Scientific contribution
No: INCOH/SAR-26/2006

STATE OF ART REPORT

Effect of climate change on water resources

K. S. Ramasastri

Publication of
Indian National Committee on Hydrology (INCOH)
(IHP National Committee of India for UNESCO)
National Institute of Hydrology, Roorkee-247 667
INDIA

INDIAN NATIONAL COMMITTEE ON HYDROLOGY (INCOH)

(IHP National Committee of India for UNESCO)

Constituted by the Ministry of Water Resources in 1982

INCOH Secretariat

Member Secretary, Indian National Committee on Hydrology (INCOH)
National Institute of Hydrology, Roorkee-247667, INDIA
Phone: +91 1332 272906 Ext. 299
Fax: +91 1332 272123, 277281
E-mail: incoh@nih.ernet.in
Web: www.nih.ernet.in

Activities of INCOH

Sponsorship of Research/Applied Projects

INCOH provides sponsorship to research and development projects to fulfil its following objectives:

- To conduct studies and research using available technology.
- To develop new technology and methodologies for application to real life problems.
- Td develop hydrological instruments indigenously and to evaluate new techniques.
- To develop new software for application in field hydrological problems.
- To give impetus to hydrological education and training.

About 48 research projects from different parts of the country have been sponsored uptil now. The funding for various projects has been provided under the following ten broad areas:

- Hydrology of surface water (rivers, lakes and reservoirs) including snow and glaciers.
- Remote sensing applications to hydrology and water resources.
- Hydrological information system and computers in hydrology.
- Hydrological instrumentation and telemetry.
- Environmental hydrology.
- Hydrometeorological aspects of water resources development and flood forecasting.
- Groundwater, springs, conjunctive use, drainage and water re-use.
- Drought, water conservation and evaporation control.
- Nuclear applications in hydrology.
- Educational and training in hydrology.

Organisation of National Symposium on Hydrology

INCOH organises at least one national seminar/symposium every year to bring together hydrologists and water resources engineers from various parts of India. Since 1987, INCOH has been organising such National Seminars every year on specific focal themes.

Sponsorship of Seminar/Symposia/Conferences/Short-Term Courses

INCOH provides sponsorship to va-1Xious agencies and organisations for organising national, regional and international events in hydrology.

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INDIAN NATIONAL COMMITTEE ON HYDROLOGY (INCOH)
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	7. Chief Engineer (Ground Water), Irrigation Department, Hyderabad.
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PREAMBLE

The Indian National Committee on Hydrology (INCOH) is an apex body under the Ministry of Water Resources (MoWR), Government of India entrusted with the responsibility of co-ordinating various activities concerning hydrology and water resources development in the country. The Committee has its members drawn from central and state government agencies as well as experts from academic and research organisations. INCOH provides technical support to MoWR in selecting the R&D schemes and studies for funding, publishing Hydrology Review Journal "Jal Vigyan Sameeksha" and supporting a number of activities including seminars, symposia, conferences, workshops, training courses, etc.. The Committee is effectively participating in the activities of International Hydrological Programme (IHP) of UNESCO by organizing regional courses and workshops and carrying out R&D work on various themes of IHP. In pursuance of its objective of preparing and updating the state-of-art in hydrology of the world in general and India in particular, the committee invites experts to prepare these reports on important areas in hydrology.

Of all the natural resources, water is unarguably the most essential and precious. India is mainly a tropical country but due to great altitudinal variations, almost all climatic conditions from hot deserts to cold deserts exists. The total annual rainfall widely varies from <100 mm (in Thar Desert) areas of Rajasthan to over 11000 mm in Cherrapunji / Mawsynram area of Meghalaya, in the north-eastern part of the country. The distribution of total land area of 329 million hectare of India under different climatic types are: Arid land, 51 million hectare; Semi-arid land 123 million hectare; Dry Sub-humid land 54 million hectare; Sub-humid land 61 million hectare. The complexity of the problem has further increased on account of possible impacts of global climate changes. Climate change has the potential to alter these patterns of water stresses. It is expected that some parts of the world will receive more river runoff (may be in the form of floods), while other parts will see a decrease in the availability of water resources. Since the capacity of the developing countries including India to cope with and adapt to the climate variability is limited, the climate change and its impact on water resources is going to be all the more important.

Realising the importance of effect of climate change on water resources, INCOH invited an expert for preparing a state-of-art report on the status of "Effect of climate change on water resources". The report has been prepared by Dr. K.S.Ramasastri, Former Scientist-F, National Institute of Hydrology, Roorkee. It is hoped that this state-of-art report would serve as a useful reference material to practicing engineers, researchers, field engineers, planners, stakeholders and implementing authorities, who are involved in the estimation and optimal utilization of water resources of the country.

25.01.06

(K.D.Sharma)
Executive Member INCOH &
Director, National Institute of Hydrology, Roorkee

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Chapter - I
Introduction

1.1 Climate and Climate Change

Climate is an observable statistical state of the earth–atmosphere system. Climate is ever-changing on all scales of time. Climate element is a hydrodynamic variable (velocity, vorticity) and also a thermodynamic variable (radiation, temperature, etc.). The World Climate Conference (WMO, 1979) defined climate as the synthesis of weather events over the whole of a period statistically long enough to establish its statistical ensemble properties (mean values, variances, probabilities of extreme events, etc.) and is largely independent of any instantaneous state.

Climate variability has two components: natural and forced. Natural (internal) variability arises as a result of the instabilities of the nonlinear system, and forced (external) variability arises due to the forcing from the slowly varying changes in the external parameters of the system.

Climate and society together constitute an interactive loop with the climate creating a significant impact on the society both in the short term and long term. At the same time, there is enough evidence to show that human actions in turn influence climate through the process of climate change. Climate, from geological epoch has been changing with time and it is reasonable to assume that it will certainly continue to do so in future also (Lamb, 1977). Evidences gathered from the past remains, preserved in the earth suggest that earth's climate has changed over time scale ranging from a few thousand years to million of years.

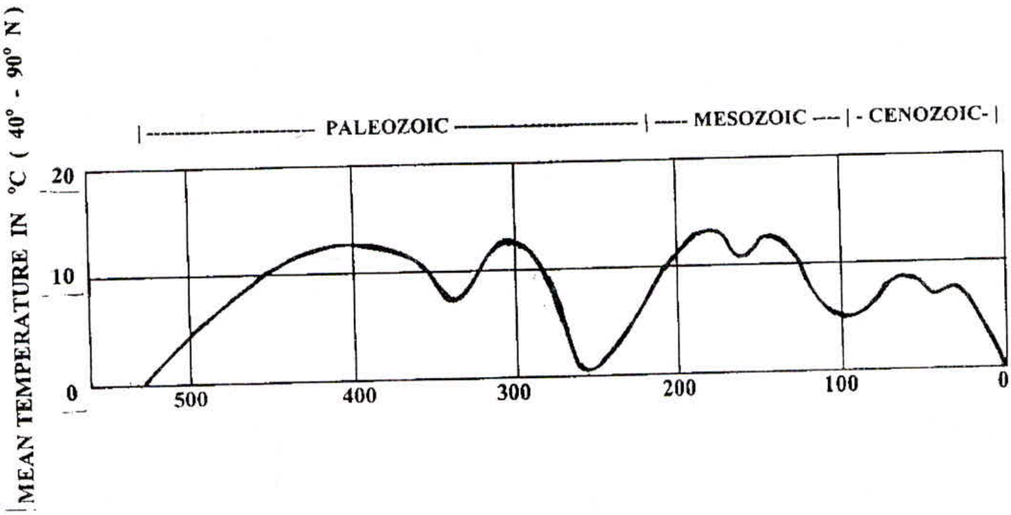

Figure 1 : Variation of temperature during geological time as estimated from fossils evidence. (from Brooks 1951)

The history of our global climate shows that climatic conditions that prevailed over last few hundred million years (figure 1) differed markedly from that of the present, with higher overall temperatures and also fewer differences in temperatures in the lower and higher latitudes (Morner and Karlen 1984).

