture*. Islamabad: Ministry of Food, Agriculture and Livestock, Government of Pakistan.

Nilson, A. (1996). Social and Environmental Role of Forest Management Plan and its Implementation. Integrating Environmental Values into Forest Planning - Baltic and Nordic Perspectives. Paper presented at the EFI Proceedings No. 13, Joensuu.

Nilson, A., & Kiviste, A. (1984). Männikute "kasvukäigu" mudel tüpiseerimata kasvukohatingimuste jägi (Pine stand growth model in continuous site types). *EPA teaduslike tööde kogumik, 151*, 50-59.

Oja, T., & Arp, P. A. (1996). Nutrient cycling and biomass growth at a North American hardwood site in relation to climate change: ForSVA assessments. *Climatic Change 34, 34*, 239-252.

Oja, T., & Arp, P. A. (1997). A Forest Soil Vegetation Atmosphere Model (ForSVA), II: Application to Northern Tolerant Hardwoods. *Ecological Modelling, 95*, 225-247.

Oude Essink, G. H. P. (1996). Impact of sea level rise on Ground water flow regimes: A sensitivity analysis for the Netherlands. Unpublished Ph.D. thesis, Delft University of Technology, Delft.

Parry, M., & Carter, T. (1998). Climate Impact and Adaptation Assessment: A Guide to the IPCC Approach. London: Earthscan Publications Ltd.

Parry, M. L., Carter, T. R., & Konijn, N. T. (1988). *The impact of climatic variation on agriculture*: Kluwer Acad. Publ.

Roostalu, H., Tamm, T., Kevvai, L., & Valgus, T. (1996). Potential effects of global climate change on Estonian agriculture, *Estonia in the System of Global Climate Change* (Vol. 4, pp. 123-138). Tallinn: Institute of Ecology.

Russak, V. (1990). Trends of solar radiation, cloudiness and atmospheric transparency during recent decades in Estonia. *Tellus, 42B*, 206-210.

Russak, V. (1994). Is the radiation climate in the Baltic Sea region changing? *Ambio, 23*(2), 160-163.

Santer, B. D., & et al. (1996). A search for human influence on the thermal structure of the atmosphere. *Nature, 382*(39-46).

Sarma, K. M. (1991). *Adaptation Measures.* Paper presented at the Climate Change: Science, Impacts and Policy.

Senedakar, S. C. (1993). Impact on Mangroves, in Manl. Climate Change in the Intra-America Sea.

Sepp, J. V., & Tooming, H. G. (1991). *Productivity resources of potato*. Leningrad: Gidrometeoizdat.

Smith, J.B. et al. (1996). Adapting to Climate Change: Assessments and Issues. New York: Springer.

Spieker, H., Mielikäinen, K., Köhl, M., & Skovsgaard, J. (Eds.). (1996). *Growth trends in European forests.* Berlin: Springer Verlag.

Stewart Environmental Systems Inc. (1980). *Proposal for Silviculture, Agriculture and Animal husbandry Potential in Barbuda*: Submission to the Government of Antigua and Barbuda.

Tarand, A. (1993). Precipitation time series in Estonia in 1751-1990. *Zeszyty Naukowe Uniwersytetu Jagiellonskiego, Prace Geograficzne, 95*, 139-149.

Tarar, R.N. 1997. "Surface Water Scenarios in the 21st Century and Needed Actions." Proceedings of the International Symposium on Water for the 21st Century: Demand, Supply, Development and Socio-Environmental Issues. June 17-19, 1997, Center of Excellence in Water Resources Engineering, UET, Lahore, Pakistan.

Tooming, H. (1993). Evolution of agrometeorological resources based on the potential productivity of crops. *J. Agr. Met., 48*(5), 501-507.

Tooming, H., & Kadaja, J. (1995). Changes in snow cover and surface albedo in Estonia during the last 100 years. *Meteorol. Zeitschrift, 4*, 67-71.

Tooming, H., & Kallis, A. (1972). Productivity and growth calculations of plant stands, *Solar Radiation and Productivity of Plant Stand* (pp. 1-121). Tartu: Est. Acad. Sci.

