METEOROLOGY AND HYDROLOGY FOR SUSTAINABLE DEVELOPMENT

WORLD METEOROLOGICAL ORGANIZATION

WORLD METEOROLOGICAL ORGANIZATION

METEOROLOGY AND HYDROLOGY FOR SUSTAINABLE DEVELOPMENT

by

J. P. Bruce

WMO – No. 769

Secretariat of the World Meteorological Organization – Geneva – Switzerland
1992

Cover picture: Grant W. Goodge

ISBN 92-63-10769-6

Contents

Foreword

"Weather and climate services for sustainable development" is the theme selected as the focus for the celebration of World Meteorological Day 1992. This day celebrates the coming into force on 23 March 1950 of the WMO Convention, when the intergovernmental World Meteorological Organization was established as the successor to the International Meteorological Organization that had existed since 1873.

This booklet on the above theme was written by Mr J. P. Bruce from Canada, former acting Deputy Secretary-General of WMO. I should like to express my deep gratitude to Mr Bruce for his work and for his contribution to the success of World Meteorological Day 1992. His long experience in environmental issues, in addition to his concern for the future of planet Earth, makes him suitably placed to demonstrate how the components of planet Earth's environment—the atmosphere, biosphere, climate, water—are inextricably bound up with sustainable development.

Mr Bruce highlights the urgent issues of pollution, natural disasters and environmental emergencies. He presents a perspective which emphasizes that the health of the planet is dependent on equitable and sustainable development which in turn involves the search for adequate solutions, ranging from sound environmental economics to a judicious use of resources, such as agriculture, water, oceans, forests and energy.

The World Meteorological Day theme this year is especially relevant because of its relationship to the coming United Nations Conference on Environment and Development in June 1992. There, at the Earth Summit, world leaders will take decisions that are likely to have far-reaching consequences for the future.

A number of the decisions to be made will be based on data and information provided through the World Meteorological Organization by national Meteorological and Hydrological Services. For such a significant confluence of science, environment and development, it is opportune that World Meteorological Day should be focused on this special theme.

The World Meteorological Organization is pleased to be able to contribute to the efforts towards sustainable development.

G. O. P. Obasi
Secretary-General

CHAPTER 1

Introduction

Sustainable development and the UN Conference on Environment and Development

> "Humanity has the ability to make development sustainable—to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs. The concept of sustainable development does imply limits—not absolute limits, but limitations imposed by the present state of technology and social organization on environmental resources and by the ability of the biosphere to absorb the effect of human activities." [1]

Other definitions of sustainable development have been made both before and after this influential quotation taken from *Our Common Future*, the 1987 report of the World Commission on Environment and Development—a United Nations Commission chaired by Prime Minister Gro Harlem Bruntland of Norway. All such definitions imply the need for forms of development that are sustainable in three senses.

First, development must not damage or destroy the basic life support systems of planet Earth: the air, the water and the soil and biological systems. Nor should development seriously degrade natural resources, such as water, soil, and the vegetation on which human economic and social activities depend. The second aspect of the sustainability of development is economic, to provide for a continuous flow of goods and services derived from the Earth's natural resources. Much more careful and efficient use of these resources, our water, our soils, our forests is required than in past decades.

The third implication of most definitions of sustainable development is the need for sustainable social systems, at international, national, local and family levels, to ensure the equitable distribution of the benefits of the goods and services produced, and of sustained life-support systems.

The last two aspects of sustainability, the need for economic and social systems, are human-centred, whereas the first aspect concerns all forms of life on the planet. It is this first aspect of sustainable development, the sustaining of natural systems and resources, and the way in which the sciences of the atmosphere and the hydrosphere, meteorology and hydrology, can assist in achieving this sustainability, that is the subject of this booklet and of World Meteorological Day, 23 March 1992.

The three aspects of sustainability are so inextricably interwoven that economic and social implications of maintaining the integrity of natural systems are evident in much of the following discussion of air, water and related biological systems.

The urgent practical need for adopting sustainable approaches to development has been well articulated in *Our Common Future*. That report also cogently argues that the often perceived dichotomy between environment and economic development has been a serious flaw in approaches to development over the past centuries, since the beginning of the industrial revolution. Wise management of environmental resources must be seen as an integral part of economic development, not as an appendage or afterthought.

The four principle goals of sustaining natural systems for use and enjoyment of future generations are:

- protection of life-support systems of the air, water and soil;
- protection and enhancement of biotic diversity;
- maintenance or restoration of stocks of renewable natural resources and ecosystems;
- prevention of, or adaptation to, global change [2].

Essential requirements to achieve these goals are scientific measurements and knowledge of the state and behaviour of the Earth's natural systems, as well as the capability and desire to make use of that knowledge. Of fundamental importance is an understanding of the atmosphere and the hydrosphere and how they change under stresses caused by human activities.

The widespread evidence of adverse environmental pressures leads to the conclusion that the forms of economic development which arose over the past century are not sustainable. The problem of local contamination of the atmosphere and water bodies observed in the first part of the 20th century has gradually led to regional and global problems. These include acid rain; critical scarcities of water in some regions; devastating droughts and desertification; a rising loss of life and property and human misery from natural disasters such as floods and tropical cyclones; airborne transport of toxic chemicals to distant seas and lakes; increasing greenhouse gases and the related climate change; depletion of the stratospheric ozone layer; oil pollution of seas and lakes; environmental emergencies from spills, fires and sudden nuclear and chemical emissions.

To address these problems and move towards nationally and globally sustainable development, profound changes are needed:

- *in the industrially developed world*—to devise means to maintain economic systems that use resources more sparingly and efficiently, and minimize waste discharges;
- *in developing countries*—to ensure that economic growth to meet the rising expectations of growing populations takes place in a manner that will minimize resource depletion and environmental stress.

A key factor in order to move towards those goals would be to ensure that indicators which reflect resource depletion and environmental changes are incorporated one way or another in national accounts. This would help to reflect the true cost to society of an economic activity. It must be appreciated that it is not a simple matter to determine the real cost of degradation of the quality of air or water, or of the use of a certain amount of water for a given activity, thus making it unavailable for other activities or for the maintenance of healthy ecosystems. However, it is *impossible* to determine such environmental and resource-depletion costs, or to wisely allocate water without the basic measurements and analyses of air and water quality and of the quantity and the flow of water. The availability of such information cannot be taken for granted. It requires long-term, painstaking monitoring by national institutions using methods established by the relevant international organizations.

As we move into the last decade of the twentieth century there are signs of a willingness on the part of many peoples and their governments to change their economic ways—to move towards more sustainable forms of development. This willingness is particularly evident in the preparatory processes for the Earth Summit (UN Conference on Environment and Development (UNCED), Brazil, June 1992). Senior representatives of national governments are meeting regularly to debate and plan the approaches to be adopted. The scientific community as a whole, led by the International Council of Scientific Unions and the water specialists of the world, with WMO chairing the conference planning meetings, are developing important statements. Three far-reaching agreements or conventions are under negotiation:

- on climate change and greenhouse gas limitations,
- on forest management, and
- on preservation of biodiversity.

An Earth Charter of guiding principles and an Agenda 21 for actions to be taken towards sustainable development will also be major goals of the UNCED process. However, a fundamental requirement for the practice of sustainable development is the availability of authoritative information on natural systems and their behaviour, drawn from long-term systematic measurement programmes and research.

Of course, some progress towards international action has been achieved already. International agreements to curb acid-causing emissions, to protect the ozone layer and to reduce pollution of some international waterways have been negotiated and signed as a start towards tackling the regional and global problems. However, the goal of global sustainable development will require much more effort, and some fundamental changes both nationally and internationally. The following chapters outline some paths towards sustainable futures from fundamental components of the environment, from some basic resources, and as well, the role played by meteorology and hydrology in the design of such pathways.

CHAPTER 2

Planet Earth's environment

The atmosphere and climate—the air we breathe, the climate that shapes life

The atmosphere of our planet is an essential environment and resource. It has developed in harmony with the biosphere of Earth, and is essential for life of all creatures. It produces the climates which determine the natural endowments of regions and the way we live [3]. For development to be truly sustainable, the character of the atmosphere must not be significantly degraded or altered.

Until the latter half of this century it was generally considered that the envelope of air around us was so vast, and the energy involved in the restless weather systems so enormous, that human activities would have but temporary and local impacts. But measurements and documentation of global contamination of the atmosphere which disprove this idea are now only too well known. Such documentation includes the increasing acidity of the rain over extensive regions, the startling reductions in stratospheric ozone over Antarctica during the southern hemisphere spring, the rapid rate of increase of the greenhouse gases throughout the global atmosphere giving rise to projections of global climate warming, and the intercontinental transport by sea and air of toxic chemicals from the Arctic to the Antarctic in detectable, even dangerous, amounts, and far away from industrial and agricultural sources.

How did we learn about this striking evidence of the declining quality of the global atmosphere, these manifestations of the unsustainability of recent forms of economic development?

The World Weather Watch

Much of our knowledge comes from globally co-ordinated scientific observation networks, operated by nearly all countries, with standards and operational and data exchange procedures co-ordinated by the World Meteorological Organization (WMO). Some of these activities began in 1873 with the International Meteorological Organization, the predecessor of WMO. The physical features of the atmosphere, including the changing temperatures, the winds and pressure patterns, and life-giving precipitation, are measured under the World Weather Watch system (see Figure 1). This unique enterprise comprises the Global Observing System for both surface and upper layers of the atmosphere, the Global Telecommunications System—so that worldwide observational data can be rapidly exchanged especially in support of operational weather forecasting—and the Global Data-processing System, a network of world and regional centres for the operational analysis and processing of millions of bits of meteorological data daily.

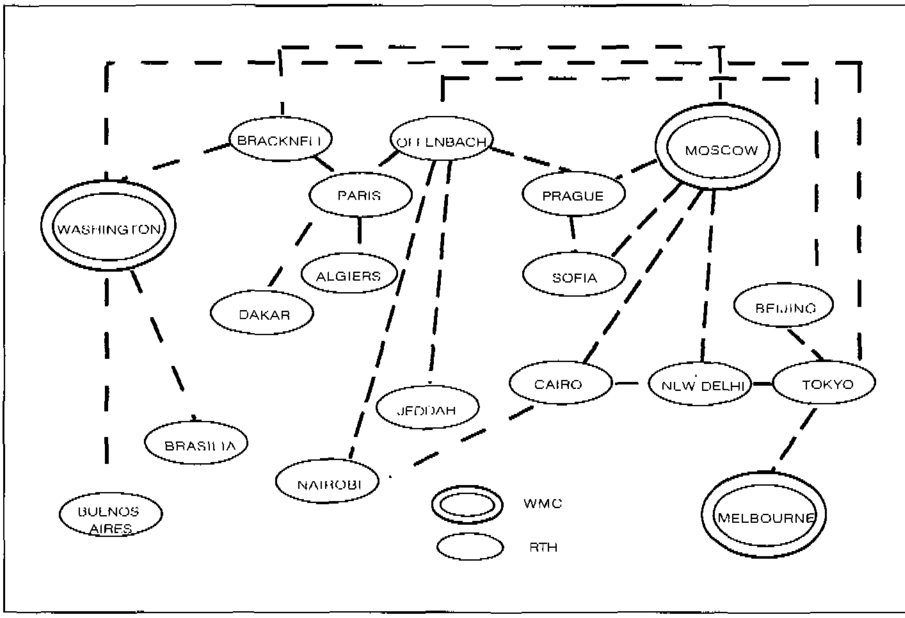


Figure 1— Main Telecommunication Network of the WMO Global Telecommunication System

From the data products of the World Weather Watch, augmented by more dense climatological (temperature, precipitation, wind, sunshine) measurement networks operated by most countries and ships at sea as part of the World Climate Data and Monitoring Programme, scientists have been able to compute global temperature trends, such as those given in Figure 2. The six warmest years on record have occurred during the past decade, 1990 exhibiting the highest global average temperature since an adequate network was established in the mid-1800s.

Climate change detection

Projected future changes in global climate, due to increasing concentrations of human-induced greenhouse gases, will be evident not only by higher global average temperatures and changed precipitation patterns, but also by changes in other meteorological factors both at the ground and in the upper atmosphere. Climate-change detection is a function of major importance of the World Climate Programme and the World Weather Watch.

Global Atmosphere Watch

The changes in atmospheric quality, that is, its chemical composition, have been documented in large measure through the Global Atmosphere Watch also co-ordinated by WMO. The GAW has two main components—the Background Air Pollution Monitoring Network (BAPMoN) and the Global Ozone Observing System (GO_3OS). The GO_3OS, since the 1960s, has shown

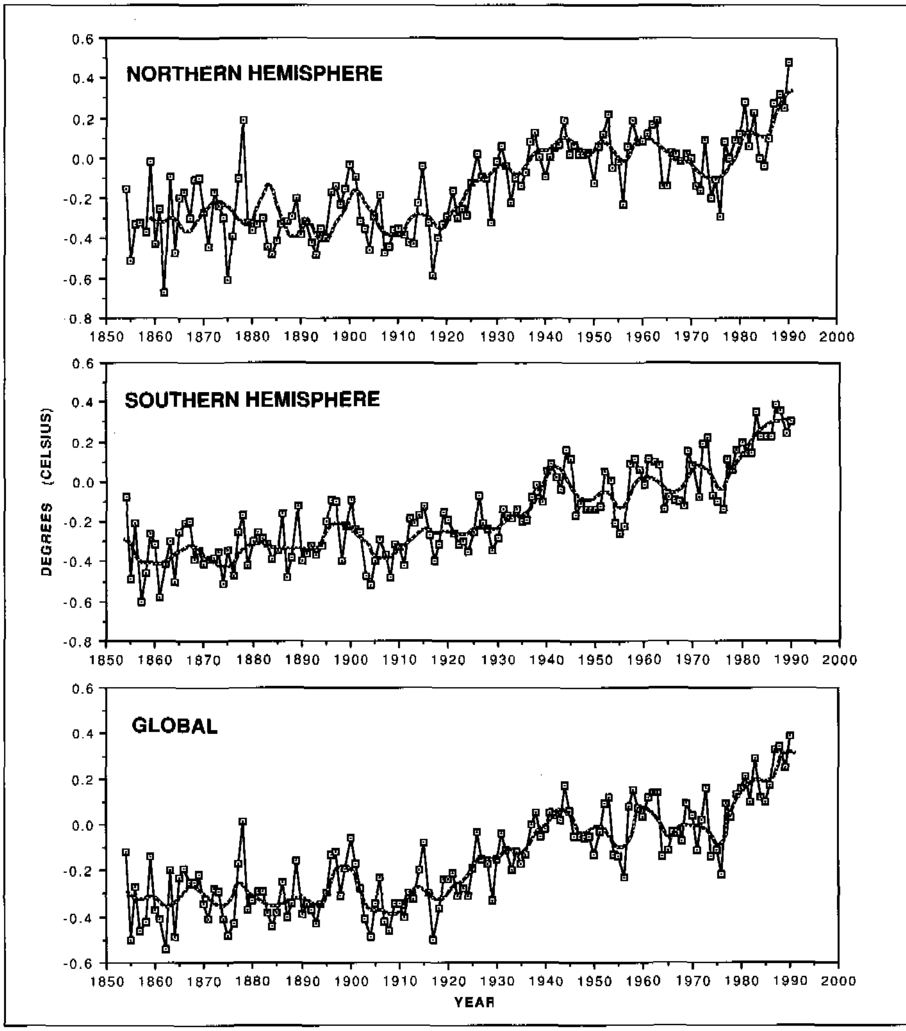


Figure 2—Annual and ten-year means of hemispheric and global mean temperatures *(after Jones and Wigley, Scientific American, Aug. 1990)* [4]

the decline of the health-protecting stratospheric ozone layer due to chemical pollutants, particularly the chlorofluorocarbons (CFCs), and the simultaneous increase of low-level ozone in and near cities, mainly associated with vehicle exhaust (Figure 3). The BAPMoN part of the GAW and other specialized networks have revealed the trends and distribution of acidity (Figure 4) and toxic chemicals in precipitation and in the air near the ground, as well as a steady increase in carbon dioxide, methane and other greenhouse gases caused by many human activities, but especially the burning of fossil fuels.