A growing body of scientific opinion predicts a continued global climate change with regional imbalances during the 21st Century as a result of increasing concentration of green house gases in the atmosphere.

Climate change refers to a statistically significant variation in either the mean state of the climate or in its variability persisting for long periods generally over a few decades or more. Climate change may be due to natural internal processes or external causes. Persistent anthropogenic changes in the composition of the atmosphere due to changes in the composition of the atmosphere due to changes brought about by man by way of modernization, industrialization and land use changes could also cause climate change. Heat content of the world's oceans has increased since 1970, consistent with that expected from anthropogenic forcing, due mainly to increase of anthropogenic gases in the atmosphere.

Proxy evidence of climate change is available from changes in glacier size detected by lichenometry and carbon 14 dating, from tree ring series and from ice cores.

Climate change poses serious threat to every part of the world especially the developing countries which are trying to ensure food security to the people. Few developing countries have the necessary financial, technical and institutional capacities for efficient adaptation to climate change impacts.

An important aspect of climate change is that an increase in climate variability and occurrence of some extreme events is likely in the future. On the basis of outputs from several models it is expected that an increase in the atmospheric concentration of Green House Gases would result in changes in frequency, intensity and duration of extreme events such as more hot days, heat waves, heavy precipitation events and fewer cold days (Pachauri, 2005).

1.2 Climate Change and Water Availability

Water is a very precious natural resource and very difficult to manage. At present approximately 1.7 billion people, out of a population of around six billion, are living in countries experiencing water stress (defined as using more than 20 % of their average renewable resources). The U N Comprehensive Assessment of Freshwater Resources of the World estimates that by the year 2025, around five billion out of a total population of eight billion will be living in water stressed countries. The complexity of the problem has further increased on account of possible impacts of global climate changes. Climate change has the potential to alter these patterns of stress. It is expected that some parts of the world will receive more river runoff (may be in the form of floods), while other parts will see a decrease in availability of water resources. The precise effect of climate change, however, depends on the relative rate of change in resource availability vis-a-vis the increase in demand. In water stressed regions, even quite small, climatically driven changes in water supply capacity can have a significant influence on water resource systems that are already under pressure.

Since the capacity of the developing countries including India to cope with and adapt to the climate variability is limited, the climate change and its impact on water resources is going to be all the more important. Global warming is likely to bring significant stress on soil, water and crop productivity in developing countries. Some of the probable impacts that have been identified include changes in temperature and rainfall regime, agriculture yields, sea level rise, extreme weather events, melting of glaciers and changes in co system function.

1.3 Climate Change in Snow and Ice Covered Areas

The effects of global warming on the cryosphere in mountainous regions are most visibly manifested in the shrinkage of mountain glaciers and in the reduced snow concentration.

Simon Ratallack, leading expert on global warming and guest editor of the "The Ecologist" published from London suggested that "We have to start thinking on what could be done to prevent the impending disaster ahead." Dr Ratallack regretted that both Arctic and Antarctic ice caps are melting fast. Over the past 50 years 40 per cent of the arctic ice cap has melted. In Antarctica, the ice caps have shown large cracks and slowly, it is melting and breaking away from the main cap and floating as ice bergs. Due to melting of glaciers and polar ice, sea levels have swelled globally by an estimated 10 to 20 cm during the past century. It is expected that further melting of ice caps could result in the raise of sea level by as much as 6 meters. In such an event, the worst affected will be the developing countries like Bangladesh, India and Maldives.

According to latest reports of NASA, USA (September 2005) satellite photos have shown that the ice pack in Arctic has shrunk by 30 % since 1978 and the melting is speeding up. Scientists said Arctic may be caught in a "Vicious Cycle" of global warming. As ice melts, there is less white matter to reflect sun's heat back to space. The dark ocean absorbs more of sun's heat and that, in turn, would melt more of the ice pack.

Climate related disasters have brought widespread misery and huge economic losses to India, adversely affecting public health, food security, agriculture, water resources and bio-diversity. Climate change is a matter of grave concern for developing countries like India, which are highly vulnerable to its potential impacts. An understanding of the impact of global climate change on both the intensity and frequency of extreme events including heavy rainfall, floods and droughts is important for the efficient planning, development and management of the precious water resources of the country.

Climate information and skilful climate forecasts have the potential not only to help developing countries cope with climate fluctuations but also to assist in adapting to long term climate change.

Chapter - II
International Initiatives

2.1 The Earth Summit

Global warming has been perceived as a serious threat to the existence of mankind by the international communities. Several steps have been taken the world over to limit the threat of rapid change in global atmosphere and its associated consequences. In 1972, the United Nations Conference on the Human Environment (UNCHE) was held at Stockholm, Sweden.

The United Nations Conference on Environment and Development (UNCED) was held at Rio de Janeiro during 3-14 June 1992. This conference also called the 'Earth Summit' took place 20 years after the 1972 Stockholm declaration which first laid the foundation of contemporary environmental policy. As a high level forum with universal participation the main aim of UNCED was to show the way to a new global strategy for reconciling development needs with environmental protection. At this conference, the United Nations Framework Convention on Climate Change (UNFCCC), the first binding international legal instrument that deals directly with climate change was signed by representatives of 154 countries. By 19 June 1993 when the treaty was closed for signature, 164 countries had signed the treaty.

The ultimate objective of the convention (UNFCCC) is *Stabilization of green house gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner.*

The key results of UNCED were the Rio Declaration, Agenda 21, Forest principles, and two international conventions concerning climate change and bio diversity.

2.2 Inter Governmental Panel on Climate Change (IPCC)

The Intergovernmental Panel on Climate Change (IPCC) headquartered in Washington D.C., USA was established by the United Nations Environment Programme (UNEP) in November 1988 to assess the scientific, technical and socio economic information relevant to the understanding of the risk of human induced climate change. IPCC bases its assessment mainly on peer-reviewed and published scientific/ technical literature. IPCC has published three assessment reports (1990, 1995 and 2001).