Tooming, H., & Karing, P. (1977). Agroclimatic Estimation of the Potential Yield of Perennial Grasses and the Yield Shortage Due to Water Deficit. *Meteorology and Hydrology, 2*, 81-86 (in Russian).

Tooming, H. G. (1977). *Solar radiation and yield formation*. Leningrad: Gidrometeoizdat.

Tooming, H. G. (1984). *Ecological principles of maximum crops productivity*. Leningrad: Gidrometeoizdat.

UNDP. (1994). *Human Development Report 1994*. New York: Oxford University Press.

UNDP. (1998). *Human Development Report 1998*. New York: Oxford University Press.

UNDP. (2000). Analytical Tools for Human Development. http://www.undp.org/hdro/anatools.htm. United Nations Environment Programme (UNDP).

UNEP. (1996). *Handbook on Methods for Climate Change Impact Asseessment and Adaptation Strategies*. Amsterdam: UNEP and Institute for Environmental Studies, Vrije Universiteit.

Vallner, L. (1996). Kirde-Eesti hüdrogeoloogiline mudel (The Hydrogeological Model of North-East Estonia). Tallinn: Eesti Geoloogiakeskus, Eesti Geoloogiafond.

Vallner, L. K. (1980). Hydrogeodynamical subdivision and budget of groundwater in Estonia. In L. K. Vallner (Ed.), *Hydrogeological Problems of Estonia* (pp. 11-120). Tallinn: Estonian Academy of Sciences.

Viilup, Ü. (1996a). Forest resources, *Yearbook of forest 95* (pp. 10-22). Tallinn.

Vincente, V. P., Singh, N. C., & Botello, A. V. (1993). Ecological implications of potential climate change and sea-level rise. In G. A. Maul (Ed.), *Climate change in the Intra-Americas Sea* (pp. 262-281).

Watson, R. T., Zinyowera, M. C., Moss, R. H., & Dokken, D. J. (1996). *Climate Change 1995: Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analysis*. Cambridge: Cambridge University Press.

Watson, R. et al. (1998). The Regional Impacts of Climate Change: an Assessment of Vulnerability. A special report of Working Group II. Cambridge: Published for the Intergovernmental Panel on Climate Change by Cambridge University Press.

Wigley, T. M. L., & Raper, S. C. B. (1987). Thermal expansion of sea water associated with global warming. *Nature, 330*, 127-131.

Wigley, T. M. L., & Raper, S. C. B. (1992). Implications for climate and sea level rise of revised IPCC emissions scenarios. *Nature, 357*, 293-300.

Wigley, T. M. L., Smith, R. L., & Santer, B. D. (1998). Anthropogenic influence on the autocorrelation structure of hemispheric-mean temperature. *Science, 282*, 1676-1679.

World Bank Group. (2000). Classification of Economies . http://www.worldbank.org/data/databytopic/class.htm#Classification.

Yates, D. (1994). WatBal - An Integrated Water Balance Model for Climate Impact Assessment of River Basin Runoff. *IIASA Working Paper 64*.

Yates, D., & Strzepek, K. (1994). Comparison of Models for Climate Change Assessment of River Basin Runoff. *IIASA Working Paper 45*.

Yearbook. (1995). Tallinn: Economics and Information Centre of Forestry.

Zhukovsky, E. E., Sepp, J. V., & Tooming, H. G. (1990). Probabilistic forecast of possible yield. *Meteorol. and Hydrol., 1*, 95-102.

Appendix I: Country Study Teams

Antigua and Barbuda
Country Case Study on Climate Change Impacts and Adaptations Assessment, Antigua and Barbuda. Ministry of Planning, Government of Antigua and Barbuda, UNEP, GEF.

