Executive summary

Introduction

Working Group II has examined aspects of four of the tasks approved at the fifth plenary session of IPCC in March 1991. These tasks were:

- prediction of the regional distributions of climate change and associated impacts studies, including model validation studies;
- energy and industry related issues;
- agriculture and forestry-related issues;
- vulnerability to sea-level rise.

From the stimulus provided by the publication in 1990 of the IPCC Impacts Assessment, many regional studies have been carried out on assessment of impacts of climate change. A questionnaire circulated by Working Group II in June 1991 was valuable in revealing new information and in defining areas of common concern to many countries (see Appendix A). Thus, roughly 50% of the responses highlighted the impacts of climate change on hydrology and water resources, emphasising the importance of water in most countries. Other topics of priority interest, particularly for developing countries, were agriculture and forestry, and the world's oceans and coastal zones. Both reflect the apprehension of countries over availability of food supplies from land and sea sources.

Additional areas of concern identified in the questionnaire were desertification (particularly Africa and Asia), cyclones and other extreme events (particularly their economic impacts), and climate variability associated with the El-Niño Southern Oscillation (ENSO) phenomenon, prolonged droughts and extreme events. The national responses showed concern that changes in climate variability as a consequence of climate change may create increased risks, especially in those parts of the world where climate variability is known to have significant social and economic impacts. It is important to note that many countries, particularly in the Southern Hemisphere, also identified increases in UV-B radiation as a significant area of concern.

Working Group II's activities focused only on the portions of the four tasks noted above that directly related to the impacts of climate change and the report should be read in association with the reports of Working Groups I and III. These activities built on the earlier work reported in the first IPCC Impacts Assessment The previous format of subgroups dealing with specific topics was maintained and task forces were set up to deal with monitoring and guidelines for assessment of impact.

In view of the extreme concern expressed over impacts of climate change on hydrology and water resources and on changes in UV-B radiation in the responses to the questionnaire, additional work was carried out on those topics although they were not identified in the tasks approved at the fifth IPCC plenary session. Further work was also carried out on the cryosphere in view of its importance to global climate change.

The findings of the subgroups and task forces are reported under the four tasks as:

- prediction of the regional distributions of climate change; this includes:
  - Systematic observations to identify climate change consequences;
  - Preliminary guidelines for assessing impacts of climate change.
- energy and industry-related studies; this includes:
  - Energy; human settlement; transport and industrial sectors; human health; air quality; effects of ultraviolet B radiation.
- agriculture and forest-related issues; this includes:
  - Agriculture and forestry; natural terrestrial ecosystems; hydrology and water resources.
- vulnerability to sea-level rise; this includes:
  - World oceans and coastal zones—ecological effects; terrestrial component of the cryosphere.

Although all the studies reported here have served to extend our knowledge of the potential impacts of climate change and, to some extent, reduce the uncertainties, they do not radically alter the conclusions of the IPCC Impacts Assessment. Thus, as stated there:

> Any predicted effects of climate change must be viewed in the context of our present dynamic and changing world. Large-scale natural events such as El Niño can cause significant impacts on agricultural and human settlements. The predicted population increase will produce severe impacts on land use and on the demands for energy, fresh water, food and housing, which will vary from region to region according to national incomes and rates of development. In many cases, the impacts will be felt more severely in

regions already under stress, mainly the developing countries. Human-induced climate change due to continued uncontrolled emissions [of greenhouse gases] will accentuate these impacts. . . The severity of the impacts will depend to a large degree on the rate of climate change.

Prediction of the regional distributions of climate change and associated impact studies, including model validation studies

Regional climate change prediction

The precise prediction of climate change at regional level is subject to great uncertainty. Prediction of precipitation changes is particularly uncertain, although the changes are of great practical significance. Progress in the development of global circulation models (GCMs) is urgently needed, particularly in terms of improving their capability for regional prediction and to understand changes in arid and semi-arid regions. Work on improving regional predictions using the palaeo-analog method continues in Russia and other countries. In the further work of the IPCC, all methods of regional climate prediction should be reviewed and assessed together.