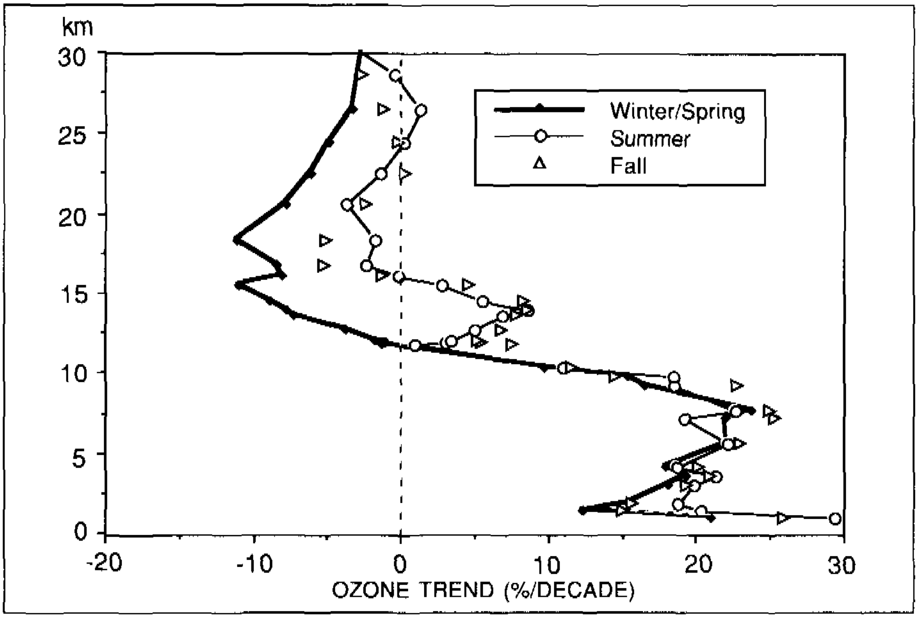
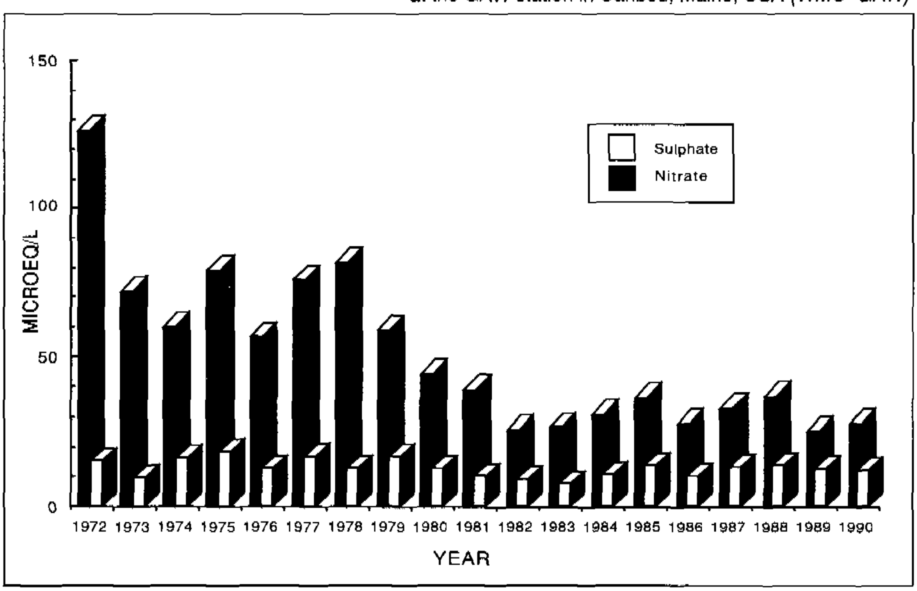


Figure 3—The seasonal ozone change (in % per decade) from the ozone soundings at Hohenpeissenberg, Germany (1967–1991) indicating strong increase in the troposphere and decrease in the lower stratosphere especially during the winter-spring (December, January, February, March). *(Bojkov, 1991)*

Figure 4—Trends in sulphate and nitrate from precipitation chemistry analyses at the GAW station in Caribou, Maine, USA *(WMO–GAW)*



These global observation systems provide the basic data, the first essential step, for a diagnosis of the changes of the Earth's atmosphere. They help to identify the need for research and greater understanding of the natural and unnatural processes involved. From these scientific foundations, the systematic monitoring and the research, human activities that adversely affect atmospheric composition can be identified. Under a regime of sustainable development the degradation of the atmosphere, must be arrested or reversed. Action now is needed to return to more sustainable pathways for those activities that at present adversely affect the atmosphere. Those activities and the contaminants they produce are summarized in Table 1 [5].

Table 1—**Anthropogenic trace gases**

Gas	Major anthropogenic sources	Anthropogenic total emissions per year (millions of tons)	Average residence time in atmosphere	Average concentration 100 years ago (ppb)	Approximate current concentration (ppb)	Projected concentration in year 2030 (ppb)	Impacts
Carbon dioxide (CO_2)	Fossil-fuel combustion, deforestation	5 500/~5 500	100 years	290 000	350 000	400 000 to 550 000	greenhouse effect
Methane (CH_4)	Rice fields, cattle, landfills, fossil-fuel production	300 to 400/550	10 years	900	1 700	2 200 to 2 500	greenhouse effect
NO_X gases	Fossil-fuel combustion, biomass burning	20 to 30/ 30 to 50	days	.001 to ? (clean to industrial regions)	.001 to 50 (clean to industrial regions)	.001 to 50 (clean to industrial regions)	acid deposition, smog
Nitrous oxide (N_2O)	Nitrogenous fertilizers, deforestation biomass burning	6/25	170 years	285	310	330 to 350	greenhouse effect
Sulphur dioxide (SO_2)	Fossil-fuel combustion, ore smelting	100 to 130/ 150 to 200	days to weeks	.03 to ? (clean to industrial regions)	.03 to 50 (clean to industrial regions)	.03 to 50 (clean to industrial regions)	acid deposition, corrosion
Chlorofluorocarbons (CFCs)	Aerosol sprays, refrigerants foams	~1/1	60 to 100 years	0	about 3 (chlorine atoms)	2.4 to 6 (chlorine atoms)	greenhouse effect, ozone layer depletion

(after T.E. Graedel and P. J. Crutzen 1989)

World Climate Programme

The World Climate Data and Monitoring Programme is only one component of the WMO-led multi-agency World Climate Programme (see Table 2).

Table 2—**Components of the World Climate Programme (1991)**

1.	World Climate Data and Monitoring Programme (WCDMP)	WMO
2.	World Climate Applications and Services Programme (WCASP)	WMO
3.	World Climate Impact Assessment and Response Strategies Programme (WCIRP)	UNEP
4.	World Climate Research Programme (WCRP)	WMO–ICSU–IOC (UNESCO)

The World Climate Research Programme, organized by WMO in partnership with the International Council of Scientific Unions (ICSU) and the Intergovernmental Oceanographic Commission (IOC) of UNESCO, is probably the most extensive global research programme ever initiated. Its purpose is to determine the behaviour of the global climate system, which consists of the atmosphere, oceans, land and ice, including its interactions with the biological systems (plankton, forests), in such a manner that permits mathematical modelling of the whole intricate system. Such climate system models are then used to predict the climate that would occur as a result of major perturbations of parts of the system, e.g., an increase in greenhouse gases, deforestation, changes in ocean temperatures.

The work of the WCRP is undertaken through major projects that involve the mobilization of contributions from government agencies and research institutions of many countries. Special observation campaigns on a large scale are required, involving satellites, ships, upper-air soundings and observations at ground level and in, on and over the sea. These projects currently include: the Tropical Ocean and Global Atmosphere (TOGA) Programme to predict *El Niño* or Southern Oscillation events and their seasonal disturbances of global climatic and oceanic patterns; the World Ocean Circulation Experiment (WOCE) to measure and understand the transport of heat and momentum by the major ocean currents; and the Global Energy and Water Cycle Experiment (GEWEX) to better understand and model energy partitioning in the climate system, and the Earth's hydrological cycle.

The WCRP is closely co-ordinated with the International Geosphere Biosphere Programme (IGBP) of ICSU, which has a strong chemical-biological emphasis. Together WCRP and IGBP are the two pillars of global change research.

The World Climate Programme has two important components in addition to those dealing with climatic data and research—the Applications and Services Programme and the Impact Assessment and Response Strategies Programme. In the applications component, methods are developed and techniques exchanged throughout the world to apply meteorological and climatic data and knowledge so as to improve the efficiency and sustainability of economic production. Some of those techniques will be described in subsequent sections of this booklet. The Impacts Assessment and Response Strategy component, led by UNEP, assesses the ecosystem, economic and social effects of variations and changes in climate with a view to devising adaptation strategies.

The Second World Climate Conference (SWCC) called for a much strengthened observing system, the Global Climate Observing System (GCOS) to provide basic information on the climate system, its variability and changes so as to help all countries manage their natural resources efficiently, and in order to support all phases of the World Climate Programme. Not only do observational systems over land areas need strengthening by surface measurements and observations from satellites, but there are major gaps over the global commons—the world's ocean areas, that must be filled.

Greenhouse gases and climate change

> "Emissions resulting from human activities are substantially increasing concentrations of the greenhouse gases. These increases will enhance the natural greenhouse effect, resulting on average in additional warming of the Earth's surface. Without actions to reduce emissions global warming is predicted to reach *2 to 5°C over the next century, a rate of change unprecedented in 10,000 years . . .*"
>
> Conference Statement, SWCC, November 1990 [6]

Perhaps the most serious threat to sustainable use of the Earth's renewable natural resources lies in the rapidly increasing contamination of the atmosphere by greenhouse gases, and the changes in climate expected as a result. It is a pervasive issue which provides the most obvious reasons as to why more sustainable development practices must be adopted.

The energy that drives and shapes the constantly changing atmosphere–ocean–biological system, comes from the Sun. The energy budget of planet Earth is illustrated in Figure 5 (see centrefold). About one-half of the incoming solar energy is absorbed and reflected by the atmosphere with its clouds and dust, and the other half absorbed and reflected by the surface of the Earth. The incoming energy is balanced by the outgoing radiation at longer, infra-red, wavelengths from the Earth and the atmosphere. A number of gases occurring naturally in the atmosphere, especially water vapour, carbon dioxide and methane, radiate much of this long wavelength energy back to Earth, warming the air masses near the Earth's surface. Without this natural "greenhouse effect" the global climate would be some 33°C colder, an uninhabitable environment for most present life forms. However, since the beginning of the Industrial Revolution, human economic activities have emitted pollutants to the atmosphere that have increased the natural greenhouse effect, mostly by adding to the existing concentrations of carbon dioxide, methane, nitrous oxide and low-level ozone, but also by the

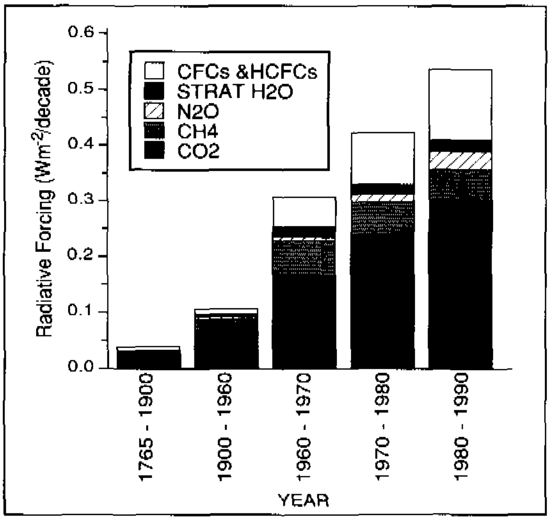


Figure 6—Decadal contributions of greenhouse gases to radiative forcing (W/m^{-2}) for periods between 1765 and 1990. The changes that took place over the periods 1765–1900 and 1900–1960 are the total changes that occurred during those periods divided by the number of decades *(IPCC Working Group I report)*

introduction of wholly artificial greenhouse gases, especially chlorofluorocarbons (CFCs) (Figure 6).

The IPCC

The Intergovernmental Panel on Climate Change (IPCC), was formed in 1988 by WMO and UNEP to assess the present scientific knowledge, the potential impacts of climate change and to recommend strategies to respond.

The rate of further increases of greenhouse gases will depend upon future economic activities and the policies, especially related to energy and forests, adopted by governments. The IPCC, in its first assessment report (1990) provided estimates of future greenhouse gas concentrations, based on various assumptions or scenarios of future development. Under IPCC's "Business as Usual" projections, no deliberate actions would be taken to curb greenhouse gas emissions except the control of CFCs under the Montreal Protocol. In such circumstances the combined greenhouse effect of all the gases, before the year 2030, would be equivalent to the doubling of pre-industrial concentrations of CO_2.

To determine what effect such a doubling would have on climate, a limited number of climate research groups throughout the world, equipped with powerful super-computers, have developed mathematical models of the atmosphere–ocean–land–ice system that creates climate. They built upon the understanding of the behaviour of the climate system derived from studies made under the World Climate Research Programme. A model is built that simulates well the present and past climates, the concentrations of the greenhouse gases are changed to the equivalent of doubled pre-industrial CO_2 levels, and the future climate that would result is projected.