The IPCC estimated that during the 20th century the average surface temperature of the earth went up by 0.6^{o} C with accelerated warming in the last 10 to 15 years. IPCC in 1990 predicted that in the future the average global surface temperature may rise by 0.2 to 0. 5^{o} C per decade if human activities, which cause greenhouse gases emissions continue unabated. It is expected that by the end of 21st century, temperatures would go up by any where between 1.4° C and 5.8° C. Inventory of climate change predictions made with regional climate models is available with the IPCC's Data Distribution Centre (ipcc - ddc. cru. uea. ac.uk)

IPCC points out that, developing economies rely more heavily on climate sensitive sectors like agriculture, which operate close to environmental and climatic tolerance levels. The increase in temperatures would have impacts on agriculture, increase in vector borne diseases, erosion of coastal areas, threats to existing eco systems and bio diversity.

The importance of the issue of impacts of climate change on water resources has been very well brought out by the Third Assessment Report of the IPCC (2001) as follows:

"Climate change will lead to an intensification of the global hydrological cycle and can have major impacts on regional water resources, affecting both ground and surface water supply for domestic and industrial uses, irrigation, hydropower generation, navigation, in stream ecosystems and water based recreation. Changes in the total amount of precipitation and its frequency and intensity directly affect the magnitude and timing of runoff and the intensity of floods and droughts, however, at present, specific regional effects are uncertain"

"The impacts of climate change will depend on the base line condition of the water supply system and the ability of water resources managers to respond not only to climate change but also to population growth and change in demands, technology, and economic, social and legislative conditions. In some cases – particularly in wealthier countries with integrated water management systems – improved management may protect water users from climate change at minimal cost; in many others, however, there could be substantial economic, social and environmental costs, particularly in regions that already are water stressed and where there is considerable competition among users."

2.3 Kyoto Protocol

The global community is addressing this challenge through multilateral and cooperative approach. The United Nations Framework Convention on Climate Change (UNFCCC) was adopted at the Rio Earth Summit in 1992.

More than 180 countries had signed the United Nations Framework Convention on Climate Change at Kyoto, Japan in 1997. The Kyoto accord mandates emission reductions for the developed world and establishes a flexible emissions trading market to enable them to meet their targets. The Kyoto protocol provides for legally binding commitment by the developed countries to reduce their emissions of six green house gases by at least 5.2 % compared to 1990 levels by the period 2008 – 2012. The protocol also establishes joint implementation, an emission trading regime and a 'Clear Development Mechanism'. The Kyoto protocol is the only international instrument available to check the emission of the Green House Gases (GHG) which causes global warming resulting in intense precipitation in some areas and lesser precipitation in some areas leading to extreme floods and droughts. As per the protocol, the developed countries had decided that they would reduce the emissions of GHGs to 5.2 percent below the 1990 levels by 2008 to 2012.

At the convention held in Bonn, Germany in 2001 the signatories to the Kyoto protocol had arrived at an agreement on how to operationalise the protocol. Other than the USA all the countries who were signatories to the Kyoto protocol had agreed on how to achieve the reduction of GHGs. A greater efficiency in the burning of fossil fuels would, it is estimated, reduce emissions by less than 2 per cent while the rest of the 5.2 per cent reduction by the year 2012 is to be brought out by the use of other indirect approaches. This, however, means that the developed countries can continue to be less careful about burning of fossil fuels. A definite achievement of the Bonn agreement was the framing of rules for punishment of countries which do not meet their targets by 2012.

India has demonstrated its deep and continuing commitment to global efforts to address climate change by acceding to the Kyoto protocol to the UNFCCC and hosting the eighth session of the Conference of Parties to the UNFCCC at New Delhi.

At the Eighth conference of parties to the United Nations Framework Convention on Climate Change held during 23 October-1 November 2002 at New Delhi, environmental ministers and delegates from Canada, Japan, Russia, and Europe announced their intent to bring Kyoto protocol on climate change into force by the year 2003. While this was a step in the right direction, progress was also achieved on technical issues such as the Clean Development Mechanism (CDM). Countries of the European Union have been adhering to the guidelines of Kyoto protocol and many (excluding the former East European bloc) have achieved emissions reduction largely through public awareness, industrial incentives and fines, and alternative energy resourcing. (Times of India, 2005)

According to Pier Vellinga (2001) " even if the Kyoto agreement and further emission reductions were to succeed a major part of the climate change predicted for the next 50 to 100 years would still be unavoidable. The effects of climate change are already making themselves felt and we must be prepared to adjust to them"

2.4 US Asia- Pacific Partnership on CDM

In July 2005, a climate agreement has been reached between USA, Australia, China, South Korea and India all non signatories to the Kyoto protocol. The USA and Australia are the world's biggest polluters while the rest emit much lower volumes of green house gases (GHG). The European Union has reacted to the new climate Asia-Pacific agreement by threatening to push for legally binding global restrictions on GHG emissions (Times of India, 2005)

Chapter - III
Green House Gases and Global Warming

3.1 Radiation Balance

The radiant energy from the sun reaching the earth's surface is partly reflected to the space and partly absorbed at the surface. The amount of absorbed radiation undergoes several energy transformations but a part is emitted back to space as terrestrial radiation. While the atmosphere is transparent to the solar (short wave) radiation it is opaque to the terrestrial (long wave) radiation. In the radiation balance at the surface, the net radiation is partly utilized to drive the evaporative process, in modifying the ground temperature and sensible (turbulent) heat flux. Both carbon dioxide and water vapour absorb long wave radiation. The green house gases affect the climate by changing the amount of out going infra red radiation i.e. they change equilibrium state of the earth's atmosphere radiative energy by exerting a radiative forcing. The radiative forcing in turn is dependant on the concentrations of the green house gases in the atmosphere

3.2 Green House Gases

In the last few decades the changing climate is referred to as the increase in the global mean surface temperature. In the Kyoto protocol six gases were identified whose cumulative emissions are leading to climate change. The Green House Gases (GHG) such as carbon dioxide an inherent product of fossil fuel (oil, coal and gas) use, methane, nitrous oxide and Chloro Fluoro Carbons are seen as major contributors to the increase of global mean surface temperature. Of these carbon dioxide is a major source. The GHGs in the atmosphere increase the global temperature due to the transmission of the incoming short wave radiations and absorption of the out going long wave radiation (Figure 2).

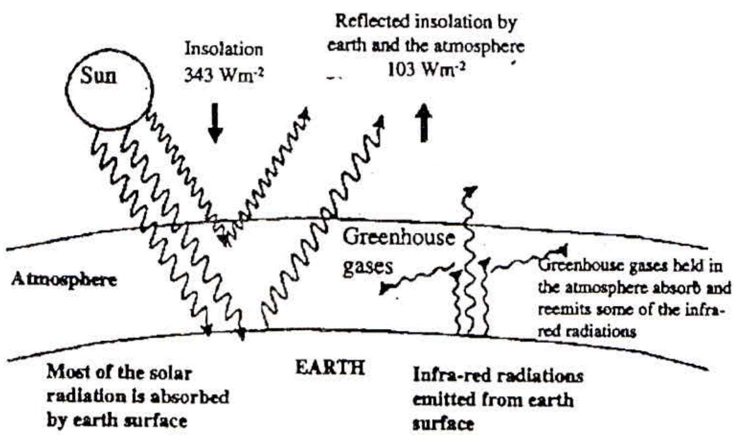

Figure 2 : Global warming by green house gases – A schematic representation

The emission of GHGs to the atmosphere has become a matter of great concern because of the future projections of global warming and climate change. Spreading of oil companies, increase in mining activities, and emissions from vehicles are adding to global warming. Cutting down of forests and poor agricultural practices are also known to contribute to the increase in GHG emission. Deforestation is a major anthropogenic climate forcing agent, next only to fossil fuel related emissions.