Guidelines for assessing impacts of climate change

Working Group II has prepared guidelines to assess the socioeconomic and environmental impacts of potential climate change. These guidelines outline a framework for the study of climate-environment-society interactions and the estimation of the impacts of climate change which will allow comparisons and integration of impacts across various geographical areas and economic sectors. Further work will continue as a long-term task.

Impact assessments involve several steps:

- definition of the problem;
- selection of analytical methods;
- testing the method;
- development of climatic and socioeconomic scenarios;
- assessment of potential impacts:
- evaluation of technical adjustments; and
- consideration of policy options.

Definition of the problem includes identifying the specific goals of the assessment, the sector(s) and geographical area(s) of interest, the time horizon of the study, the data needs and the wider context of the work.

Selection of analytical method(s) depends upon the availability of resources, models and data. Impact assessment analyses could range from the qualitative and descriptive to the quantitative and prognostic. Thoroughly testing the method(s), including model validation and sensitivity studies, before undertaking the full assessment is necessary to ensure credibility.

Development of the climatic and socioeconomic scenarios involves several steps. First, the current and projected climatic, socioeconomic and environmental conditions expected to exist over the study period in the absence of climate change should be established. Second, scenarios of regional climate change over the study time frame must also be developed. Third, biophysical and environmental effects should be projected under the altered climate. These projections should then be used, preferably in integrated environment-economic models, to calculate the socioeconomic effects under the altered climate. Assessment of potential impacts of the sector(s) or area(s) of interest involves estimating the differences in environmental and socioeconomic conditions projected to occur with and without climate change.

Projections of effects with and without climate change should incorporate 'automatic' adjustments. However, the impact assessment should seek to evaluate the additional technical adjustments resulting from application of existing and new technologies or practices that may be available over the study period, assuming no change in the current legal and institutional framework.

The costs and benefits of climate change should be assessed, to the extent possible, using a common measure and discounted to net present value. Alternatively, costs and benefits should be described qualitatively. The above general framework would also allow consideration of policy options and their socioeconomic and environmental impacts.

Monitoring to identify climate change consequences

There is a need to increase the available information and data to support impact studies, particularly in developing countries. This need can be met through enhancing and, where appropriate, establishing integrated monitoring programs including biological, chemical, physical and climatological parameters, as well as constructing concurrent social and economic assessments, at the national, regional and global levels to identify climate change consequences. Data quality needs to be assured and data analyses and their interpretation need to be carried out carefully. The use of common protocols for collection and analysis processes, including Geographical Information Systems (GIS), and for equipment will aid in assuring

intercomparability and further encourage international cooperation. The development of the preliminary IPCC guidelines for assessing the impacts of climate change is an important contribution to this end.

Monitoring of sensitive terrestrial and marine ecosystems,including the cryosphere, and component species should be given priority as they could provide early detection/warning of climate change and its impacts. Also to be given priority are those species and ecosystems which have significant (locally/regionally defined) social and/or economic values. The classic ground station approach (including points, plots and transects) should provide the basic building blocks of monitoring programs; however, these should also be supplemented with remotely sensed observations (eg satellite, radar and photogrammetry). Advantage should also be taken of automatic data transmission and processing systems.

At present, international organisations such as UNEP, WMO and IOC are implementing monitoring programs to help identify ecological and socioeconomic consequences of climate change. UNEP has an initial program for observing terrestrial ecosystems with observations extending on either side of the present boundaries of plant zones for early detection of possible shifts of these boundaries. WMO and IOC, among their many monitoring activities, have designed a satellite observing system for climatic and ocean parameters. Current planning of the Global Climate Observing System (GCOS) and the Global Ocean Observing System (GOOS) should consider the value of including the monitoring of terrestrial and marine ecological impacts of climate change. These can provide an early indication of the integrated effect of climate change.