Figure 7 shows temperature changes over the globe in December–January–February as predicted by three mathematical models of a doubled

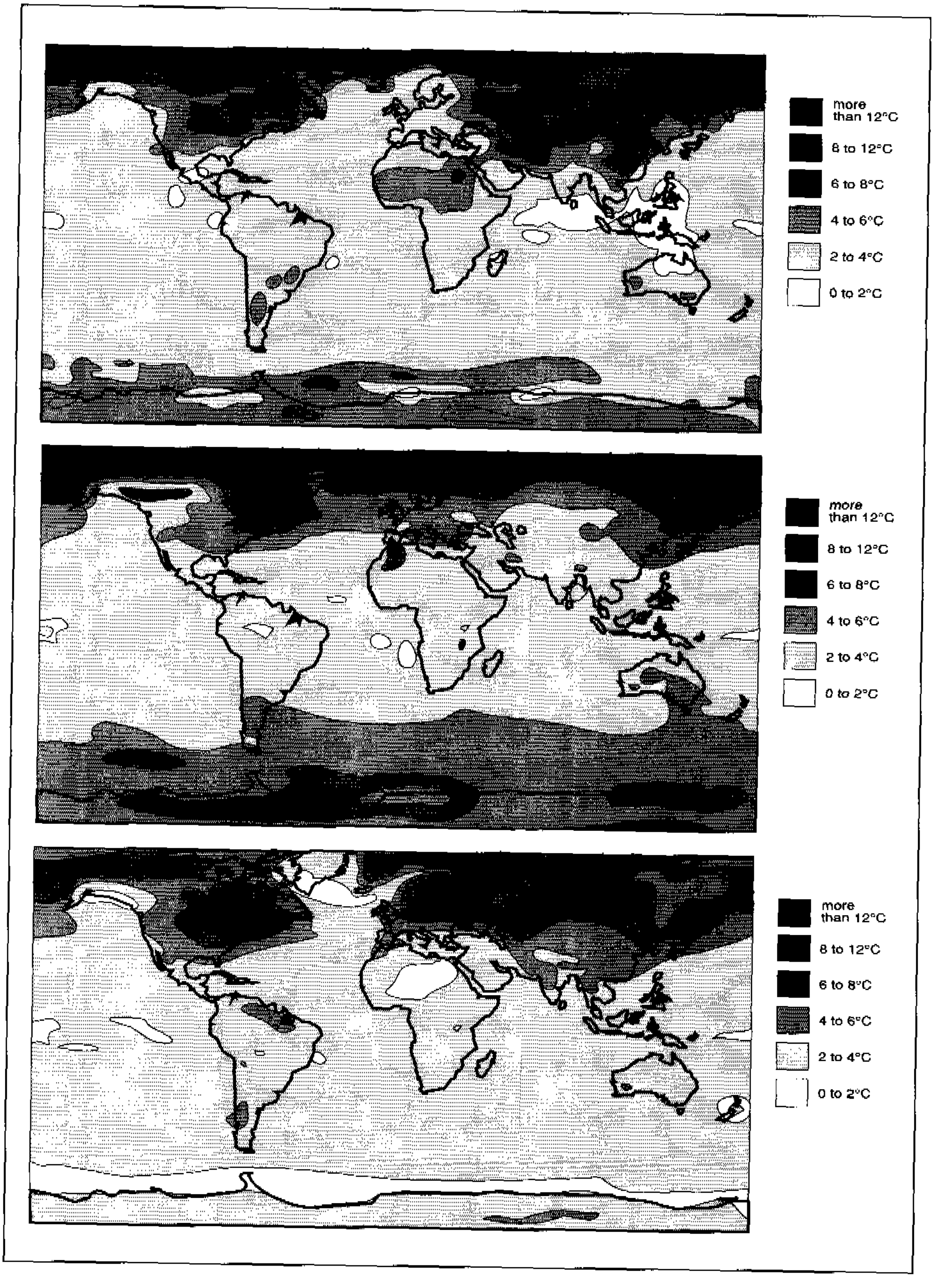


Figure 7—Change in surface air temperature (ten year means) due to doubling CO_2 for months December-January-February, as simulated by three high resolution models (*top*) CCC : Canadian Climate Centre (Boer, pers. comm., 1989), (*centre*) GFHI: Geophysical Fluids Dynamics Laboratory (Manabe and Wetherald, pers. comm., 1990), and (*bottom*) UKHI: United Kingdom Meteorological Office (Mitchell and Senior, pers. comm., 1990). See legend for contour details *(IPCC, Working Group I report)*

CO_2 atmosphere. The models agree well on the average global temperature increases to be expected—about 4–5°C—but agreement is not so good on many regional features, and especially on changes in precipitation patterns.

Impacts of climate change

In spite of the present uncertainties a number of impacts of a warmer Earth can be reasonably predicted. First, sea level is projected to rise from 30 cm to 100 cm by the end of the next century. Heavily populated low-lying coastal zones would be inundated or seriously affected by increasingly damaging storm-surges, by salt-water intrusion into coastal aquifers, and changes in shorelines. A sea-level rise of the order of one metre at the upper end of the IPCC projections, would threaten the very existence of some small islands, e.g. Vanuatu.

A second major impact and a robust outcome of all the models is that Arctic and sub-Arctic areas would be 6–12° warmer in winter than at present which would mean that the surface layers of permafrost would melt, the stability of buildings, roads and other structures in those areas would be threatened, and Arctic sea ice would be reduced. In the snowmelt season, greater floods due to both a more rapid melt and greater accumulation of snow would occur.

Changes in agricultural production are less predictable because of uncertainties as to the distribution of rainfall. However, most models suggest a drying of the southern portions of the great grain-growing areas of North America and Eurasia that would seriously reduce world cereal production and change the balance of agricultural exports and imports for a number of countries. There would, as well, where adequate water is available, be direct stimulation of plant growth rates because of the increased concentrations of CO_2 in the atmosphere.

An impact not often emphasized is the possibility of the spread of tropical diseases. The importance of water in spreading a range of tropical diseases is discussed in the following section (see p. 20). In many cases the agents that transmit the diseases, mosquitoes, snails, bacteria, are markedly limited in their range by the water and air temperatures—they cannot thrive at temperatures lower than certain thresholds—often about 26°C. With gradual warming the areas would expand in which favourable conditions for these agents persist, resulting in a spread poleward of these tropical diseases.

These are a few of the projected impacts of global warming. A comprehensive analysis and report has been prepared by the second working group of the IPCC [7].

Response strategies

What steps can be taken to reduce impacts of climate change and to slow the rapid rate of change? It is clear that greenhouse gas increases must be controlled. To reduce carbon dioxide emissions and stabilize atmospheric concentrations, wasteful and unnecessary use of fossil fuels, and the destruction of forests must be curbed.

The Statement of the Second World Climate Conference (November 1990—see below) noted that a 1–2% per year reduction of global CO_2 emissions beginning now would result in the stabilization of atmospheric concentrations early next century. The statement also noted that technically feasible and cost effective means of reducing emissions through energy efficiency and switching to renewable fuels already exist in many countries.

The Montreal Protocol, which provides for the reduction of the global production of CFCs and other substances that deplete the ozone layer, will also be effective in reducing the impact on climate of those powerful greenhouse gases. It is important, however, that substitute chemicals for refrigeration and other uses, should not be strong absorbers of the wave-lengths that trap infrared radiation—i.e., that they should not be strong greenhouse gases.

Methane emissions are a more difficult problem to address since they arise from a wide range of agricultural and industrial sources and from landfill sites (dumps). However, since methane is much shorter lived in the atmosphere than CO_2 or CFCs, a relatively small reduction of emissions, about 15–20%, would result in the stabilization of atmospheric concentrations. Much of this reduction could be obtained through reducing gas losses in the energy industry. The nitrogen oxides and low-level ozone contributions to climate forcing could be significantly reduced by the vigorous enforcing of automobile and industrial emission-control standards, such as those of the 1990 Clean Air Act of the USA. In summary, actions needed to reduce the rate of global warming are technically feasible, and many of these actions are economically beneficial in the long run.

Second World Climate Conference (SWCC)

The first assessment report of the IPCC was completed in August 1990. Some 1 000 specialists from more than 100 countries participated in this unprecedented international effort. The IPCC assessment report and the first decade of work under the WCP then formed the basis for discussion at the landmark Second World Climate Conference, Geneva, 29 October to 7 November 1990. The Conference had two components, a scientific session involving 750 of the world's experts on the topics, which produced a major consensus statement, (see box on p. 10) and a ministerial session, which adopted a Declaration for action.

The Ministerial declaration of the SWCC, adopted by the 137 participating countries, recorded the commitments of 21 industrialized countries to reduce or limit their emissions of greenhouse gases, called unanimously for early negotiation of a global Convention on Climate Change and recognized that developing countries would need financial and technical assistance to move towards low CO_2-emission developments, for example, towards net afforestation instead of deforestation. United Nations Member countries have begun to convert the commitments and ideas of this declaration into a legal document, a global

Convention, through an International Negotiating Committee established in December 1990 by the UN General Assembly. The INC's task is formidable as the negotiations, which began in February 1991, must take into account the basic patterns of development and resource management world-wide and address the necessity of financial assistance and the transfer of technology to the developing countries in order that their economic development should increase in a sustainable manner. Such a course of action would go some way towards reducing the present disparity of wealth that exists between the poor and rich nations of the world.

Without commitments to move towards reducing human impacts on the global climate system, we cannot achieve a sustainable and equitable use of natural resources, and preservation of a healthy environment for all living creatures.

Other atmospheric international agreements

In connection with substances, such as chlorofluorocarbons (CFCs), that deplete the ozone layer, nations have agreed under the Montreal Protocol to the Vienna Convention for the Protection of the Ozone Layer, to phase out production of the most ozone-damaging chemicals. Under the Economic Commission for Europe's Convention on Transboundary Air Pollution, protocols agreeing on the reduction of sulphur dioxide (SO_2) emissions and nitrogen oxides have been negotiated so as to begin to confront the problems of acid rain and transboundary smog in Europe and North America. Although sulphur deposition has been shown to be declining in these areas, the SO_2 protocol is in serious need of strengthening since acid deposition levels are still too high in many sensitive regions. In particular forest damage continues at elevations of around 1 000 m in alpine areas due to the high acidity of the bases of clouds and to ozone emitted from urban and industrial centres.

A "Law of the atmosphere"?

No international agreements have yet been reached to reduce the toxic chemical burden of the atmosphere through the adoption of appropriate control measures to lead to more sustainable agricultural and industrial practices. As inter-country agreements are being developed that attack other atmospheric issues, it is becoming increasingly urgent to address the problems of the industrial, agricultural and other sources of toxic chemicals that pervade the atmosphere which has become a major pathway for the contamination of the seas (Figure 8), and of both aquatic and terrestrial ecosystems, including that of humans.

Several international actions underway or needed include:

- A convention to address toxic chemical emissions into the atmosphere;
- Successful negotiation of a greenhouse gas–climate change convention through the INC process;

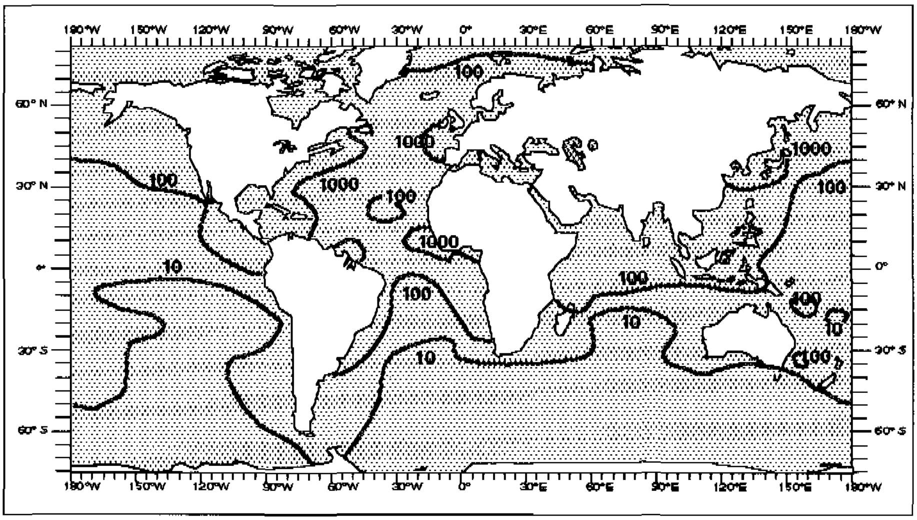


Figure 8—Global fluxes of lead to the oceans in µg Pb m^{-2} yr^{-1}

- Strengthening the provisions of and strong enforcement of the Montreal Protocol on Substances that Deplete the Ozone Layer; and
- Tougher and geographically broader agreement on the control of acid deposition and other forms of transboundary air pollution.

In the future it may be possible to combine these interrelated initiatives, both regional and global, each of which deals with one aspect of pollution of the world's atmosphere. What ultimately may be required, is a "Law of the Atmosphere" containing international commitments to drastically reduce the use of the global atmosphere as a *dump* for wastes arising from human activities.

Water resources—the source of life

Earth is known as the water planet. Its blue seas and lakes and white clouds as seen from space make it unique. But only two per cent of the 1.41 billion cubic kilometres (km^3) of water on Earth is freshwater of which eighty-seven per cent is estimated to lie in ice caps and glaciers and the rest in deep groundwater. Only about 2 000 km^3 is at any instant readily available in lakes, rivers and shallow groundwater for numerous human uses. The desalination of sea water is technically feasible, but the costs and high energy requirements limit this technology to a very few locations. Figures 9 and 10 provide only a snapshot view of global water at any one time. The fluxes of water over a period of time through the stages of the hydrological cycle are much larger than these instantaneous values since atmospheric moisture is replaced on average every 12 days and river water every 18–20 days. The annual discharge of all the rivers of the world is estimated at about 40 000 km^3 (range of estimates 31 000–47 000 km^3).