The absorption of radiant energy due to carbon dioxide is matter of concern as the carbon dioxide concentration in the atmosphere is steadily increasing due to the burning of fossil fuels and other man's activities. Carbon dioxide currently accounts for about 60 % of the net radiative forcing and has a strong potential to affect current and future climate. Over the last 150 years the amount of carbon in the atmosphere has increased by 30 %. Extensive studies carried out all over the world during the past three decades have indicated towards global warming and possible climate changes due to increased concentrations of carbon dioxide and some radioactive trace gases in the atmosphere.

Using General Circulation Models (GCMs), it has been predicted that the doubling of the current Carbon Dioxide CO_2 level in the atmosphere will cause an increase of 1.5 to 4.0 $^{\circ}$ C in average global surface air temperature with accompanying changes (Adams et al. 1995). A similar increase has been predicted for the Indian sub continent also (Sinha and Swaminathan, 1991)

Aviation also contributes to GHG emission and climate change (Times of India, October 2005)

- Booming aviation growth is fast emerging as one of the biggest sources of GHG
- Aviation emission at high altitudes contains up to 70 % carbon dioxide
- Gases and particles emitted by aircraft alter concentration of GHG, trigger formation of condensation trails and increase cirrus cloudiness, which cause climate change
- Between 1990 and 2003, GHG emissions from aviation in countries of European Union grew by 73 %. At this rate, it is expected to hit 150 % of the 1990 level by 2012.

3.3 GHG Emissions from Agriculture

Agriculture is not only affected by climate change but also contributes to the problem. Agricultural soils contribute substantially to the green house effect, primarily through the emission and consumption of these gases. Rice cultivation and remnant livestock, emit methane when they do not ferment efficiently. Methane is considered to be a GHG with larger warming potential than even CO_2. However, agriculture can also help in Carbon sequestration and providing farm alternatives like bio diesel to reduce consumption of fossil fuels.

Soil contributes significantly towards Nitrous oxide emission to the atmosphere. Both fertilized and un-fertilized soils emit Nitrous oxide. N_2O which is present in the atmosphere at very low concentration, assumes greater importance because of its longer life time and greater global warming potential than CO_2 (Table 1 and figure3).

Table 1: Concentration of Green House Gases in the atmosphere

	CO_2	CH_4	N_2O
Average concentration 100yrs ago (ppbV)	290, 000	900	285
Current concentration (ppbV)	356, 000	1,700	310
Projected concentration In the year 2030 (ppbV)	400, 000 to 500, 000	2200 to 2500	330 to 350

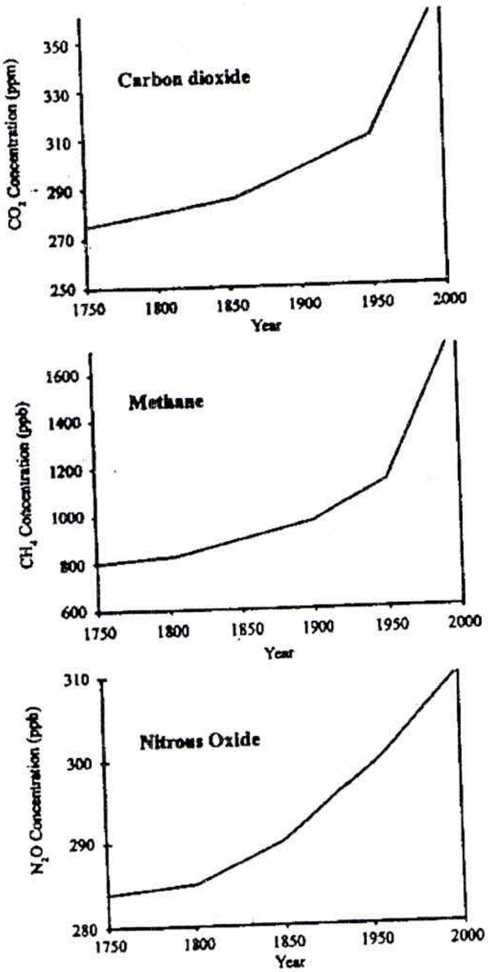

Figure 3: Rise in the concentration of green house gases in the atmosphere

3.4 Contribution of Trace Gases

Dr James Hansen and Dr Makiko Sato of NASA's Goddard Institute of Space studies at the Earth Institute at Columbia University suggested that avoidance of large climate change requires the global community to consider aggressive reductions in the emissions of both carbon dioxide and non- carbon dioxide gases called trace gases such as methane, the trace gas HFC-134a, ozone and the precursor gases that form ozone. (Science Daily, 23rd November 2004). It was mentioned that the reduction of trace gases may allow stabilization of climate so that additional global warming would be less than 1° C, a level needed to maintain global coastlines. Although Carbon Dioxide emissions must also be slowed, the required Carbon Dioxide reduction is much more feasible if trace gases decrease. Hansen and Sato warn that the trace gases also influence the rate at which major atmospheric GHG are sequestered, a primary strategy for curbing global warming from Carbon Dioxide emissions. As global warming continues the Earth naturally releases CO_2, CH_4 and N_2O. Therefore, another benefit of reducing trace gases and their warming effect is a reduction of the induced 'natural' releases of these gases.

3.5 Effect on Ozone Layer

Most of the ozone in the atmosphere, the so called 'ozone layer' is in the lower stratosphere, at an altitude of about 20 – 25 km above sea level. It acts as a shield by absorbing high energy ultraviolet light from the sun. Nitrous Oxide besides causing global warming, is responsible for the destruction of stratospheric ozone and also hinders the ozone forming 'Chapman reaction' in the stratosphere.

It has been found that radiative forcing due to tropospheric ozone increases as a result of biomass burning aerosols. However, geographical extent of increases in tropospheric ozone is considerably larger than that of aerosols.

3.6 Effect of Aerosols

It has also been suggested that aerosols produced by tropical biomass burning could lead to additional negative radiative forcing. It is well known that the dust and aerosol content in the atmosphere significantly controls the cloud formation. In tropical countries, this is all the more important be because clouds have a negative feedback on atmospheric radiation budget.

Galloway and Meillo (1998) suggest the following changes in Asia for 2030 – 2050 due to GHGs and aerosols.

Table 2 : Changes Due to Green House Gases and Aerosols

Conditions	Temperature °C		Precipitation mm/day		Soil moisture (cm)	
	Dec-Feb	Jun-Aug	Dec-Feb	Jun-Aug	Dec-Feb	Jun-Aug
Green House Gases Only	3. 7	3. 5	0. 2	0. 3	0. 4	- 0. 6
Green House Gases and Aerosols	1. 7	2. 8	0. 0	0. 6	0. 2	- 1. 4

3.7 GHG Emissions in India

The emission of CO_2 (as in 1990) from coal, petroleum products and natural gas were estimated at 328.4 Tg/yr, 162.7 Tg/yr and 17.5 Tg/yr respectively. In the last few years industrial growth and increasing urbanization in India have led to associated environmental changes. A variety of industrial processes, which transform materials by physical or chemical processes, are responsible for emissions of various GHG like CO_2, CH_4 and N_2O.