Energy and industry-related issues

Energy, human settlement, transport and industrial sectors, human health, air quality and effects of ultraviolet-B radiation

In terms of human settlement, recent studies for the Maldives and for the Pacific island states including Tuvalu, Kiribati, Tokelau and the Marshall Islands have reconfirmed that small low-lying island states and large populations living in low-lying coastal areas will be increasingly vulnerable to the combination of sea-level rise, storm surges and coastal flooding, particularly if adaptive measures are inadequate.

The high dependency on biomass and hydro-electric energy in many developing countries indicates that these countries are quite sensitive to the impacts of climate change. Biomass production, on which developing countries depend for much of their energy needs, could be altered by climate change.

On the other hand, there has been little work that has shed new light on the question of socioeconomic impacts in the areas of energy, human settlement, transport and industrial sectors, human health and air quality.

A UK study shows that soil shrinkage as a result of climate change in clay-rich areas has major implications for the construction and insurance industries and for human settlement. Water-dependent industries such as food processing, paper making and power generation could be affected by hydrological changes under changed climate conditions.

Knowledge of climate change on human health has extended and confirmed the previously reported results with greater understanding of potential shifts in disease vector habitats with global warming, particularly in New Zealand and Australia. Diseases such as malaria, lymphatic filariasis, schistosomiasis, leishmaniasis, onchocerciasis (river blindness), dengue fever, and Australian and Japanese encephalitis could increase or be reintroduced in many countries as a consequence of global warming. Regarding the impact of UV-B radiation on health, recent studies have linked UV-B radiation to additional effects that had not been proposed previously, such as those affecting the human immunosuppression system and vision.

Agriculture and forest-related issues

Agriculture and forestry

New studies, such as those in the European Community, North America, and Southeast Asia, highlight the conclusions of the IPCC Impacts Assessment that impacts will vary greatly, depending on the extent of climate change and on the type of agriculture. These findings largely amplify, but do not radically alter, the conclusions made in the first IPCC Impacts Assessment. They do, however, confirm that the impact of global warming on agriculture may be serious if warming is at the upper end of the range projected by the IPCC Working Group I.

Recent studies have reinforced concern that drought is the area in which climate change poses the greatest risk for agriculture, and consequently arid and semi-arid regions are likely to be most vulnerable to climate change.

Other recent studies confirm the earlier conclusion that climate change may benefit ecological conditions for insect growth and abundance, which is likely to have a negative effect on crop, livestock and forest production in some regions.

Research continues to address the relative importance of direct and indirect effects of CO_2, in combination with

a rise in temperatures, on future crop production. While some scientists emphasise enhanced photosynthesis and more efficient water use as seen in controlled settings, others are sceptical that these benefits will arise in farmers' fields under changing climate conditions.

The effects on plant growth may result in the maintenance of present-day soil conditions in some regions, as greater soil organic matter and denser ground cover may counter the effects of soil erosion caused by increased rainfall intensities and oxidation rates of organic matter in soils caused by higher temperatures.

Adaptation to climate change by the existing agricultural production system should be possible, and the worldwide systems of agricultural research should be able to provide new crop cultivars that maintain high yields and nutritional quality. However, efforts will be needed to make such developments available to small farmers in developing countries in time to respond to changes in local climate conditions.

New analyses support the conclusion of the IPCC Impacts Assessment that the impacts of climate change on forests could have significant socioeconomic consequences. This is especially important for those countries and regions where economic and social welfare, and economic development are highly dependent on the forest sector.

Key uncertainties require continued data collection and research for policy development and decision making. These include:

- the extent of managed and natural forests, their spatial and temporal variation and their roles in the global carbon cycle;
- genetics and physiology of tree species and the relationships among subordinate and competitive species;
- regional impacts; and
- the linkages among the regional impacts, socioeconomic structures, and the thresholds and critical limits where changes take place.