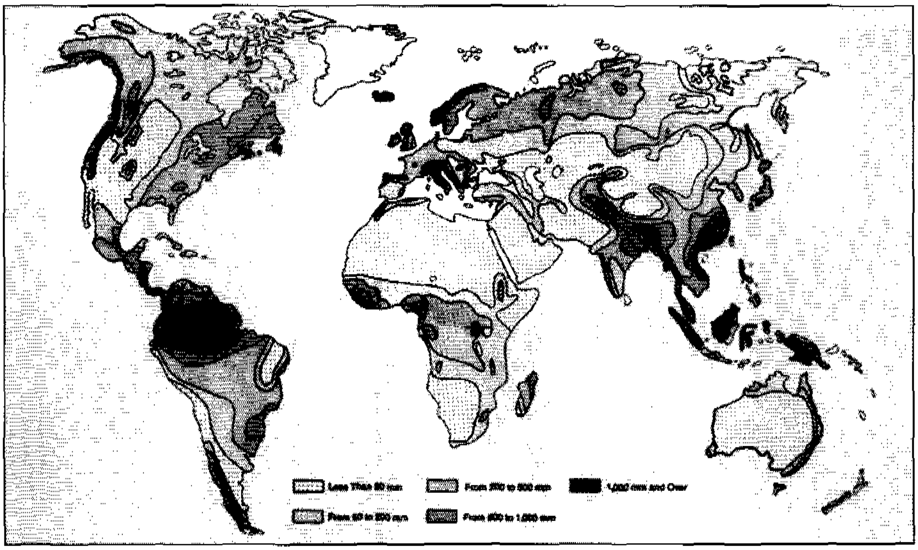
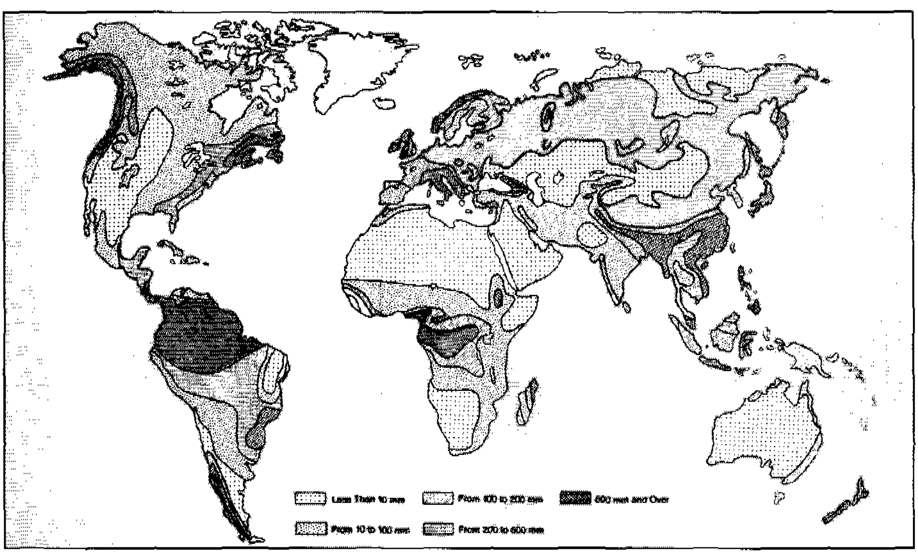


Figure 9—Global river runoff *(Institute of Geography, USSR Academy of Sciences, Moscow, World resources 1990–91)*

Figure 10—Global groundwater flow to rivers *(Inst. of Geography, USSR Academy of Sciences, Moscow, World resources 1990–91)*



A large volume of freshwater is also contained in the lakes and reservoirs of the world, but their water volumes would be lost without continual replenishment by the inflowing rivers. Thus river discharges represent the *renewable* water volumes available for human use. Such use now is about double the instantaneous volume in rivers, i.e. about 3 700 km^3 per year [8, 9], but less than one tenth of the annual flow averaged over the globe.

Our knowledge of river flows, lake levels and groundwater levels are the result of water-level and hydrometric measurements carefully made by water agencies in many countries. Most of these follow standard measurement procedures established through WMO's Hydrology and Water Resources Programme, and the procedures for the international exchange of data, especially on transboundary river systems. The Global Runoff Data Centre (GRDC) [10] established by WMO and the Federal Institute of Hydrology at Koblenz, Germany, compiles selected runoff data from 1 200 stations in some 67 countries to provide regional, continental and global estimates of water availability—the river component of the hydrologic cycle. For some locations daily flow data are available through the GRDC and for other observation stations monthly discharge values are available.

These data give an overview, but water availability for human uses, i.e. the water resource, is enormously variable. South America has by far the highest ratio of runoff to land area (26% of world's total runoff), and Africa has the lowest, less than half the world's average. Annual runoff is also extremely variable within each continent, as can be seen from Figure 9.

Variability over time is even greater, with the lowest river flows during the year being zero in many rivers in semi-arid areas, though peak flows in flood periods may be thousands of cubic metres per second. The stability of flow in any river depends largely on the proportion of total flow that is drawn from stable groundwater reserves rather than from surface runoff in rapid response to rainfall or snowmelt. Figure 10 shows the amount of total river runoff derived from groundwater, the higher amounts being the regions of more stable flows and higher reliable minimum flows. In tropical forest zones the groundwater component can be greater than 50% of total discharge. On a global basis it is estimated that 14 000 of the 40 000 km^3 flow can be considered stable or reliable for use.

While these and other basic data on water resources, and techniques for analyses of these data are co-ordinated through WMO's Hydrology and Water Resources Programme, much of the research effort to develop new techniques and new understanding is co-ordinated through the International Hydrological Programme (IHP) of UNESCO. These agencies work closely together on these two aspects of water resource assessment, and have published a water resources assessment manual [9].

If human uses of water are to be on a renewable, sustainable, basis they should be at a rate that does not exceed the minimum flows of the accessible rivers and in the case of groundwater, the rate at which it is recharged through precipitation. In many locations these sustainable rates are being exceeded.

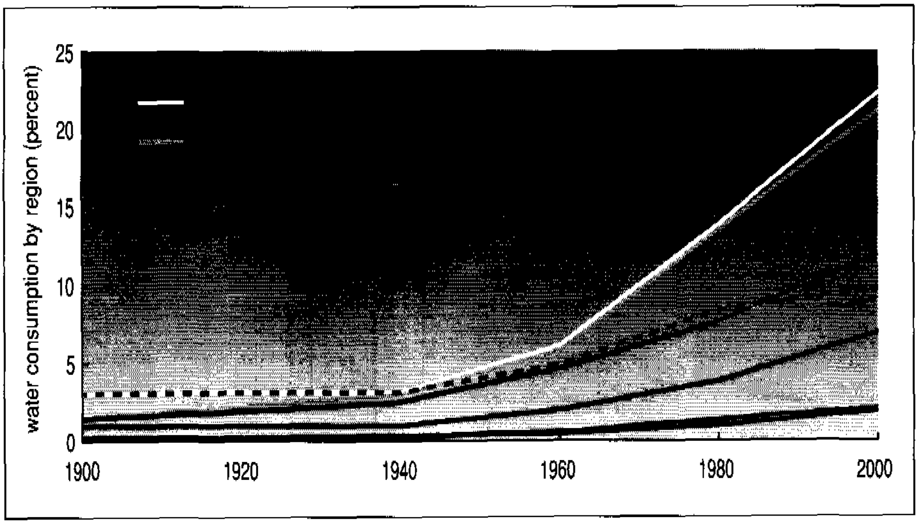


Figure 11—Evolution of water consumption *(WMO/UNESCO Water resources assessment)*

In addition, pollution of water bodies by human activities is effectively reducing even more the available safe supply, especially for domestic use. It is estimated that human water use has grown 35 times in the past three centuries, and is now growing at between 4 and 8% per year due to rapid increases in both per capita use and the total population. It is clear that such rates of growth would not be sustainable for long in many parts of the world (Figure 11).

To overcome the problem of very low river flows and water availability in the dry season and too high flows in the rainy and snowmelt periods, more than 30 000 storage reservoirs have been built around the world, 75% over the last 35 years. While beneficial in many ways such dams and reservoirs can have detrimental effects as well. They flood valuable valley lands, reduce needed annual downstream silting; they may increase water-borne diseases, and evaporation. Total evaporation from surface storage has been estimated at 240 km^3 with Brazil, Canada, China, Egypt, India, Iraq, USA, and the former USSR accounting for more than three-quarters of this total [11].

Individual human use varies greatly around the world ranging from a minimum subsistence level of 5 litres/day in some African countries to 500 litres/day in North America [12]. To sustain a "reasonable" quality of life requires about 80 litres per day per person. The lifestyle in a developed country thus depends, more than we suspect, on freshwater availability. If taps or wells were to run dry, human lives would be enormously disrupted, affecting washing, cooking, drinking, flushing wastes and many other household activities.

But most household uses are not "consumptive". Consumptive use of water occurs when water does not return to a watercourse, but mainly evaporates into the atmosphere. The major consumptive use is for irrigation, although some portions of industrial and domestic uses are consumptive as well. Most domestic and industrial water withdrawals are not "consumed" in this sense but are returned to the water bodies as waste-waters, often containing heavy burdens of pollutants.

The largest area under irrigation in the world is Asia where 82% of its drawn water (1 300 km^3) irrigates 140 million hectares, mostly in China, India and Pakistan. South America, in contrast, irrigates only 8.5 million hectares with 70 km^3 of water.

Domestic and municipal water withdrawals generated about 153 km^3 of waste water globally in the 1980s and that is projected to grow to 282 km^3 by the year 2000. Similarly waste water from industrial withdrawals is also expected to increase, from about 660 km^3 in the 1980s to close to 1 000 km^3 by 2000 [11]. Since most of these waste waters are discharged untreated, the pollution burden to the world's water systems is thus increasing rapidly, greatly reducing useable water resources.

At present, water pollution kills some 25 million people in developing countries each year, 60% of them children. Half the world's leading diseases are transmitted by or through water vectors. Polluted water is an ideal breeding ground for pathogens and carriers of diseases such as malaria, yellow fever, trachoma, schistosomiasis, typhoid, cholera, diarrhoea, and intestinal worms, among others. The United Nation's Water and Sanitation Decade (1980-1990) led by the World Health Organization made some progress towards providing clean water and sanitation for the additional 1.8 billion people in need though much remains to be done.

To pin-point sources of pollution, to determine the type of pollutants present and avoid use of the most contaminated sources, water quality monitoring and assessment programmes are essential. WMO with its Member countries provides standard procedures for regular sampling and field tests for the monitoring of water quality and has encouraged the use of those methods by water agencies in co-operation with national health organizations. In this way governmental savings can be made as one water agency undertakes both the field measurements of water quantity and sampling for water quality determinations. WHO and UNEP, through the GEMS system, co-operate with the National Water Research Institute of Environment, Canada, in collecting and making available water quality data from many countries.

Management of water resources to ensure that adequate supplies of suitable quality are available requires basic information on water quantity and quality and their variability. These data can be obtained only through long-term systematic monitoring programmes and applying well-documented techniques for analysis and interpretation of the data. WMO and UNESCO have produced a report on strategies for the 1990s for assessment of water resources [9]. Planners and decision-makers can use such assessment methods to ensure that municipal, irrigation and industrial demands and available supplies are as closely balanced as possible and that can often be best effected through preparation of river- or lake-basin plans in which sustainable use of renewable water resources is the central aim.

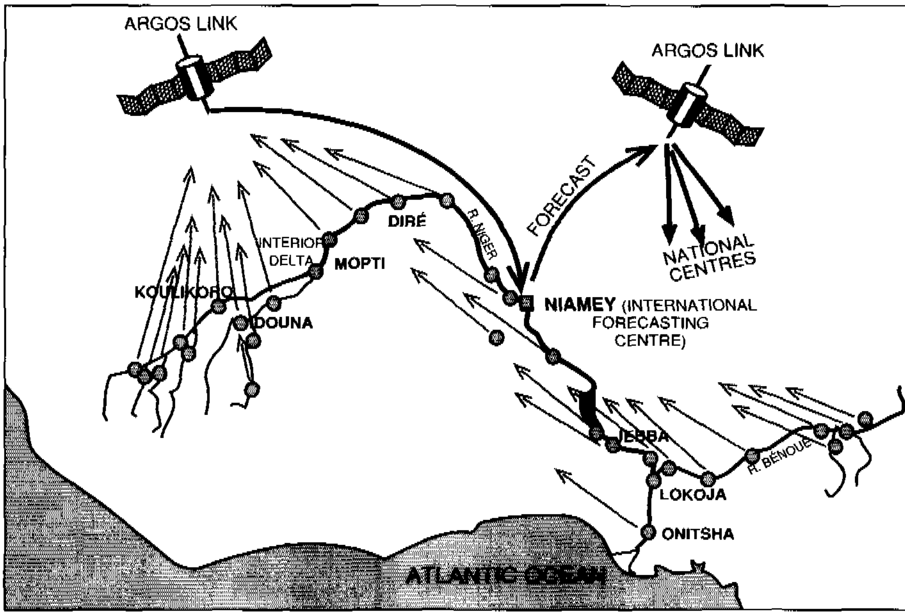


Figure 12—The Hydro-Niger forecasting system

Measurements of parameters in the hydrologic cycle other than streamflow and water levels can also be of vital importance in water resource planning. For example, precipitation and evaporation measurements and estimates are essential in assessing groundwater recharge rates and optimum irrigation needs and scheduling. Precipitation, rain and snow, are among the earliest of meteorological parameters measured, from at least as far back as the 3rd or 4th centuries AD in China and India. Accordingly it is surprising that on a global basis estimation of the precipitation component of the hydrologic cycle is one of the least well known, especially over the large part of the Earth covered by oceans. A Global Precipitation Climatology Project has been launched as part of the World Climate Research Programme (WMO-ICSU) to improve global precipitation estimates.

Good predictions of daily river flow and seasonal water supply are most valuable in management and allocation of available water resources to competing needs. Such predictions are a common feature of water management in developed countries, and are being adopted in the critical river basins of the developing world, such as the Niger River, through the multi-nation Hydro-Niger project in West Africa, with the forecast centre based in Niamey (Figure 12)—a WMO/UNDP supported project. Such forecasting systems are of great importance in helping to allocate water for irrigation, navigation and domestic uses, and to avoid disputes in international river basins. Advice from hydrological and meteorological specialists based on reliable data are necessary to produce useful daily, weekly and seasonal flow predictions.

CHAPTER 3

Towards sustainable futures

Energy—the central industrial–environmental issue

In no other economic activity are the dilemmas of sustainable development so clearly evident as in the production and distribution of energy. And in few other fields is meteorological and hydrological knowledge as important to ensure efficiency, minimum waste and the possibility of moving to more renewable or sustainable sources. Energy use has increased eightyfold since the middle of the 19th century, with profound effects on carbon, sulphur and nitrogen flows on the planet.

The wealthy industrial economies of the world have developed on the basis of abundant cheap energy, mainly through the burning of fossil fuels, i.e. coal, oil, and natural gas. These are non-renewable resources, dug from the earth. It is estimated that each year's current consumption of fossil fuels represents a million years of accumulated fossil deposits. Known oil reserves will be exhausted over the next century with, at current consumption rates, the most readily accessible and cheapest reserves being depleted in 30 to 40 years. Natural gas reserves and coal will last longer but will be consumed over the next centuries at present rates of use. In short, the burning of fossil fuels is inherently a non-sustainable activity—fossil fuel resources are being exhausted, and their burning is rapidly changing the composition of the atmosphere.