According to Dr J S Samra of the Indian Council of Agricultural Research, about 35 % of Indian Green House Gases emissions are from Agriculture. The results of the western world concluded that paddy cultivation in Asia emits large amount of methane. Systematic studies done in India had helped in changing this myth. India's total contribution to global methane from all sources is only 18.5 Tg/yr which is 3.5 % of total global methane emission (Garg and Shukla, 2002)

3.8 Measures to Mitigate GHG Emissions

Alarmed by the possible impact of the global climate change on the quality of life of human beings, efforts are being made all over the world to develop strategies to mitigate its negative effects.

The full range of stabilization scenarios might extend from 350 ppm to 1000 ppm. While from the perspective of minimizing ecological risks for sensitive ecosystems, a 350 ppm scenario may be desirable, the socio-economic and political feasibility of such a scenario is generally considered to be extremely low and at the other end of the spectrum stabilization at 1000 ppm would probably not avoid serious negative impacts during this century. Consequently, the range of stabilization experiments that could be considered, probably, embrace 450, 550, 650 and 750 ppm.

Primary strategies to mitigate climate change effect are reduction of GHGs and carbon sequestration in oceans and terrestrial systems. Reduction in carbon dioxide emission can be achieved by source and sink improvement. One of the methods recommended to reduce atmospheric CO_2 is to increase the global storage of carbon by taking CO_2 from the atmosphere via photosynthesis and sequestering it in different components of terrestrial, oceanic and fresh water aquatic eco-systems. Carbon sequestration is defined as the capture and secure storage of carbon that would otherwise be emitted to or remains in the atmosphere (FAO, 2000). However, reduction of emission from fossil fuels is definitely superior to sequestration of carbon, because apart from mitigating the climate change it also has health benefits. Maximum rate of global warming can be restricted by restraining fossil fuel emission rates during the present century. Research is, therefore, being actively pursued to produce automobiles which can use Hydrogen so that the emissions from the cars would be water vapour rather than CO_2 and other gases.

There are no significant sinks or uptake mechanisms of nitrous oxide in soil systems. Therefore, the mitigation should focus entirely on emission reduction. Appropriate crop management practices which lead to increased Nitrogen use efficiency and high yield hold key for mitigating nitrous oxide emission.

One of the most promising strategies for mitigating methane emission from rice cultivation is altering water management. Also land management systems need to be changed so as to reduce methane and nitrous oxide emissions from soil.

Chapter - IV
Impacts of Climate Change

4.1 Impacts of Climate Change Globally

Climate change is likely to have a significant impact on the global environment. Climatic zones and thus ecosystems could shift towards the poles. Forests, deserts, rangelands, and other unmanaged ecosystems would face new climatic stresses. Climate change has serious implications for food security through direct and indirect effects on crops, live stock, fisheries and pests.

The projected adverse impacts based on models and other studies include (IPCC, 2001):

- A general reduction in potential crop yields in most tropical and sub tropical regions for most projected increase in temperature
- A general reduction, with some variation, in potential crop yields in most regions in mid-latitudes for increase in average annual temperature more than a few degrees
- Decreased water availability for populations in many water scarce regions, particularly in the sub-tropics
- A wide spread increase in the risk of flooding for many human settlements from both increased heavy precipitation events and sea level rise
- Increased energy demand for commercial and domestic cooling due to higher temperatures

The projected beneficial impacts include:

- Increased potential crop yields in some regions in mid-latitudes for increase in average annual temperature less than a few degrees
- A potential increase in global timber supply from appropriately managed forests
- Increased water availability for populations in some water scarce regions like some parts of Southeast Asia.
- Reduced energy demand for commercial and domestic heating due to higher winter temperatures

A number of studies showed that different climate and environmental changes during the past 100 years over various regions in the world were experienced. Across the world, global warming is causing all manner of freak climatic phenomenon. Scientists have reported that the spring is now coming a week earlier in the northern hemisphere, the tree line in the northernmost forests of the world are moving towards the pole and the level of the atmosphere at which the temperature reaches 0° C has been rising by five metres annually. Diaz and Graham (1996) reported a rise of 100 – 150 m in the altitude of the freezing level in the atmosphere over the inner tropics (10° N – 10° S) between 1970 and 1986. This was said to be correlated with a warming in the sea surface over the eastern tropical pacific.

The more significant are the El- Nino effect in which the warming of ocean currents has led to the decline of certain aquatic species. The frequency and intensity of El-Nino southern oscillation (ENSO) have been unusual since the mid 1970s as compared to those of previous 100 years. The warm phase of ENSO has become relatively more frequent, persistent and intense than the cool phase (La Nina) and this has been linked with the likelihood of intense precipitation and floods in some areas.

A number of studies have demonstrated the relationship between stream flows and the occurrence of El Nino and La Nina episodes (Pichota and Dracup 1996 ; Chew et.al, 1998). Mosley (2000) studied the effects of El Nino and La Nina on the low flows and floods in 18 rivers in New Zealand .

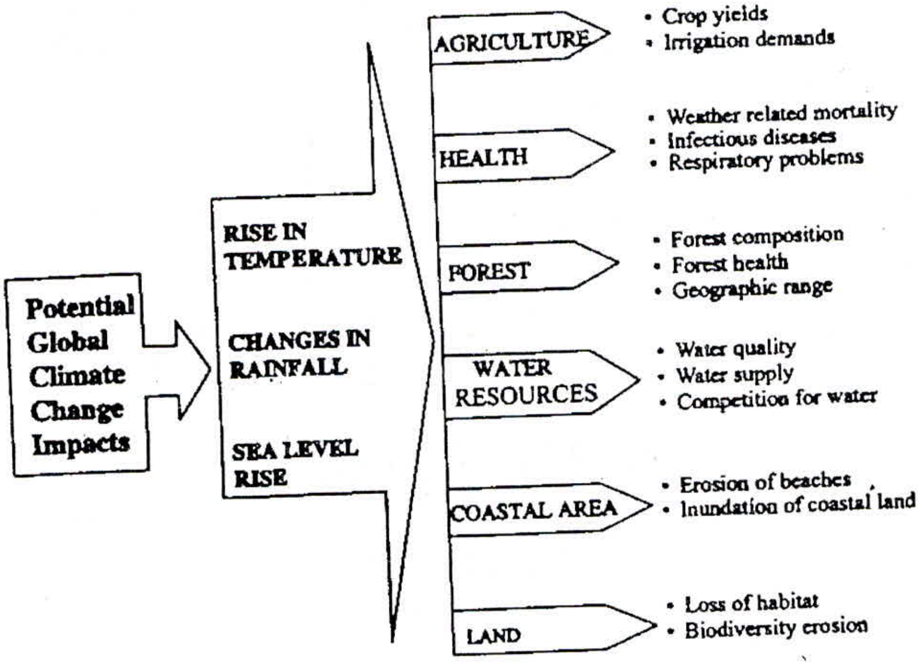

Figure 4: Possible impacts of climate change

It is well established that the atmosphere's capacity to absorb moisture, and thus the potential for intensive precipitation increases with temperature. Instrumental records of land surface precipitation show an increase of 0.5 to 1 per cent per decade over much of the mid and high latitudes of the northern hemisphere (IPCC, 2001a), particularly pronounced in autumn and winter (IPCC, 2001b) i.e. seasons when catchments capacity to store water is limited (Table 3).