Natural terrestrial ecosystems

Analyses subsequent to those included in the IPCC Impacts Assessment reinforce the conclusion that natural terrestrial ecosystems could face significant environmental impacts as a result of the global increases in atmospheric concentrations of greenhouse gases and associated climatic changes. In particular, these studies continue to suggest that the rate of these changes will be the major factor in determining the type and degree of impacts, with a variety of responses expected for different regions and for different communities within ecosystems. Current climatic projections continue to suggest that rates of change are likely to be faster than the ability of some component species to respond, and that the responses of species and ecosystems may be sudden, potentially leading to ecosystem destabilisation or degradation.

The promotion of heightened public awareness of the general values of natural terrestrial ecosystems is essential to gaining public support for sustaining these ecosystems in a changing climate. Particular emphasis should be placed on involving ecosystem managers and local people in the assessment of the impacts, consequences and response strategies.

One of the major issues regarding the impacts of climate change on terrestrial ecosystems is water availability, with recent studies suggesting that while water use efficiency of vegetation could increase in an enriched CO_2 atmosphere, the same amount of water per unit soil area may be necessary because of increased leaf area ratios due to greater biomass produced in that enriched atmosphere.

Projected climate changes are expected to result in an accelerated reduction of tropical forest on the African continent and an encroachment of the Sahel syndrome into the savannas. These changes could worsen the already precarious production systems in the affected regions of Africa, further stressing the associated natural ecosystems and component species. Degradation of wetlands and shallow lakes (eg within savanna ecosystems in Africa and within the Great Plains of North America) as a result of projected decreases in rainfall or soil moisture could adversely impact on resident animals and migratory species.

With projected climate change, profound impacts, both beneficial and destructive, can be expected for the distribution and productivity of valuable fisheries and the industries associated with them. The added stresses to freshwater ecosystems as a result of climate change can be expected to reduce species numbers and genetic diversity within freshwater populations in the short term. By contrast, with warming, a longer growing season could lead to greater fish productivity where temperature is currently a limiting factor.

Uncertainties and gaps in the knowledge base continue to exist in terms of our understanding of the environmental impacts and associated socioeconomic consequences of climate changes. National, regional and global efforts need to be cooperatively concentrated on reducing these deficiencies, which primarily exist as a result of the lack of sufficient information and data on:

- fundamental ecological processes;
- the links between climate and atmospheric chemistry on the one hand and the response of natural terrestrial ecosystems andtheir component species on the other; and

- the links between natural terrestrial ecosystem changes and social and economic welfare under a changing climate.

In particular, there is a lack of information on the sensitivity of these ecosystems and their component species to climate change, the vulnerability of social and economic systems to ecosystem changes, and thresholds/critical levels for these ecosystems and associated social and economic systems. Existing international programs such as GEMS and MAB can provide one means of examining these deficiencies.

Hydrology and water resources

Since the publication of the IPCC Impacts Assessment, several studies on impacts of climate change on hydrology and water resources have been conducted. Unfortunately, there is not yet adequate information on regions affected by aridity and desertification; efforts should be made to fill that gap. The new studies expanded on the geographic scale of the original surveys and confirmed many previous conclusions, but few new insights were offered on hydrologic sensitivities and vulnerability of existing water resources management systems.

The principal conclusions suggested by the new studies are:

- Significant progress has been made in hydrologic sensitivity analyses in developed countries, yet large gaps exist in the information base regarding the implications of climate change for less developed nations;
- Comparative sensitivity analyses that rely on existing GCMs offer generic insights regarding the physical hydrologic effects and water resources management impacts, but the differences in the outputs of the GCMs coupled with large differences in hydrologic sensitivity analyses make it difficult to offer region-specific impact assessments;
- Temporal streamflow characteristics in virtually all regions exhibited greater variability and amplification of extremes, with larger flood volumes and peak flows as well as increased low flow episodes and a shift in the turning of the seasonal runoff;
- The higher the degree of water control, regulation and management of sectoral water demands, the smaller the expected adverse effects of global warming. Conversely, unregulated hydrologic systems are more vulnerable to potential hydrologic alterations.