Team Leader
Mr. Daven Joseph, Ministry of Planning

Climate Scenarios
Mr. Patrick Jeremiah,
Mr. Franck Jacobs

Coastal Zone
Ms. Cheryl Jeffrey,
Mr. Philmore James

Agriculture
Mrs. Florita Kentish
Mr. Jerry Fernandez
Mr. Everette Williams
Mr. David Lewis

Health
Mr. Dorbrene O'Marde
Mr. Lionel Michael

Fisheries
Mr. Robin Mahon
Mr. Daven Joseph

Human Settlements
Mr. Ernest Benjamin
Ms. Angela Braithwaite
Mr. Jaysee Sebastian

Water Resources
Mr. Jerry Fernandez

Adaptation
Mr. Brian Challenger

Cameroon
Cameroon Country Case Studies on Climate Change Impacts and Adaptations Assessments. 1998. Climate Change Unit, Cameroon, UNEP, GEF.

Team leader
Mr. Roger Tonleu, Ministry of the Environment and Forestry

Final report:
Dr. Francois Mkankam Kamga
Dr. Innocent Takougan
Dr. Joseph Youmbi
Dr. Fondo Sikod
Mr. Richard Ndemanou
Mr. Ameddee Sida
Mr. Dudley Sama

Sector reports:
Cameroon Estuary Mangrove Ecosystem
Dr. Joseph Youmbi Tientcheu
Mr. Collins A. Angwe.
Dr. Ndongo Din

Coastal Infrastructures
Mr. Amaddée Sida
Mr. Dudley A. Sama
Mr. Enoh P. Ayuk

Biodiversity in the Waza Logone Flood Plains
Mr. Thomas F. Tata
Mr. Richard Ndemanou
Mr. Jean Claude Hell

Human Health in the Sudano-Sahelian
Dr. Innocent Takougang
Dr. Joe Louis Mvondo

Socio-economic Analysis of Potential Climate Change Impacts on the Cameroon Coastal Zone
Dr. Fondo Sikod
Plains Climate Change Scenarios for Impacts Assessment in Cameroon Coastal Zone and the Northern Flood Plains
Dr. Francois Mkankam Kamga

Estonia

Country Case Study on Climate Change Impacts and Adaptation Assessments in Republic of Estonia. 1998. Stockholm Environment Institute and Ministry of Environment, Republic of Estonia, UNEP, GEF.

Team Leader
Andres Tarand, Ministry of Environment

Project coordinator
Dr. Tiit Kallaste, Stockholm Environment Institute Tallinn Centre

Mr. Anto Aasa
M.Sc. Rein Ahas
Dr. Agu Eensaar
Dr. Jüri Elken
Prof. Ivar Etverk
Dr. Jaak Jaagus
Dr. Ago Jaani
Mrs. Anne Järvet
Dr. Tiit Kallaste
Prof. Peeter Karing
Mrs. Kulla Kivi
Prof. Andres Kiviste
Prof. Henn Korjus
Mrs. Ly Kovanen
Mr. Paavo Kuiv
M.Sc. Ain Kull
Mrs. Helve Meitem
Dr. Saadi Mihkelson
Mrs. Tiina Mällo
Prof. Artur Nilson
Prof. Tonu Oja
Prof. Evald Ojaveer
Prof. Hindrek Older
Mrs. Evelin Peenar
Prof. Rein Ratas
Dr. Urmas Raudsepp
Prof. Jüri Roosaare
Dr. Viivi Russak
Dr. Mati Sepp
M.Sc. Toomas Tamm
Dr. Andres Tarand
Prof. Heino Tooming
Dr. Aleksander Toompuu
Mrs. Aide Uueni
Dr. Leo Vallner
Mrs. Kersti Vemik
Mr. Üllar Vösumaa
Mrs. Ede Ümarik

Pakistan

Study on Climate Change Impact Assessment and Adaptation Strategies for Pakistan. Government of Pakistan, Ministry of Environment, Local Government and Rural Development, UNEP, GEF.