On the other hand, renewable energy sources, solar, wind, wave, tidal power and biomass energy represent a very small proportion of the current global energy mix. Hydro-electricity is the only renewable source with a significant share (6.6%) of global commercial power production. Nuclear power occupies an important niche in a some countries such as Canada, France, Japan, the Russian Federation, Sweden and USA, but represents only five per cent of total commercial energy production. Table 3 shows for each continent commercial energy production and consumption by fuel in 1988 [11]. The daily demand for energy, the load forecast for an electrical utility, a gas pipeline operator, or a fuel oil supplier is highly dependent on the weather. A good load forecast requires a good weather forecast. A very cold day will necessitate a certain distribution of energy to customers and a hot day, or a dull cloudy day will lead to different energy demands in different locations. By accurately predicting probable need, energy utilities can adjust their producing facilities to the right amount, neither over-producing and wasting fuels or short-changing their consumers. Also referring to energy supply, good forecasts of river flows and winds permit the prediction of probable hydro- and wind-power availability and thus more efficient day-to-day planning to meet demand.

It must be emphasized that energy conservation and efficiency are not only concerns of the industrialized countries. In the developing countries, with

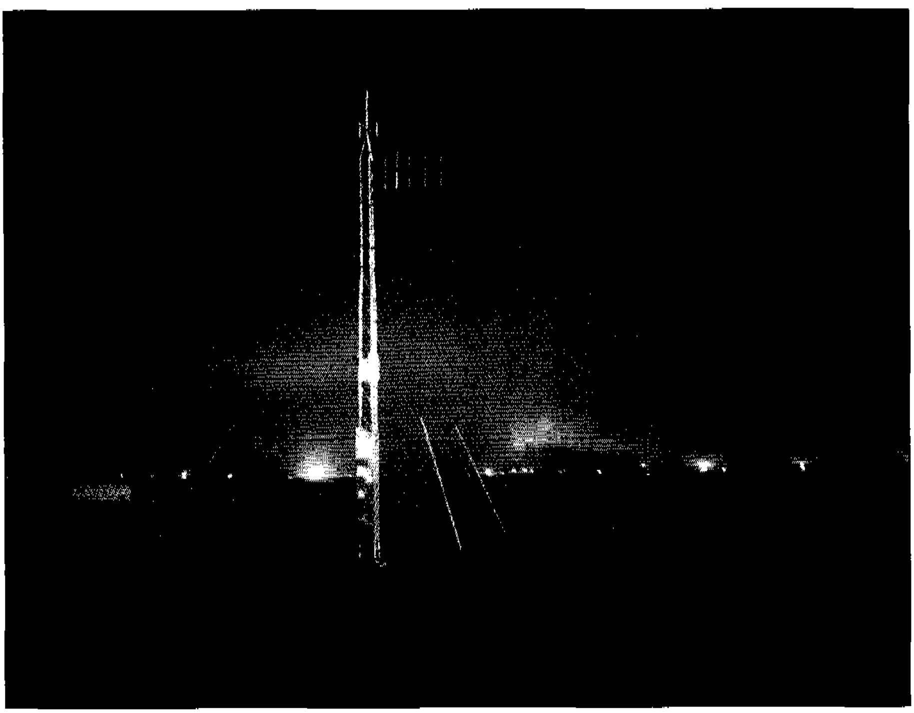
Figure 5—The energy budget of planet Earth *(after the Gaia atlas of planet management, Pan Books, 1985).*

Left: Participants at the Second World Climate Conference were made aware of popular concern by calls for immediate action by governments and industry *(Kathleen Holman)*

Below: Kuwaiti oil fires create environmental problems on a regional and even global scale. The photo, taken at 2 p.m., shows the smoke cloud completely blocking the sun. No prevailing wind exists, air is drawn inward from all directions by the fires. The newly erected meteorological tower is in the foreground *(Randy White)*

Top right: GAW stations, such as this at Cape Grim, Australia, monitor on a daily basis changes in the composition of the atmosphere

Bottom left: Model output of dispersal of radioactive debris from the Chernobyl reactor accident output for nine days after the accident *(J. Pudykiewicz, Canadian Meteorological Center, Montreal)*



Meteorological and hydrological information can help in increasing agricultural production and in reducing losses *(FAO)*

Mogadishu wind-power plant—renewable energy sources are vital to sustainable development *(Danish Energy Agency)*

Table 3—**Commercial energy production and consumption by region and fuel, 1988 (petajoules)[a]**

Region	Oil		Natural gas		Coal		Nuclear power	Hydro-power	Total	
	P	C	P	C	P	C	P & C	P & C	P	C
North America	22 857	36 171	21 203	21 211	23 866	21 542	6 883	5 987	80 797	91 796
Latin America	14 278	9 551	3 601	3 308	888	959	96	3 902	22 765	17 816
Western Europe	8 290	24 875	6 297	8 332	7 821	11 033	6 155	4 509	33 073	54 904
Middle East	30 954	5 669	2 734	2 278	29	105	X	109	33 827	8 160
Africa	10 991	3 609	2 227	1 264	4 187	3 048	80	791	18 276	8 793
Asia and Australasia	6 816	19 507	4 539	4 091	9 877	12 779	2 759	2 491	26 483	41 627
Centrally Planned Economies										
USSR	26 127	18 385	29 045	22 982	16 409	12 984	1 779	2 345	75 705	58 476
China	5 699	4 216	528	561	24 251	24 331	X	1 319	31 796	30 427
Other	888	5 238	2 617	4 262	14 994	14 881	620	1 038	20 156	26 039
World total [b]	126 900	127 222	72 791	68 290	102 322	101 660	18 373	22 493	342 878	338 037

Source: after World Resources l990-91 (Table 9.l, p. 142)

a – Conversion factor: 1 million metric tons of oil equivalent = 41.87 petajoules   b – Figures may not total because of rounding

P – Production: C – Consumption: X – Not available:

less capital available from domestic resources and foreign assistance, future commercial energy demands, for electricity needs alone, projected on the assumption of traditional operation, will be very difficult to meet. Thus the adoption of highly energy-efficient pathways is essential to meet energy requirements of the growing populations in the developing world. Fortunately, there are some examples of how this can be achieved drawing upon experiences and planning activities in Brazil and India [13].

At the beginning of the next century energy production and use are expected to account for some two-thirds of the radiative forcing due to anthropogenic greenhouse gases (Figure 13). In addition the energy sector is responsible for substantial proportions of other atmospheric pollutants. Data for Canada (Figure 14) show that 65% and 23% respectively of the toxic metals lead and mercury in the atmosphere derive from the energy sector, and more than 40% of the acid-rain producing sulphur oxide emissions come from these sources. In other countries the acid-causing emissions are even more dominantly the result of energy production, but in Canada metal smelters are a major source.

Not only is fossil-fuel burning inherently non-sustainable, but present energy practices over the world place a pollution burden of acid rain and large quantities of toxic metals on the atmosphere as well as greenhouse gases which result in global warming projections. Reduction of the human appetite for fossil fuels in industrial countries is an essential step towards sustainable development.

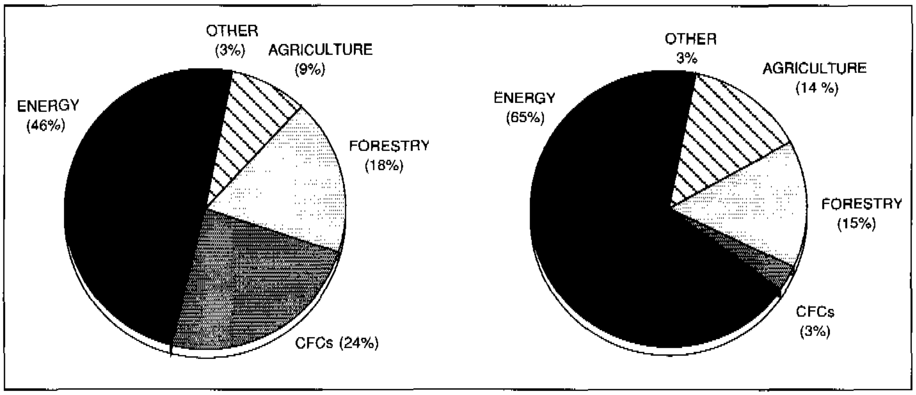


Figure 13—Contribution to radiative forcing by sector 1980s (left) and 2025 (right) *(IPCC)*

How possible is a reduction in dependence on fossil fuels, and how can meteorology and hydrology help to achieve such an objective?

There are two main approaches. One is to reduce total energy demand through improved efficiency and conservation, and the other is to use forms of energy that do not produce the carbon emissions which are the result of burning fossil fuels.

Such a change in carbon dioxide emissions would be the product of three factors:

- change in energy intensity, i.e. in the amount of energy used per unit of Gross Domestic Product (GDP);
- change in carbon intensity, i.e. in the fuel mix towards more or less reliance on carbon-emitting fossil fuels; and
- change in GDP.

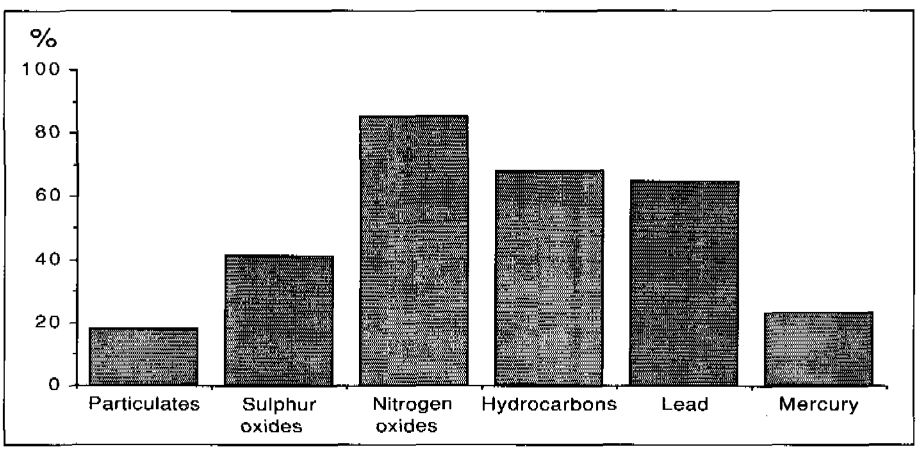


Figure 14—Contaminants from energy production and consumption in Canada *(EMR 1989)*

No country, especially not a developing country with rising needs and expectations, wishes to plan for a stabilization or reduction of GDP. However, reductions in both energy intensity and carbon intensity are possible in most countries.

Energy intensity is a matter of the mix of industrial and other uses and efficiency of use which varies greatly from country to country, with the most economically successful industrialized countries, such as Germany and Japan, being among the most successful in reducing energy intensity. Among OECD countries energy intensity dropped 20% in the period 1973-1985 under the pressure of higher energy prices and government regulations.

Among the most important additional steps that can be taken are:

- To improve the efficiency of cars and light vehicles;
- To improve the design and insulation of buildings;
- More efficient lighting;
- To adapt utility operating procedures to make maximum use of climatic data and meteorological and hydrological forecasts.

On the matter of automobile efficiency, the half billion cars and light trucks in the world (1986) are projected to increase to 1 billion by 2030. Growth rates in the number of small vehicles are greatest in Asia and South America. One-half to two-thirds of the oil demand in industrialized countries is for light vehicles. The present automobile fuel consumption average in the USA, with the largest number of cars of any country, is about 8.4 litres per 100 km. Major manufacturers have prototype vehicles, some four-passenger, safe, roadworthy cars, with consumption of 2 to 4 litres/100 km. In addition, a number of new technologies, including battery powered automobiles, ultra-lean-burn gasoline engines, biomass fuel-driven cars have proved effective under certain conditions. To achieve sustainable energy development and reduce pollution of the global atmosphere, it is imperative that these more efficient or low-gasoline-using vehicles form the majority of the half billion additional vehicles that will be introduced over the next four decades.

Energy systems of most kinds are often highly vulnerable to extremes of weather and climate. The efficiency and reliability of national energy systems can be much enhanced through wise use of climatic information and weather forecasts. Extreme winds, waves, currents, storm surges, fog, ice, storms and cold temperatures can seriously affect the production of energy, especially from off-shore facilities, as well as its transmission and distribution [14].

The most widely used renewable energy sources are hydro-power and biomass. However, solar and wind energy are gaining acceptance in special

Table 4—**Per cent of hydro-electric potential developed (1990)**

Africa	Asia	Europe	Latin America	North America
5%	9%	36%	8%	59%

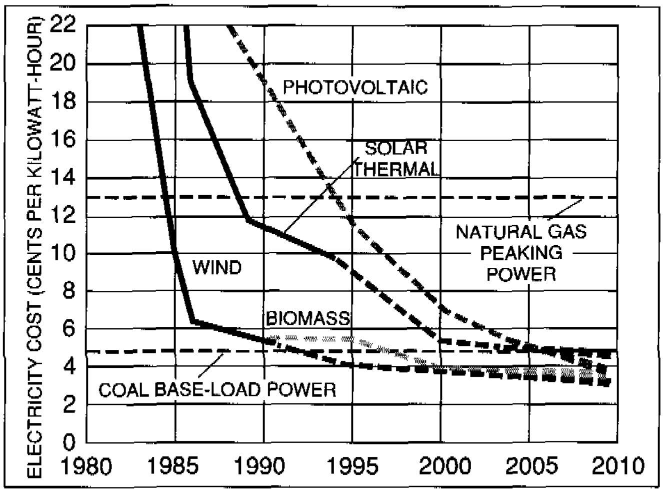


Figure 15—Cost trends for renewable energy forms *(after C. J. Weinberg and R. H. Williams, Scientific American, Sept. 1990)*

markets and improving technologies continue to lower production costs to more competitive levels (Figure 15). Large-scale hydro-electric potential has been developed in various continents as shown in Table 4 which also indicates the scope for additional renewable energy from this source.

However, large hydro-projects are capital intensive and cause environmental problems. Such problems must be balanced against the advantages of hydro-power as a renewable energy form, of minimum fuel cost, placing only a small additional pollution burden on the atmosphere. Small scale hydro-power projects produce benefits and have fewer disadvantages. The US Agency for International Development estimates that small stand-alone hydro-plants in developing countries, serving community and agricultural complexes, produced 29,000 megawatts in 1991, three times the 1983 installed capacity. World-wide potential from small hydro-plants exceeds 100,000 megawatts.

It is essential to note that the safe and efficient design and operation of hydro-power plants of all sizes require reliable, long-term data on river flows, i.e. hydrometric data, backed up by information on precipitation and evaporation. Statistical analysis of these data are used to estimate the largest flood a dam would withstand, the lowest sustained flows to be expected and thus the minimum energy production, as well as the average energy output a plant could achieve. Techniques for making such estimates and for inferring and predicting flows at ungauged sites on rivers are outlined in the WMO Guide to Hydrological Practices [15]. Advanced analysis techniques are available for technology transfer to all countries through the computer-based HOMS (Hydrological Operational Multipurpose System) of WMO [16].