The principal recommendations are:

- Increased variability of floods and droughts will require a re-examination of engineering design assumptions, operating rules, system optimisation, and contingency planning for existing and planned water management systems;
- More studies on hydrologic sensitivity and the vulnerability of water resource management need to be focused in arid and semi-arid regions and small island states;
- A uniform approach to the analyses of hydrologic sensitivity to climate change needs to be developed for comparability of results.

Vulnerability to sea-level rise

World oceans and coastal zones: ecological effects

Since the first IPCC Impacts Assessment, new studies reconfirm that rising sea-level is of more concern in low-lying coastal ecosystems than rising water temperatures. However, the combination of sea-level rise and temperature rise, along with changes in precipitation and UV-B radiation, are expected to have strong impacts on marine ecosystems, including redistributions and changes in biotic production.

The impact of sea-level rise depends on the total net rise resulting from the relative vertical movements of the land and of the sea. In areas undergoing natural eustatic uplifting of the land due to tectonic plate movement, glacial rebound, and vulcanism, there will be little relative rise of sea-level. In land areas that are naturally falling, as in the south-eastern USA, because of tectonic and compaction forces, impacts of sea-level rise will be more important.

A new study of the Bering Sea indicates that in areas without natural land uplift, there could be important impacts where there is a high density of marine organisms dependent on certain types of onshore and near-shore marine environments that may be affected by sea-level change. Nevertheless, sea-level rise is of far less consequence in northern areas than are other impacts of climate change to northern ecosystems and to global carbon cycling. These regions are very important in the global carbon cycle and a small temperature rise may cause significant increases in bioproductivity and in carbon flux to the oceans.

Coral organisms grow 1–20 cm/year and reef growth rates as a whole are known to be up to 1. 5 cm/year. Not all reefs accumulate at these rates, but most should keep pace with the expected rise in sea-level if other factors do

not alter growth conditions. Stress on the reefs from other variables (storms, sedimentation, disease, rainfall, radiation, turbidity, overfishing, mass mortality in algal grazers etc) may prevent some reefs from keeping pace with rising sea-level, resulting in changes to near-shore hydrodynamics.

With respect to temperature rise, marine organisms in the tropics live closer to their maximum thermal tolerance than those in more temperate climates. Although a 1–2°C temperature rise would raise summertime mean temperature to over 30°C over much of the tropical/subtropical region, most migratory organisms are expected to be able to tolerate such a change. Temperature rise may trigger bleaching events in some corals, but it is expected that the other stresses mentioned above will be more important.

Intertidal plants, such as mangroves, can withstand high temperature and, unless a rise in temperature affects reproduction, it is unlikely to have any effect. Because mangroves grow best in moderately saline environments, mangroves can probably keep pace with sea-level rise in rain-fed humid areas, but may be over-stepped and abandoned in more arid areas, particularly if inland retreat is not possible. Thus, future changes in patterns of rain and runoff and of overcutting may be more important than sea-level rise. With respect to marshes, new studies indicate that mid-latitude plants seem to tolerate salinity better and are more productive under elevated CO_2.

New findings of WMO/UNEP indicate that UV-B radiation reaching oceanic and coastal zone environments will increase faster than expected when the first IPCC Impacts Assessment was written. Since so many marine resources spend all or substantial parts of their lives near the water surface, there is a significant threat to some fisheries. The first assessment expressed concern about leaching of contaminants during sea-level rise from coastal waste disposal sites. There are also bacteria and viral agents in such sites and in coastal septic sewerage systems which could be increasingly released into coastal waters. There are potential impacts on coastal resources, but the primary concern is for the humans who consume them and the loss of commerce owing to the closure of fish and shellfish areasby health authorities. Lastly, potential changes in storm frequency or intensity could have important ecological consequences to coastal resources.

Cryosphere

Analyses continue to support the conclusion that projected changes in climate associated with enhanced atmospheric concentrations of greenhouse gases are expected to reduce substantially the areal extent and volume of seasonal snow cover, mountain glaciers, terrestrial ice sheets and frozen ground including permafrost and seasonally frozen ground.