Team Leader
Mr. Mehboob Elahi

Socio-economics
Dr. Tariq Banuri
Dr. Shaheen Rafi Khan
Dr. Jennifer Bennett
Dr. Kaiser Bengali
Dr. Shahid Rahim
Dr. Shahid Zia
Mr. Sajjid Kazmi

Water Resource
Dr. Munir A. Bhatti
Mr. Tariq Masood
Mr. Abdul Rehman
Dr. M. Nawaz Bhutta
Dr. Mansoor A. Hashmi
Mr. Ayaz Beg

Agriculture
Dr. Qazi M. Hanif
Dr. Shahid Ahmed
Dr. Abdul Majid

Forestry
Dr. K. M. Siddiqui
Dr. Mohammad Ayaz
Mr. Mohammed Iqbal

Meteorology
Dr. Qamar-uz-Zaman Chaudhry
Dr. Ghulam Rasul
Mr. Anjum Bari

Appendix II: Climate Models

HadCM2 - Hadley Centre, UK, 1994-95, resolution 2.5 x 3.75, transient, mean monthly precipitation pattern correlation coefficient 0.77.
UKTR - UK Meteorological Office/Hadley Centre, 1991-92, resolution 2.5x3.75, transient, mean monthly precipitation pattern correlation coefficient 0.76.
UKHI - UK Meteorological Office, 1989, resolution 2.5x3.75, equilibrium, mean monthly precipitation pattern correlation coefficient 0.72.
CSIRO9M2 - Commonwealth Scientific and Industrial Research Organisation, Australia, 1995, resolution 3.2x5.6, equilibrium, mean monthly precipitation pattern correlation coefficient 0.71.
ECHAM3TR - European Centre, Hamburg, 1995, resolution 2.8x2.8, transient, mean monthly precipitation pattern correlation coefficient 0.67.
ECHAM1TR - European Centre, Hamburg, 1989, resolution 5.6x5.6, transient, mean monthly precipitation pattern correlation coefficient 0.64.
CSIRO9 - Commonwealth Scientific and Industrial Research Organisation, Australia, 1991, resolution 3.2x5.6, equilibrium, mean monthly precipitation pattern correlation coefficient 0.64.
UKLO - UK Meteorological Office, 1986, resolution 5x7.5, equilibrium, mean monthly precipitation pattern correlation coefficient 0.64.
CCCEQ - Canadian Climate Centre, 1989, resolution 3.7x3.75, equilibrium, mean monthly precipitation pattern correlation coefficient 0.63.
BMRC - Bureau of Meteorology Research Centre, Australia, 1991, resolution 3.2x5.6, equilibrium, mean monthly precipitation pattern correlation coefficient 0.61.
OSU - Oregon State University, USA, 1988, resolution 4x5, equilibrium, mean monthly precipitation pattern correlation coefficient 0.59.
GISSEQ - Goddard Institute for Space Studies, USA, 1983, resolution 8x10, equilibrium, mean monthly precipitation pattern correlation coefficient 0.58.
GFDLLO - Geophysical Fluid Dynamic Laboratory, USA, 1986, resolution 4.5x7.5, mean monthly precipitation pattern correlation coefficient 0.58.
LLNL - Lawrence Livermore National Laboratory, USA, 1989, resolution 4x5, equilibrium, mean monthly precipitation pattern correlation coefficient 0.56.

Source: Estonia (1998). Country Case Study on Climate Change Impacts and Adaptation Assessments in Republic of Estonia. Tallinn: SEI.

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CICERO (Center for International Climate and Environmental Research – Oslo) was established by the Norwegian government in 1990 as a policy research foundation associated with the University of Oslo. CICERO's research and information helps to keep the Norwegian public informed about developments in climate change and climate policy.

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- Chemical processes in the atmosphere
- Damage to human health and the environment caused by emissions of greenhouse gases
- Domestic and international climate policy instruments
- International negotiations on environmental agreements

CICERO (Center for International Climate and Environmental Research – Oslo)
P.O. Box 1129 Blindern, N-0318 Oslo, Norway
Visiting address: Sognsveien 68, Oslo
Telephone: +47 22 85 87 50 Fax: +47 22 85 87 51
E-mail: admin@cicero.uio.no Web: www.cicero.uio.no

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- Internasjonale forhandlinger om miljøavtaler

CICERO Senter for klimaforskning
Postboks 1129 Blindern, 0318 Oslo
Besøksadresse: Sognsveien 68, Oslo
Telefon: 22 85 87 50 Faks: 22 85 87 51
E-post: admin@cicero.uio.no Hjemmeside: www.cicero.uio.no