However the greatest long-term potential for renewable energy is through direct use of energy from the Sun. The two main approaches to converting the Sun's energy into useful forms are through photo-voltaics, the production of electricity from the Sun's energy through solar cells, and the solar-thermal approach in which the Sun's heat is converted to useable energy in various ways.

The direct conversion to electricity of solar energy (i.e. photo-voltaics) has proved costly compared to other energy forms, but costs are rapidly being reduced by use of the new technologies (Figure 15). If such technological progress continues and photo-voltaic energy conversion becomes widely available, it has the potential to be a major source of electrical energy in the latter half of the 21st century. It is already the energy source of choice of some decentralized systems. For example, in Mali, photo-voltaic pumps provide low cost water for villages of 250 to 2 000 people and when used in larger centres are about equal in cost to diesel pumps (UNDP, 1991 [17]). In addition, photovoltaic techniques are well adapted to producing hydrogen from the breakdown of water, and hydrogen fuels are likely to become the main transport energy source towards the late 21st century.

Solar thermal is becoming an established technology for electricity production as well as for the heating of buildings. The largest electrical plants being operated or constructed are in the deserts of southern California where by 1994 one plant will be serving 800 000 residential consumers at five cents a kilowatt hour. Plans for large solar-thermal electrical energy developments are also underway in Brazil, India and Spain.

It should be noted that both solar energy and wind energy production depend upon the availability of the resource. Available solar energy depends on the latitude and the amount of cloudiness, precipitation, dust storms, and other phenomena obstructing the Sun's rays. Estimates can be made from climatological and satellite data of the percentage of total solar energy reaching the ground at a given location and thus of potential solar energy available (Figure 16).

World-wide wind energy resource distribution estimates have also been provided by WMO (Figure 17). The viability of a site for wind energy production is critically dependent on the mean windiness and extremes, both high and low. Accordingly it is important to examine the micrometeorological conditions at any proposed wind-energy site in order to realistically assess the wind energy potential.

Thus climatological data on solar radiation, hours of sunshine, and on wind, and their appropriate analysis are essential for locating and planning new forms of energy development. In addition, the amount of energy that such facilities could feed into an electrical grid on any one day can be predicted most accurately through use of reliable weather forecasts.

Agriculture and food—the sustenance of human life

During the two decades before 1980 a remarkable increase in food production was accomplished in most parts of the world, due to the expansion of cropland, new high-yielding seeds, and the greater use of chemical fertilizers and pesticides. For example, cereal production, about one-half of the

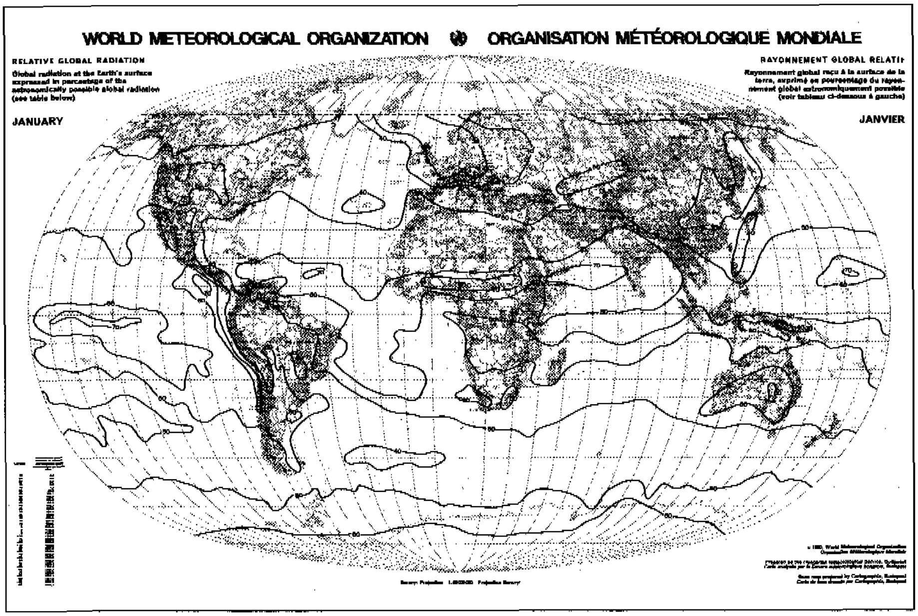
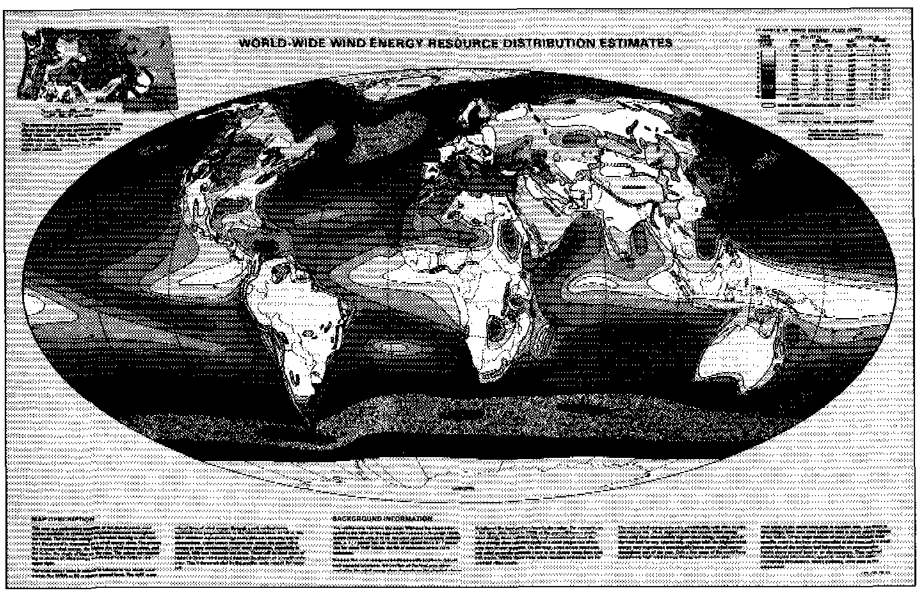


Figure 16—Relative global radiation, January *(G. Major et al, WMO Technical Note No. 172)*

Figure 17—World-wide wind energy resource distribution estimates *(WMO Technical Note No. 175)*



calorie requirements of the world's people, increased by 70% between 1963 and 1983.

In this *green revolution*, the most rapid gains were manifest in Asia where fertilizer use increased from 42 kg/hectare in 1975–1977 to 93 kg/hectare in 1985–1987. Unfortunately this increase in the use of nitrogen and phosphorus-based fertilizers resulted, in many areas, in eutrophication (over-enrichment) of lakes and coastal areas, and in groundwater contamination.

There are signs that these gains may be accompanied by even more serious environmental degradation. Cereal production has levelled off since 1984 with even the bumper crop due to good growing weather in North America in 1989 only slightly exceeding the 1984 yield. Root crop production peaked in 1984. On the bright side, fruits, vegetables, milk, fish and meat have continued a steady global increase since 1983.

The major exception to the general increase in agricultural production has been in sub-Saharan Africa, where persistent drought in the 1970s and 1980s and rapid population growth have created a serious crisis in food supplies, with a grim outlook for the future. As an Ethiopian scientist has put it, "the economic case of most African countries is agriculture. Agricultural production and weather are so highly interrelated that a good rainy season means a healthy economy, and failure of the rains . . . means famine and death" [14].

Current world population growth rates, if continued, will put enormous pressures on available cropland. In fact, if population trends continue the 0.28 hectare/person now devoted to crops will fall to 0.17 hectare/person by 2025. There are two remaining large reserves of potential cropland, the savannah grass-lands of South America, now used mainly for ranching, and the lands of sub-Saharan Africa. The latter area has had very uncertain rainfall over the past few decades, soils are mostly marginal and much of the woody vegetation that might have protected the soil has been used for fuel wood.

Given these constraints, for 93 developing countries nearly two-thirds of the increased production projected by FAO to the year 2000, must come from higher production on existing land under cultivation. About 22% is projected to come from increasing the area of cultivated land [18].

To achieve such an increase in production, without serious environmental degradation, will require the adoption of greatly improved techniques, of all kinds, including the maximum use of agrometeorological and hydrological knowledge and procedures. This is true for both rainfed and irrigated agricultural economies. It is not possible in this booklet to describe in any detail all the applications of meteorological, climatological and hydrological knowledge and data that increase productivity, reduce losses and minimize fertilizer and pesticide applications. However, a partial list of successful applications may give some perspective of the extensive scope and potential.

Proven applications can be listed in three main categories:

- Better land use through agroclimatological analyses, for optimum crop selection, timing of cropping practices, agricultural and food supply planning;
- Operational applications to support seasonal and day-to-day agricultural tasks;
- Storage and marketing of crops.

Examples in the boxes are drawn mainly from WMO technical publications 1990 and 1980 (Omar) [14, 19] and illustrate proven uses of agrometeorological and climatic information to improve production and reduce losses to rain-fed agricultural economies. Additional examples are well documented. It must be noted that many of these applications not only reduce crop losses, but also reduce the use of chemical fertilizers and pesticides, and their spread throughout the environment. In these two areas, agrometeorology can contribute substantially towards achieving more sustainable agriculture.

For irrigated agriculture, the effective use of hydrological, climatic and meteorological information can be even more valuable in planning, design and operation. To move towards meeting the world's growing food needs, more

1.—Analyses for planning purposes

* Rainfall reliability maps in East Africa to determine suitable areas for cultivating tea, sugar, tobacco (Tewungwa)
* Soil-moisture estimates from climatological data to select and develop appropriate new corn strains in East Africa (Dagg)
* Areas with suitable climatic conditions in Cameroon for pineapple and banana growing (WMO–Omar)
* Agro-climatic delineation of areas suitable for soybeans in Ecuador (WMO–Omar)
* Agro-climatic data used in estimating soil moisture regimes in Ethiopia for selection of crops and varieties of seed (Tamerie)
* Agro-climatic zoning for 10 crops in Hunan Province (China) resulted in 14% increase in crop value (1980-84) (Yu Xmin and Shi Guoning)
* Moving the sowing date of rice in Indonesia to gain the maximum benefit from sunshine duration during the flowering stage (Baradas)
* Matching the growing season with water availability periods and selecting a suitable short-duration seed variety or long-duration drought-resistant variety of seed (H. P. Das, India)

2.—Operational applications

* Selection of dates for cotton planting using observed and forecast weather data in southern USA. (McQuigg, Calvert & Decker)
* Daily agrometeorological advisories from the WMO–CILSS AGRHYMET Centre in Niamey demonstrated in pilot projects, e.g. in Mali, crop losses of millet, sorghum and groundnuts were reduced by more than 20% with an allied reduction in the use of fertilizer and pesticide (Konaré)
* Scheduling of fertilizer applications to avoid loss in runoff due to any subsequent heavy rains (Konaré–Sahelian region)
* Reducing grape losses by 15% through using weather forecasts to select harvest dates in Bordeaux, France (Giovanelli)
* Elimination of two or three pest control applications per season in orchards and vineyards through meteorological scheduling in southern France (Giovanelli)
* Using knowledge of weather-related locust reproduction and movements to predict outbreaks and swarms in order to efficiently deploy resources to combat locusts in northern Africa (WMO-FAO)
* Heavy rain warnings to protect and preserve tomato and grape crops in Australia (Gibbs)
* Wind forecasts to reduce the dispersion of insecticide sprays away from crops during aircraft applications (Canada)
* Prediction of end of season size and worth of cattle herds through using meteorological data to foresee grazing availability (Botswana)

3. —Storage and marketing

* Prediction of wheat yields from soil moisture budgets based on meteorological data, to improve marketing in Canada and USA (Baier)
* Forecasts for peanut storage in Africa to permit preventive action against pests and diseases (Rijks)
* Tailored weather forecasts for protecting grapes during drying California, USA. (Kolb and Rapp)
* Design of optimum storage houses for grain drying in USA (McQuigg & Doll)

extensive and efficient irrigation will be required. It has been estimated that world-wide, up to 60% of irrigation water is wasted, i.e. does not contribute directly to plant growth. Scheduling of irrigation according to need determined by meteorological and hydrological information could reduce this excessive use of water (see item 4. below). Today Asia has by far the largest area under irrigation of any continent, some 60% of the world's total of about 270 million hectares (FAO, 1986), and the irrigated area must continue to grow to serve the rapidly increasing populations. Expansion of irrigation is also essential to meet burgeoning needs in Africa. However, excessive and unwise irrigation practices can lead to water logging and salination of soils, with, in some regions, widespread reduction of productivity. Dams and reservoirs for storage of irrigation waters can also result in some environmental damage as outlined in the section on water resources. To minimize these environmental impacts requires careful use of hydrological and meteorological data and information.

Among the most important hydrometeorological applications for irrigation are the following:

1. Use of hydrologic data to determine quantity and quality of water reliably available during the driest periods.
2. Use of climatic data in soil moisture budgeting to determine mean and extreme water demands of crops for planning of projects.
3. Hydrometric and meteorological data analyses for optimum design of dam and reservoirs for irrigation-water storage.
4. Operational soil moisture budgeting by daily precipitation and evaporation measurements or estimates to determine when plants need water, for optimum timing and amount of irrigation applications. This avoids excessive use of often limited available water and can minimize soil salinity and water-logging problems.

In short, to feed rapidly growing populations, agricultural production must increase. Application of meteorological and hydrological knowledge can contribute substantially to achieving increases while at the same time minimizing environmental damage from excessive use of pesticides, fertilizers, and irrigation waters.

Forests—economic, environmental and social values

The pressure for greater food production, especially in tropical regions, is one of the main causes of deforestation as forest land is converted to agriculture. For example, in Indonesia, the government's policy is to convert about 20% of forested land to plantations devoted to rice, coffee, and other agricultural crops—to provide food for its 170 million people—as well as rubber and teak production to boost the economy.

In temperate, boreal and tropical forests logging for wood, paper and fibre production can also result in areas of deforestation. Some countries have adopted policies of replanting and regeneration of forests. However, these policies are often not rigorously followed and in some areas do not exist. Even where regeneration is attempted, soil disturbance from logging and other factors may leave a much degraded forest. In other regions, cattle grazing, fire, drought and insect and disease infestations, reduce the amount of forested land.

Since humans began to cultivate the soil some 10 000 years ago, the world's forested area has declined from 5–6 billion hectares to the present 4 billion, with the largest losses occurring in the temperate zones (32–35%). At present tropical forests are under the greatest pressure. Deforestation is one factor that has contributed to the changing composition of the global atmosphere. However, the reduction of absorption of CO_2 by forest vegetation is now a very much smaller factor than the burning of fossil fuels in increasing concentrations of atmospheric CO_2, although it was a major factor in earlier periods (Figure 18).