Table 3: Sample of observed changes in Intense Precipitation (after IPCC,2001 a)

Location	Time Period	Observation
Globally	1961-1990	A 4 % increase in the annual maximum five day precipitation total
Mid and high latitudes of the Northern Hemisphere	Latter half of the twentieth Century	A 2 to 4 % increase in the frequency of heavy precipitation
Many regions of Australia	1910 – 1995	A 10 to 45 % increase in heavy rain fall as defined by the 99th percentile of daily precipitation totals
Siberia	Summer season 1936-1994	Increase in the frequency of heavy rainfall (>25 mm) of 1.9 % per decade

Global mean temperature has risen by over 0.6° C during the 20th Century with accelerated warming after 1990 (Figure 5). Adverse impacts on flood hazard related to climate variability have been observed. IPCC (2001) had predicted that the area averaged annual mean warming by 2020 is expected to be between 1.0 and 1.4 °C and between 2.23 to 2.87 for 2050. The IPCC in 2002 reported that the earth warmed by between 0.3 and 0.6 ° C in the past century. IPCC then predicted that the global temperature will most likely rise between 1.0 to 3.5 °C by the year 2100. Sea levels could rise between 15 and 95 cm by 2100.

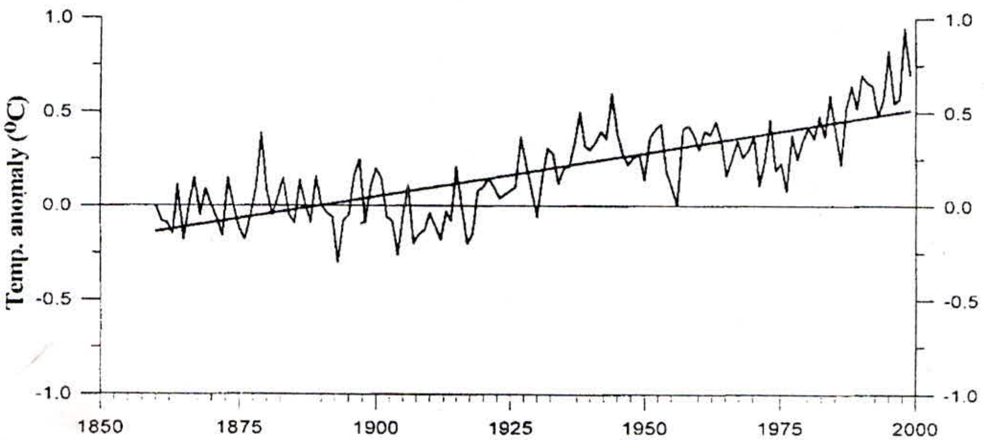

Figure 5 : Observed rise in global mean temperature since 1860 (IPCC,2001)

Diaz and Bradley (1997) presented changes in zonally averaged temperatures for 1951- 1989 between 30 ° N and 70 ° N, versus elevation. Mean maximum temperatures increased slightly between 500 and 1500 m, with minor changes at higher elevations, while minimum temperatures rose by about 0.2 ° C/decade at elevations from 500 m to above 2500

m. In the tropical Andes, mean annual temperature trends have been determined for 268 stations between 1 ° N and 23 ° S, for 1939 – 1998 (Vuille and Bradley, 2000). They found an overall warming of about 0.1 ° C /decade.

According to a regional simulation done with a doubled CO_2 concentration forcing using a Regional Circulation Model, projections of the global warming in the Alps could lead to a seasonally dependent temperature rise of 1.4 to 3.9 ° C at the screen level (Rotach et al, 1997).

Under the aegis of the Intergovernmental Panel on Climate Change (IPCC) some 700 scientists from different countries carried out a research project "Climate Change 2001: Impacts, adaptation and vulnerability". The summary of the research was released as a report by the United Nations on 19th February 2001. According to the report, the melting ice caps in the polar regions unleash climate changes which are expected to continue for centuries. The poor countries would bear the brunt of devastating changes as a result of global warming. The report cautions that the rich countries also would not be immune to the climate changes, with Florida and parts of the American Atlantic coast likely to be lashed by storms and rising sea levels.

Global warming is likely to bring significant stress on soil, water and crop productivity in developing countries. In the event of global warming one of the major impacts would be significant alteration in the regional hydrologic cycle and changes in regional water availability, specially, the timing of magnitude and surface runoff (Gleick, 1986 and 1989).

Globally, rising temperatures have been wiping out many species of flora and fauna. One of the most devastating side effects of global warming has been the increase of communicable diseases.

4.1.1 Impact on water resources

It is possible to identify a logical framework for studying the water related impacts of climate change

Climate Change

↓

Hydrological Processes

↓

Water Resources Systems

↓

Society

When considering the future scenarios of demands on water by various sectors, it also becomes essential to know with certain degree of reliability the future trends in availability of water considering the possible effects of climate change.

Model studies suggest and observational evidence tends to confirm that an enhanced hydrological cycle is an important change associated with potential "greenhouse gas warming". Past progress in global science now motivates that, at catchment and regional scales, the hydrological variables are influenced by observable, global scale hydro-meteorological fluctuations and may be changing because of modification brought about by green house gases.

In the event of global warming one of the major impacts would be significant alteration in the regional hydrologic cycle and changes in regional water availability, specially, the timing of magnitude and surface runoff. Gleick (1986 and 1989) had reviewed different approaches for evaluating impacts of global climatic changes on the regional hydrology. The results of some of the early studies are given in Table 4.

Table 4 Effects of climatic changes on runoff : some early results

Region	Climatic change	% Change	Author
Average for seven Western U S Regions	+ 2 °C temp and – 10 % precip	- 40 to - 76	Stockton and Boggess (1979)
Arid basin	+ 1 °C temp and + 10 % precip	+ 50	Nemec and Schake (1982)
Arid basin	+ 1 °C temp and - 10 % precip	- 50	Nemec and Schake (1982)
Humid basin	+ 1 °C temp and + 10 % precip	+ 25	Nemec and Schake (1982)
Humid basin	+ 1 °C temp and - 10 % precip	- 25	Nemec and Schake (1982)
Colorado river basin	+ 2 °C temp and + 10 % precip	- 18	Revelle and Waggoner (1983)
Colorado river basin	+ 2 °C temp and - 10 % precip	- 40	Revelle and Waggoner (1983)
Great basin	+ 2 °C temp and - 10 % precip	- 17 to – 38	Flaschka(1984)
Central U S A	Double CO_2	- 26	U.S.A. E P A(1984)
Northwest U S A	Double CO_2	+ 20 to + 60	U.S.A. E P A(1984)

Note : Each assessment uses different method. Direct comparison, therefore, not possible.