Recent analyses have shed some further light on the potential impacts for these elements of the terrestrial cryosphere:

- analysis of satellite-derived data on snow cover has shown the extent of snow in the Northern Hemisphere to be at record low levels since the middle of 1987, with the largest negative anomalies occurring in the spring;
- above normal temperatures throughout much of the Northern Hemisphere in 1989 led to the initiation of extensive active layer detachment slides within permafrost in some regions of the Canadian and Russian Arctic with damming and degradation of water quality in affected streams and further failures initiated;
- emissions of methane from hydrates in Arctic regions as a result of permafrost degradation may have been underestimated;
- there is some evidence to suggest that glaciers in the Northern Hemisphere polar and subpolar regions are receding at a slowerrate than previously suggested with some having advanced in the past thirty years. Although the Southern Hemisphere record is not as detailed, records for several New Zealand glaciers showthat they have retreated since the mid 1800s, with the suggestion that this has been the result of an increase intemperature and an accompanying decrease in precipitation.

Key uncertainties are associated with understanding fundamental cryological processes, the relationship among these elements (eg impacts of changes in snow cover on permafrost and glacier dynamics), the impacts of climate change on these elements of the cryosphere, the interdependency of associated ecosystems (eg soil erosion and stability changes associated with permafrost degradation) and human systems (eg structures, transportation, transmission lines), and the role of the cryosphere in local, regional and global climate and climate change.

Summary of issues for further consideration

Regional climate predictions

IPCC has continued to stress that research leading to information on likely regional climate change (and its association with global change) is of the highest priority, and has noted that there are certain aspects of regional climate change that are particularly important in some areas. Among these are tropical cyclones and the tidal surges associated with such storms. Guidance on likely

changes in frequency, intensity and distribution of such events, as a result of climate change, is urgently needed in states in and bordering the Pacific, Indian and Atlantic Oceans. Special attention should be given to the needs of small island states which are particularly vulnerable to climate change. Prediction of regional precipitation is another area of particular concern. Further, the connections between local, regional and global pollution require further study.

The question of the validity of the technique of palaeo-analog for the prediction of regional climate change needs further debate. Although palaeo-data concerning past climates are of great value, clear analogs from the past which can be applied to future climate changes have not yet been identified. In the further work of the IPCC, all methods of regional climate prediction should be reviewed and assessed on a continuing basis.

Country studies and methodologies

IPCC has recognised the valuable work on methodologies for country studies—such as that for national inventories of greenhouse gas emissions and sinks—which were being carried out by the three Working Groups and elsewhere. It has acknowledged that this is a cross-cutting issue. It has recognised the utility of further work on methodologies for both limitation and adaptation and, in particular, their integration into a broader framework.

Priority should be given to assessing the work in progress and to the development of coherent guidelines for country studies, keeping in mind the circumstances of different countries and the evolving nature and pattern of their use of natural resources. The next step in this process should be the convening of a workshop, possibly before the eighth session of IPCC, with a report to be reviewed at that time.

Dissemination of IPCC information

With financial support provided by some countries, the IPCC has conducted a series of information exchange seminars in several developing countries, and the IPCC Impacts Assessment and some other IPCC reports have been translated into several languages. Non-government organisations are also contributing significantly to the dissemination of information on climate change. The seminars have attracted participation from all levels of society, including heads of state and government ministers, specialists, experts, non-government organisations and the public. They have contributed significantly to the understanding of the various aspects of the climate change issue. Further seminars in developing countries should be undertaken in response to requests, but are dependent on the availability of financial and human resources.

Resource issues

The IPCC assessments are critically dependent on research and development carried out under international programs and by national research teams. The need to increase these research efforts has become obvious in the course of the IPCC work. At all levels of society, there is insufficient knowledge and understanding of both the climate change issue itself, as well as all the socioeconomic impacts and further societal implications. The IPCC strongly urges that greater means be made available for these activities and that the major international global programs be given adequate resources. It is particularly important that means are made available to permit developing countries to become genuine partners in this global research effort. The progress of our understanding is dependent upon dealing with the global environment in its entirety.