Forest loss also affects the hydrologic regime of a region. While under some conditions total runoff from a recently deforested area may increase, due to reduced evapotranspiration losses, the seasonal distribution can be drastically altered. The loss of trees usually results in higher peak flows or floods, and more prolonged and intense low flow periods in the dry season. In addition, soil losses create large sediment loads in rivers and lakes especially when hilly slopes are denuded, and these sediments often contain pesticides, fertilizers and other water pollutants. Due to the high mobility of the atmosphere, forest cover has generally little effect on local precipitation amounts, but over a very large river basin in tropical regions, such as the Amazon, the loss of forest and its replacement by grassland could reduce precipitation by as much as 20% over the whole basin [7].

Meteorological and climatic information can be valuable in reducing loss of forests due to fire, and insect and disease infestations. For example, in Australia, it has been estimated that US $34 million worth of timber per year is saved by application of meteorological data and forecasts in preventing and

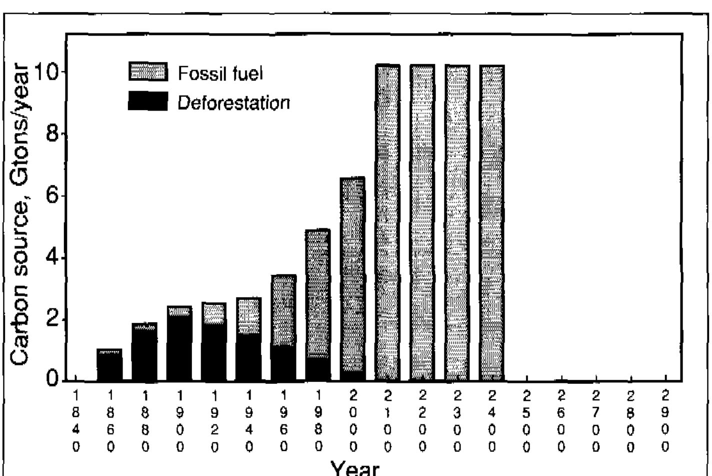


Figure 18—
Anthropogenic sources of carbon to the atmosphere
(H. S. Khishgi [20])

controlling timber and bush fires (Gibbs). In many countries, forest fire hazard indices, based on meteorological observations and forecasts, related to the dryness of the duff layer and other materials in the forest, are used to control access to forested areas in fire susceptible periods. Fire-fighting operations are critically dependent on forecasts of wind and rain.

Studies of the relationship of particular insects and diseases that adversely affect forests and the weather conditions that stimulate them, allow use of weather data and forecasts to predict the area and timing of outbreaks which in turn will allow the appropriate prevention or remedial actions of chemical spraying and biological controls to be taken. Aircraft spraying operations are also highly dependent on forecasts of wind and weather conditions to minimize the dispersion of sprayed substances beyond target areas.

Thus maintenance of forested areas or afforestation requires strong governmental policies to ensure sustained use and management. Given such objectives and policies, meteorological information can be of great value in defending forest stands from fires, insects and diseases and thus assisting in their sustainable management. In addition the selection of species for replanting logged areas can be made more effective if species and strains are matched to the expected climatic conditions, as well as to the soils. In an era of changing climate such matters are of great importance.

Marine environment and resources

The oceans and the atmosphere are intimately linked. The oceans are an integral part of the global climate system, storing heat and releasing it to the atmosphere at different times and places, and exchanging momentum through winds, waves and currents. The oceans receive significant quantities of nutrients such as nitrogen and phosphorus from the atmosphere, as well as persistent toxic chemicals such as the heavy metals: lead, mercury and cadmium. Pesticides, herbicides and other industrial chemicals are also transmitted through the atmosphere to the ocean.

The coastal zones of the world are especially important for biological production, and are the sites of many of the world's great cities. Coastal zones and their productivity are sensitive to many stresses, including pollution transported by river systems and through the atmosphere, coastal erosion by wind-driven currents and waves, inundation in storm surges augmented by sea-level rise induced by climate change, by river flooding, and by sediment transport and deposition. It is estimated that since the beginning of the 18th century the amount of sediment discharged from large river basins to the sea has tripled and from smaller rivers has increased by as much as eight times. In addition to the physical effects of these sediment deposits in estuaries and along coasts, the flow of carbon to the world's oceans from such sediments amounts to one to two billion tons per year.

Measurement of sediment transport and river flows to the sea coordinated through WMO's Hydrology and Water Resources Programme make a valuable contribution to studies of coastal processes and management of the coastal zone as does information produced by WMO co-ordinated programmes related to winds and storms, and the medium- and long-range transport of air pollutants. In undertaking this type of work WMO collaborates closely with the Intergovernmental Oceanographic Commission (IOC) of UNESCO.

Fisheries too are affected by seasonal climatic fluctuations. The most striking example was the effect of the strong "*El Niño*–Southern Oscillation (ENSO)" in 1972 and 1982–1983 on anchovies and herring off the west coast of North and South America, especially Peru, Ecuador and California, and on salmon migration routes further north off the coast of British Columbia and Oregon. While the effects were very great in those particular years, similar but lesser fluctuations are observed most years. The ENSO phenomenon is an interaction between the tropical Pacific Ocean and the atmospheric circulation of that region and eventually of the whole globe. It results in cold water upwelling on the American coast and major climatic anomalies in the Pacific and world-wide. Under the Tropical Oceans Global Atmosphere (TOGA) project of the World Climate Research Programme, the possibility of predicting ENSO events is emerging so that in the future, fishing fleets would be able to adapt to changes in the geographical distribution of important commercial species of fish. In the longer term, climatic changes induced by rising concentrations of greenhouse gases will change ocean temperatures and currents, and thus the distribution and abundance of many fisheries [21].

CHAPTER 4

Some urgent issues

Multi-media pollution

Degradation of the atmospheric and freshwater environments as a manifestation of unsustainable forms of economic development were outlined in Chapter 2. However, it is important to recognize that pollutants are not confined to compartmental or geographical boundaries. Contamination of the atmosphere, due to industrial activities in one country, can lead to pollution of lakes in another, or of the oceans or regional seas. Some pollutants discharged into rivers from factories and municipalities are transported to lakes and the sea, to rivers, or into sediments deposited at the rivers' mouth. Pesticides and fertilizers applied to soils often filter into groundwater, streams and lakes. It is even suspected, but not well understood, that pollutants in water bodies may volatilize and be transported to the atmosphere partly through foam and bubbles on the water's surface.

Manifestations of the pervasive nature of some contaminants, once they are discharged, are very striking. In 1985 on Broughton Island in Canada's high Arctic, far removed from industrial activities, the man-made chemicals, polychlorinated biphenyls (PCBs) were found in two-thirds of the Inuit children tested, at levels higher than recommended safe levels. The contaminant proved to have existed in their mothers' milk. The Inuit people of this region eat a diet of mainly fish, and sea and land mammals, and as those creatures are close to the top of the food chain the toxic chemical had bio-accumulated through the many links of the chain. Meteorological analyses show that the PCBs were probably transported through the atmosphere primarily from Europe and Asia and deposited in initially low concentrations in the seas and on land. Transport by the sea and sea creatures may also be occurring.

- Atmospheric pathways are dominant inputs to the oceans for a number of toxic organic compounds, representing more than 80% of the total loading from all sources of PCBs, chlordane, DDTs, dieldrin and of the HCHs (hexachlorocyclohexanes) and HCBs (hexachlorobenzines);
- Sulfate and nitrate emissions from thermal power plants and industrial activities in North America and Europe have resulted in dramatic increases in acidity of precipitation, (acid rain) in turn adversely affecting lakes, soils, vegetation and buildings, hundreds and thousands of kilometres downwind of the sources;
- Pesticides such as DDT, dieldrin and others are found in significant concentrations in fatty tissue and organs of creatures in both polar regions: seals, polar bears, penguins, etc. Again transport through

the atmosphere from industrial, agricultural and forested areas thousands of kilometres away is occurring;

- Pollution of regional seas like the Mediterranean and many coastal areas by the toxic metal lead and several other contaminants, is due mainly to atmospheric pathways, though those areas receive large direct industrial discharges from shoreline factories and rivers. Lead in the atmosphere comes mainly from vehicle exhaust (see Figure 8);
- Biological processes in the sediments of lakes and oceans can gradually transform metals such as mercury, inert when discharged, into highly toxic methylated forms which bioaccumulate in the food chain.

From these examples, two key lessons can be drawn. The first is that economic activities which emit persistent toxic contaminants can be considered to be unsustainable as they pollute the environment and biosphere both for this generation and generations to come. Secondly, to understand the probable sources of wide-spread contaminants and thus take action to reduce them, requires globally co-ordinated monitoring and analysis of all components of the environment, particularly the highly mobile atmosphere, water systems, and oceans. Monitoring of toxics in biota is also of critical importance in assessing actual and potential bio-accumulation of various contaminants to toxic levels.

WMO undertakes international co-ordination of the research and monitoring of the first two of these environmental components (air and water) and works closely with other UN agencies responsible for studies of oceans and biota.

Natural disasters

Tropical cyclones, earthquakes and floods are the most widespread and devastating causes of natural disasters. Other natural phenomena that cause significant losses are thunderstorms, tornadoes, snow- and ice-storms, volcanoes, heat waves, avalanches, landslides, and tidal waves (tsunamis) [22].

Other forms of disasters resulting from natural forces that come about more slowly with gradual and cumulative effects over a period can be even more devastating. These include droughts, locust and other insect infestations and wildfires of forests, bush and grasslands.

The World Bank estimates that natural disasters take about 250 000 lives world-wide each year. In 1990 47 billion US dollars worth of physical damage was estimated. Reinsurance companies estimate that damage due to natural disasters has increased threefold between the 1960s and 1980s. For developing countries of the world, such damage can seriously set back economic development activities for many years. Thus establishment of warning systems and preparedness to reduce losses due to natural disasters must become an integral part of the planning and development process.

It is striking that most natural hazards are meteorological or hydrological in character or weather related (landslides, wildfires, insect infestations). The other scientific fields of major importance in connection with phenomena that result in natural disasters are geology (earthquakes, volcanoes, landslides) and oceanography (tsunamis and storm surges).

But such hazards become disasters only when human habitation and activities are located in the areas in which such phenomena occur. A flood in an uninhabited flood plain will not constitute a human disaster though it will affect the ecosystems of the flood plain. However, with rapidly growing world populations, increasingly few of these violent manifestations of nature occur without causing loss of life, economic losses, hardship and human misery.

In some countries, prevention, warning and preparedness systems have been instituted that have been remarkably effective in reducing loss of life and property damage in severe storms, floods, earthquakes and landslides. The tragedy is that in many developing countries, which suffer most from natural disasters, such techniques are not in place or are inadequate.

Recognizing the enormous losses, the manner in which natural disasters prevent the sustaining of economic development, and the disparity between regions in preparing for and coping with disasters, the United Nations has launched the International Decade for Natural Disaster Reduction, 1990-1999. The goals of the Decade are to reduce loss of life and damages by ensuring widespread use of proven disaster mitigation methods, and to mobilize the scientific and engineering communities to improve warning and damage reduction methods and adapt them for different regions. An international Scientific and Technical Committee guides the overall programme, supported by a small Secretariat based in Geneva. The UN organizations with responsibilities in this field, WMO, the UN Disaster Relief Office (UNDRO), UNESCO, WHO and FAO, are active participants at an international level along with the non-governmental International Council of Scientific Unions, the World Federation of Engineering Organizations and the League of Red Cross/Red Crescent Societies. By mid-1991, 92 countries have formed national committees or focal points for the IDNDR.

Meteorological and hydrological agencies, both national and international, are playing a major role in the IDNDR. These agencies, including WMO, have had many years experience of disaster prediction, prevention and mitigation. The IDNDR will provide an opportunity for strengthening and better co-ordination of these efforts.

Meteorological and hydrological information and services are important to disaster mitigation at four stages:

1. **Planning**: Analysis of meteorological and hydrological data on storms, drought and river flows permits determination of the frequency of occurrence of extreme events of various magnitudes in different parts of a country. Based on these analyses land-use planners can take account of and reduce risks. For example, flood-plain

lands can be designated as such and flood-susceptible developments prevented or discouraged in those areas; coastlines especially susceptible to tropical cyclones and accompanying storm surges can be appropriately zoned with building restrictions.

2. **Design and construction**: Estimates of the frequency of severe weather and hydrological events can be used to design structures of all types to ensure safety and to avoid loss of life. For example, buildings and bridges must be designed to withstand the most severe wind forces that are likely to occur in their lifetime; dams must be designed to withstand the largest floods projected to occur; channels and drainage structures can be optimally designed to carry away heavy rain and river overflows of a magnitude that would minimize damages and costs.

3. **Warning and preparedness systems**: Under the World Weather Watch (WWW) of WMO, five regional tropical cyclone programmes ensure the rapid exchange of information between countries in a geographical region, and the prediction of movement and intensity of tropical storms as a basis of warning systems. All national weather services have as a primary goal the production and dissemination of warnings of severe weather conditions. The WWW provides basic information, including computer-based forecasts from designated World and Regional Meteorological Centres to achieve effective warnings. For provision of warnings of floods and of very low flows many national meteorological and hydrological agencies co-operate. On international rivers such as the Niger, co-operative arrangements are fostered by WMO, UNDP and others, to provide the needed forecasts and warnings. Such warnings are of limited value without disaster preparedness plans at personal, local and national levels to take the appropriate action to save lives and reduce property losses. It is estimated that up to 30% of the damage from a major flood would be avoidable if, after adequate warning and preparedness, property (cattle, cars, furnishings, etc.) were removed from the area.

4. **Immediate post-disaster actions**: Many lives can be saved in major disasters in the phase immediately following its onset. However, without reliable forecasts of how soon floodwaters would abate or strong winds lessen or rains cease, action to save lives and protect public health would be completely ineffective.

Over these four critical phases of planning and mitigation of disasters, it is essential that national, regional and international meteorological and hydrological agencies are active partners with emergency preparedness or civil defence agencies. In the latter two phases, to be of value, warnings must be communicated and acted upon, so both the normal communication channels of the weather and water agencies, and emergency communications of civil defence agencies are essential to saving lives and property at the time of the disaster.

Environmental emergencies

The role of meteorological and hydrological services can be as essential in environmental emergencies (unnatural disasters) as in natural disasters. One of the first questions asked after an industrial accident releases toxic or radioactive substances to the air is, where will the winds take the contamination and when and in what concentrations will it be deposited. In the sea or a river or lake the question is, where will the currents take the spilled substances? and how fast?