Due to climate change there are likely to be significant changes in seasonal rainfall patterns and other factors controlling stream flow. The possible impacts of climate change on the hydrological regime include: increase in summer evaporation, more rain storms caused by increased convective precipitation in summer months, increased intensity of tropical storms and increased monsoon rainfall in the tropics. The rate and timing of snow melt is likely to change. (IPCC, 1990)

Zhang et al (2001) assessed the joint impacts of tropical deforestation and green house warming by using NCAR community climate model (CCMI-Oz). The results have shown that climate changes over tropical rainforest regions comprise large reductions in surface evapotranpiration (by about 180 mm/yr) and precipitation reduction (by about 312 mm/yr) over the Amazon basin along with an increase of surface temperature by 3.0° C. Over south east Asia, precipitation decreases by 172 mm/yr, together with surface warming by 2.1° C.

Climate change is likely to affect water supply, quality and demand and may have ramifications for decision makers. Water demand generally increases with time as population and per capita consumption increases. Water availability, on the other hand has been considered relatively constant. The effect of change in climate on water resources would be to increase the uncertainty in the area where the curves of water supply vs time and water demand vs time intersect. (figure 6)

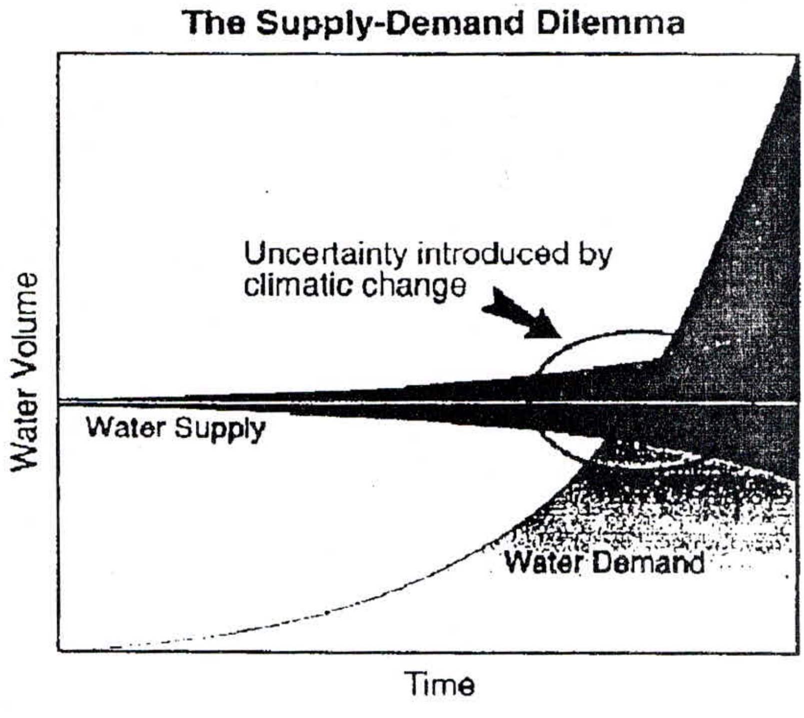

Figure 6 : The water supply and water demand dilemma

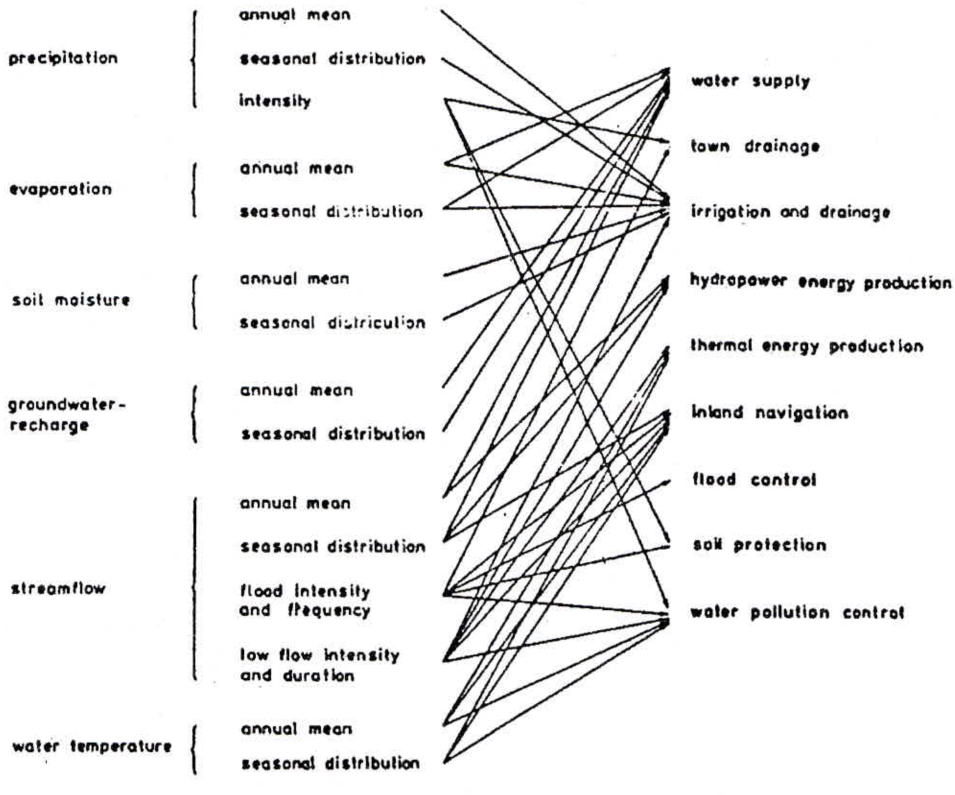

Figure 7: Impacts of climate change through the hydrological cycle on water resources management

Climate change may either increase or decrease water availability through precipitation, temperature, cloudiness and humidity, increasing the level of uncertainty. This can also result in increased recurrence of hydrologic hazards such as floods and droughts.

The frequency of droughts and floods is also largely influenced by climatic changes as a result of increased concentration of the atmospheric green house gasses such as CO_2, methane and nitrous oxide. Impact assessment of future climatic changes is, therefore, very important.

In recent decades, losses due to floods have shown a rapid growth world wide which can be linked to socio-economic, hydrological and climatic factors. The links between sensible rise in flood risk and climate variability and change have been examined in the Third Assessment Report of the IPCC (2001a, b) where floods are identified as one of the key regional concerns.

Climate related changes in flood frequency are complex, depending on the flood generating mechanism. Flood magnitudes typically increase with warming if high flows result from heavy rainfall and decrease where they are generated by spring snowmelt (IPCC, 2001a). The intra regional variability induced by climate change together with inter- regional heterogeneities due to spatial non homogeneity make the picture more complicated.

Groundwater systems tend to respond much more slowly to short term variability in climate conditions than do surface water systems. Climate change could, therefore, affect groundwater sustainability.