In the case of lakes, mathematical models have been developed by water agencies that predict surface currents on the basis of wind observations and forecasts. These models allow for forecasts of the movement and dispersion of an oil slick or a light contaminant, and the closing of appropriate intakes or curtailing of other water uses in the path of the spill. Similar techniques are used in regional seas and ocean areas. Not only are reliable wind and weather forecasts essential to predicting the movement and dispersal of an oil slick, they are indispensable in guiding operations to deploy equipment such as booms, dispersants, slick-lickers, etc. to combat the spills. The International Maritime Organization has developed a contingency plan for coping with oil spills in the international oceans, and has enlisted the close co-operation of WMO in the provision of the essential meteorological advisories through the co-operative efforts of appropriate national weather agencies. Warnings of severe weather at sea made possible by the World Weather Watch, permit tankers and other vessels to avoid dangerous storms that might otherwise result in oil or chemical spills.

There have been a number of cases of major accidental industrial emissions to the atmosphere with tragic national or international effects such as the Chernobyl nuclear reactor accident, and the earlier nuclear (Three-Mile Island) and chemical (Serveso, Bhopal) accidents which caused similar concerns. Following the Chernobyl incident the UN family of agencies moved to establish a more reliable warning system than had hitherto been in place. The International Atomic Energy Agency, the World Meteorological Organization, the World Health Organization and the United Nations Environment Programme are involved. As part of this system, WMO formalized procedures for disseminating predictions of the movement and dispersion of radioactive debris from an accident through use of mathematical models similar to those used to make the daily weather forecasts, and through use of river flow models. At the larger meteorological centres, such models are global in scope. The picture in the centrefold shows predictions by the Canadian Meteorological Centre's operational model of the dispersal of radioactivity following the Chernobyl accident. Such model outputs can be produced by several centres within a few hours of an accident. On the basis of such predictions, the fallout at any location can be estimated in order to provide advance warning for actions to protect water, food and people.

The oil-well fires of Kuwait (see centrefold) which were lit in late February 1991, following the Gulf War have had serious impacts on local climate, health and living conditions. Unfortunately, with the devastation brought about by the occupation and war, practically no observing sites were left to monitor the effects of the smoke pall and emissions created by the 600 fires. WMO has been co-ordinating, through its World Weather Watch and Global Atmosphere Watch Programmes, the rehabilitation of observing networks, and the monitoring of special multi-national aircraft observation programmes and studies. Financial and other assistance are being provided through UNEP.

It is estimated that at the beginning some five to six million barrels of crude oil and 70 million cubic metres of associated gases were consumed daily. In addition to the 50 000 tons of airborne particles (smoke), of the order of 800 000 to two million tons of carbon dioxide as well as sulphur dioxide, the precursor of acid rain, oxides of nitrogen, poly-aromatic hydrocarbons (PAHs) are being emitted per day (US National Science Foundation estimate—June 1991). Adverse health effects are reported due to the high concentrations of smoke particles and sulphuric dioxide.

Preliminary meteorological modelling of the regional effects of the heavy smoke plume shows a significant cooling below the smoke in the immediate area of Kuwait, and abnormally warm air above the plume. Downwind, where the plume is not intense, the long range transport of pollutants has led to increased acidity in precipitations as noted, for example, by measurements in Iran. Any global effects are difficult to predict. The volumes of smoke could negligibly increase atmospheric optical depth world-wide, however, since there is no penetration into the stratosphere, there will not be any noticeable cooling. But, the increased CO_2 emissions will add significantly (up to five per cent from the partial CO_2 contribution in 1991) to the longer-term enhanced greenhouse effect.

This experience reinforces the notion that it is essential that weather and water agencies, at national, regional and international levels, be involved at an early stage to establish and execute plans to respond to environmental emergencies.

CHAPTER 5

Further actions required: the UNCED connection

The countries of the world will have a unique opportunity through the United Nations Conference on Environment and Development (UNCED), in Rio de Janeiro, June 1992, to modify and strengthen the ways in which the international community and the UN system deal with the interrelated issues of environment and development. As illustrated in the examples in this booklet, scientific activities, especially in meteorology, climatology, and hydrology can make key contributions to the protection of the environment, and to sustainable development of water, agriculture, forestry, ocean and energy resources.

However, the availability of reliable data and authoritative information on which sustainable development can be based is often taken for granted. Sustainable development cannot be achieved without the national and international institutions that ensure long-term systematic measurements and research, essential to the understanding of the behaviour of regional and global systems under the stress of pollution or over-use. This scientific foundation for protection of the global environment and resource management must be explicitly recognized in any realistic Earth Charter and agenda for action, Agenda 21 that may emerge from UNCED.

In the "guiding principles" of the Earth Charter, it is suggested that the four fundamental concepts listed below should be clearly recognized.

1. In order to protect the global environment, all countries and people must have access to authoritative scientific information on the state and behaviour of the atmosphere, climate and water resources.
2. All people must receive adequate warning of impending natural disasters, and of possible effects of environmental emergencies, and must benefit from adequate preparedness systems, to reduce loss of life and damage to property.
3. In order to meet the needs of growing populations, water resources must be managed sustainably which requires management based on sound national and international water-resource assessments founded on reliable systematic measurements.
4. Systematic measurements of environment and resources and understanding of the behaviour of natural systems, are fundamental to sustainable development of agriculture, forestry, ocean, and other resources.

Action both nationally and internationally will be needed to establish these four principles. National institutions for systematic measurements and research, such as meteorological and hydrological agencies, must be effectively supported. International institutions such as WMO which standardize, co-ordinate and stimulate these national organizations must be similarly supported, and a commitment made by all countries to freely exchange data on the atmosphere, climate and hydrosphere.

It might be thought that support for both national and international institutions is adequate but our understanding of many important phenomena is insufficient and we are not yet able to predict local or regional economic and social consequences. Measurements of the atmosphere, oceans, and climate over the "global commons", are also inadequate and unable to describe many aspects of the *present* state of the climate, atmosphere, and oceans, let alone predict future conditions. For these reasons many of the potential benefits of applying basic climatic and hydrologic data for more sustainable resource management cannot be realized in some countries.

National water assessments

Measurements and institutional arrangements in many countries are insufficient for vital comprehensive water assessments. In a recent WMO/UNESCO survey, a number of problems were identified. There was an average of nearly two-and-a-half water data collection agencies per country and in some regions as many as four. In some cases these agencies worked together effectively but in many countries they did not. Comprehensive national water assessments are at times seriously hindered because much of the data are collected and the analyses compiled by agencies with a single interest, e.g. irrigation, hydro-power, or municipal water supply, and national assessments that would allow optimum allocations of limited water resources are extremely difficult. In some countries, a minority, the hydrological and meteorological services are joined or in the same government department for efficiency in servicing field observational networks, and for scientific co-operation.

National institutions and needs

In 1990, assessments were made of the strength of meteorological and hydrological agencies in developing parts of the world. In most countries, national Meteorological Services were initiated many decades ago for the safety and efficiency of maritime operations, and for aviation. These are still important demands on meteorological agencies. However in the 1970s and 1980s confronted by widespread droughts and disasters, came the "vivid realization of the role of meteorology and operational hydrology in planning and ensuring self-sufficiency in agriculture, water resources and energy and in averting environmental degradation." [Degefu, 14].

In Africa, the basic meteorological observation networks for surface and upper-air stations are below WMO's international guidelines with only about 50% of the necessary upper-air network and 80% of the surface level synoptic network implemented. Due to interruptions in observing programmes and shortcomings of telecommunication systems only about 45% of required surface observations and 25% of the needed upper-air reports reach the World Meteorological Centres for global analyses. In a number of cases the meteorological services are scattered throughout several government departments. They do not have a sufficient core staff and cannot provide the full range of services needed.

The same problem is also evident in South America where many weather agencies serve mainly military and aviation needs, with services to environmental and resource management issues frequently only marginal. For example, only 50% of the meteorological agencies in South America undertake any climatic research, or climatic applications to environmental or water issues.

To take maximum advantage of the opportunities offered by meteorological and hydrological agencies in achieving sustainable economic development, a number of actions must be taken by governments and technical assistance agencies in order to assist national institutions. Such actions could possibly be reflected in UNCED's Agenda 21 to:

1. Support the development and maintenance of meteorological (including climatological) and hydrological observation networks, and related communication systems, to at least the minimum standards recommended by WMO. Such networks should include measurements of the chemistry of air and precipitation and water quality.
2. Support, with long-term legal and financial assurances, the basic institutions of a national Meteorological Service, and a national Hydrological Service, or a combined hydrometeorological agency.
3. Ensure that such Services play an active role in national planning for agriculture, water, energy, transportation and other fields.
4. Ensure that hydrological and meteorological agencies are part of the national teams responsible for issuing warnings and arranging responses to natural disasters and environmental emergencies.
5. Ensure that hydrological and meteorological agencies are provided with trained staff through advanced educational and training institutions at a regional or national level.
6. Support regional institutions which permit more advanced scientific activities than any one nation can afford, such as the African Centre for Meteorological Applications for Development (ACMAD), Hydro Niger, a South-East Asian Meteorological Centre, the five regional tropical cyclone programmes, etc.

WMO has established a Special Trust Fund for Climate and Atmospheric Environment Activities which is designed to assist developing countries to improve observation and analysis programmes in these fields. For many countries, and their Meteorological and Hydrological Services, only through such technical assistance can the potential benefits outlined above begin to be realized.

International actions

In addition to these actions at the national level, UNCED, through Agenda 21 should recognize the importance of supporting the UN specialized agencies, such as WMO, which work to provide co-ordinated global and regional assessments, based on standardizing and co-ordinating the efforts of the national counterparts. In addition, non-governmental scientific institutions, such as the International Council of Scientific Unions, which can mobilize the research efforts of the non-governmental scientific community must be recognized and supported.

In order to fully understand the behaviour of the natural systems, the atmosphere, oceans, land and ecosystems, which human activities clearly affect, these systems must be measured and studied together. One example of planning for a comprehensive approach is the Global Climate Observing System (GCOS) called for by the Second World Climate Conference. The Conference Statement envisages GCOS as consisting of:

- An improved World Weather Watch;
- A comparable Global Ocean Observing System effecting physical, chemical and biological measurements; and
- Related observational systems such as an improved Global Atmosphere Watch for assessment of chemical constituents of the atmosphere, as well as of the global water cycle components, changes in terrestrial ecosystems and the Earth's radiation budget.

In short, the systematic measurement needs identified by the SWCC are those necessary to understand and predict the behaviour of the Earth's interrelated climate system. The World Climate Research Programme (WCRP) together with the International Geosphere–Biosphere Programme (IGBP) provide the framework for similarly comprehensive research efforts. Innovative organizational arrangements at both national and international levels will be required to achieve these difficult but essential goals of reliable measurements and effective research. National and international commitments to the support of GCOS and related research, as well as ensuring appropriate international organizational arrangements for such comprehensive measurement and research, must be a concern of the Earth Summit.

In connection with water, international responsibilities are divided among a number of agencies and institutions. With the alarming potential for conflict over water in many international basins, with continued serious shortfalls in the provision of adequate water supplies and sanitation, with development assistance becoming urgent for national water assessments, a new level of international co-operation and co-ordination of water activities is needed. Consideration should be given, through the Earth Summit process, to mechanisms such as a proposed World Water Council, drawing upon all countries and relevant international institutions.

CHAPTER 6

Conclusion

Recent developments in environmental and resource issues related to the global atmosphere and to fresh water, have clearly demonstrated the urgent need for better measurements and understanding of these components of our Earthly inheritance. To preserve this inheritance for future generations and to use it for the benefit of all peoples, will require an unprecedented level of understanding of the atmosphere and of water systems, and wise use of that understanding in public policies.

The meteorological and hydrological communities are willing to actively contribute their skills and knowledge to the challenging task of achieving truly sustainable use of the resources and environment of our small planet.

Further reading

(1) World Commission on Environment and Development. *Our Common Future*. Oxford University Press, 1987.

(2) Robinson, J. et al. *Defining a sustainable society in alternatives: Perspectives on Society, Technology and Environment*. V.17 No. 2 July 1990, University of Waterloo, Canada.

(3) World Meteorological Organization. *The atmosphere of the living planet Earth*. J. P. Bruce, WMO-No. 735, 1990.

(4) Jones, P. D. and Wigley, T. M. L. *Global warming trends*. Scientific American V.263 No. 2, pp 84-91, Aug 1990.

(5) Graedel, T. E. & P. J. Crutzen. *The changing atmosphere*. Scientific American V.261 No. 3, pp 28-37, Sept. 1989.

(6) Climate change: Science, impacts and policy, Proceedings of the Second World Climate Conference, (November 1990). Cambridge University Press, 1991.

(7) Intergovernmental Panel on Climate Change. First Assessment Report. WMO, 1990.

(8) Shiklamanov, I. A. & Mordova, O. S. *The problems of water availability and transfer of river runoff in the world*. Leningrad, Gidrometeoizdat, 1987, p 63.

(9) WMO/UNESCO. *Water resources assessment: progress in the implementation of the Mar del Plata action plan and a strategy for the 1990's*, 1991.

(10) WMO/ICSU. *The Global Water Runoff Data Project. Workshop on the global runoff data set and grid estimation (Koblenz, FRG, 10-15 November l988)*. WCRP-22, WMO/TD 302, June 1989.

(11) World Resources Institute. *World resources 1990-91: a guide to the global environment*. Oxford University Press, 1990

(12) Myers, N. (Ed). *The Gaia atlas of planet management*. Pan Books, London, 1985.

(13) Reddy, A. K. N. & Goldemberg, J. *Energy for the developing world*. Scientific American, V.263 No. 3, pp 110-119, Sept. 1990.

(14) World Meteorological Organization. *Economic and Social Benefits of Meteorological and Hydrological Services*. Proceedings of the technical conference, 26-30 March 1990, WMO-No. 733. (Articles by Reiber, Degefu, Konare, Starosolszky)

(15) World Meteorological Organization. *Guide to hydrological practices*. WMO-No. 168, fourth edition.

(16) World Meteorological Organization. *HOMS reference manual*. 1988, second edition

(17) Robson E., *Reassessing Solar Power.* Source, June 1991, UNDP, pp 24-25

(18) Nemec J. *Impact of climate variability and change on water resource management in agriculture.* Conference on Climate and Water, Helsinki, Sept 1989, V2, pp 359-371.

(19) Omar, M. N. *The economic value of agrometeorological information and advice.* Technical Note No. 164 WMO-No. 526, 1980.

(20) Kheshgi, H.S. *The sensitivity of CO_2 projections to ocean processes.* Extended abstracts of the Third International Conference on Analysis and Evaluation of Atmospheric CO_2 Data, Present and Past. University of Heidelberg, WMO Environmental Pollution Monitoring and Research Programme Report No. 59 (TD No. 340), Oct 1989.

(21) Glantz, M. H. and L. E. Feingold. *Climate variability, climate change and fisheries.* ESIG/NMES/EPA Study. NCAR, Boulder, California, Sept. 1990

(22) World Meteorological Organization. *Natural disaster reduction: how meteorological and hydrological services can help.* D. K. Smith, WMO-No. 722, 1989.