4.1.2 Snow and glaciers

The effect of global warming is being felt all over. Climate change also threatens the high mountain ranges. People in the mountains are not only most vulnerable but are also likely to suffer the most from the unknown and uncertain consequences of the possible impacts of climate change. Scientists suspect enhanced melting is among the first observable signs of human induced global warming, caused by unprecedented release of carbon dioxide and GHGs over the past century. It is expected that climate warming during 21st century will adversely affect glaciation. The Alps have lost 50 percent of the glaciers and even Kilimanjaro has been affected, although the effect on it has been the least. The reaction of river hydrographs follows the same principles in the Alps and in Central Asia, as the general mechanism of seasonal and long term water storage and release are similar on every glacier.

Glaciers are influenced by climatic changes in a given terrain. Any change of climate disturbs equilibrium between accumulation and melting of glacier mass and causes changes in the size and shape of glacier resulting in changes in water yield from the glacier. The rising temperatures help thawing of glaciers resulting in the reduction of glaciated area and increase in the glacier melt component of runoff. Studies have also indicated that the mountain glaciers are known to respond to climatic changes more quickly than the polar glaciers.

Under current glaciation, discharge begins earlier in the year and rises towards summer, increasing the flood risk. If the glacierised area is reduced by 50 % snow melt begins one month earlier and is more intense, but the summer peaks are mostly reduced. The complete disappearance of glaciers yields a water shortage in summer. Under these conditions, the river hydrograph is controlled by groundwater and rainfall events only and water yield would drop down during dry periods.

Scientists say that the melting of snow and ice could cause flooding of glacial lakes. These lakes can burst through their moraine banks and cause widespread devastation. In Nepal, a glacial lake burst in 1985 sending a 15 metre wall of water rushing down the mountain, drowning people and destroying houses.

4.1.3 Sea level rise

Global warming can cause the accelerated melting of not only the mountain glaciers but also the polar ice caps leading to rise in sea level. In addition the thermal expansion of oceans and changes in the ocean currents can lead to rise in sea level and changes in global climate.

The rise in sea level resulting from potential global warming will bring about important hydrological, environmental and ecological changes in the coastal regions. The penetration of heat energy into the ocean occurs in the following four sages.

1. Direct absorption of solar radiation in the first few meters of depth from the sea surface
2. advection of the heat energy in the mixed layer due to wind churning and horizontal currents
3. Penetration of heat energy below mixed layer up to thermocline governed by the diffusion equation
4. Heat balance of layers below the thermocline due to the combined effect of diffusion, upwelling/down welling and deep ocean currents

Study by Vyas et al (1995) indicated that the thermal expansion could contribute approximately up to 1 metre sea level rise. The IPCC projected sea levels to rise between the years 1990 and 2100 at between 9 cm and 88 cm. Other estimates put the sea level rise by 2100 at 20 to 110 cm. Sea level rise would create further risks from surges due to tropical storms or tsunamis, for populations that inhabit small islands or low lying coastal areas.

4.1.4 Impacts on Soil

Changes in the soil brought by climate change will affect agriculture. Soil characteristics may change due to water logging and cracking. The soil moisture capacity and properties may change. Changes brought about in factors such as precipitation, evaporation and runoff may affect the soil moisture.

4.2 Impacts of Climate Change in Central Asian Region

Hydrological processes and changes in mountainous areas have a greater importance in drier parts of the continents such as Central Asia, because here highlands are not only additional water suppliers like in middle Europe but also, the most important and some times the only source of water.

For basins in Central Asia, the Goddard Institute for Space Studies (GISS) model predicted a rise of annual temperature by 4.2° C and a change of annual precipitation by a factor of 1.17 under the assumption of doubling of CO_2 which is expected between the years 2050 and 2075. The studies were carried out for the Tuyuksu region by the Kazakhstan Climate Change Study (KazNIIMOSK, 1999)

4.2.1 China

Climate change and intensified human activity in China have induced certain environmental changes such as the change in frequency of dust storms in northern China, no flows in the lower reaches of the Yellow river and the variation of river runoff in the northwest China (Qian and Zhu, 2001). It was reported that during the period 1880 to 1998, the Yangtze river experienced frequent flooding.

Shi et al (2003) made an assessment of climatic variations and a short period prediction for northwest China. It was reported that under global warming, climate changes of western and eastern parts of northwest China exhibited different variations of temperature and precipitation. In the middle and eastern parts of NW China, the air temperature was said to be rising while the precipitation was decreasing. In the western parts of NW China, the climate is generally dominated by warm-dry conditions. But since 1987, a climate shift from warm-dry to warm-wet was said to be happening. The average air temperature during 1987 to 2000 had risen by 0.7 °C as compared with that during 1961 to 1986.

Along with rise in air temperature, precipitation and glacial melt also have increased. Average annual precipitation during 1987 to 2000 increased by 22 % in north Xinjiang, 33 % in south Xinjiang, 12 % in the Tianshan mountains and 10 to 20 % in the Qilian mountains. Average annual melt water from glacier no.1 at the source of Urumqi river in Xinjiang has increased by 84.2 % during 1986 to 2001 as compared to that during 1958 to 1985.

Most rivers in Xinjian as well as rivers in the middle and west Qilian mountains of Gansu province and southeast Qaidam basin of Qinghai province have experienced increase in annual runoff by 5 to 20 % since 1987.

4.2.2 Kyrgyzstan

According to analysis of meteorological data, temperatures of April – September in Kyrgyzstan have shown a rising trend in the last few decades.(Mamatkanov, 2005). Studies on the annual temperature trends during 1972 – 2001 showed a rising trend of 0.05 °C per year. Investigation of the annual precipitation trends in Kyrgyzstan revealed their rise at almost all the 21 stations, data of which have been considered for the analysis. In general, precipitation rise was observed in summer months with maximum in July.

The institute of water problems and hydropower of National Academy of Science in the Kyrgyz Republic has conducted investigations of modern day climatic variations and their influence on river flow, glaciation dynamics and water balance of the Issik – Kul lake.

Kara-Batkak glacier on the northern slopes of Terskey Ala – Too range had an average decrease of 18 m during the period 1957 to 2000. Ak – Shyirac glacier system lost snow and ice mass resulting in loss of 8.3 m length of glacier. It has been estimated that a 2 °C rise will result in the reduction of glaciated area of Kungey Ala-Too by 76.5 %, and glaciated area on northern slope of Terskey Ala-Too will reduce by 32 %.

4.2.3 Tajikistan

Normatov (2005) reported on the effect of climate change on temperature and precipitation in Tajikistan. For the period of observation of more than 70 years, a regular rising trend of average annual and average monthly air temperatures was detected. Average annual temperature increased upto 0.73 °C in the alpine mountains.

The rise in temperature was more in winer months than in the summer. The maximum increase of 7.3 °C in 100 years has taken place in winter at Dushanbe followed by 5.4 °C in 100 years at Kurgan – Tube. In the Alpine mountains, the rise was smaller in summer. But in winter, it was 2.8 °C in 100 years.

Precipitation has increased more in mountains, than in the valleys. For the century period, the annual amount of precipitation has increased by 1.6 % in southern valleys and upto 10 – 14 % in middle mountains. These changes were said to be of the same order as those observed at similar latitudes in other parts of the world.

In Tajikistan, negative mass balance and change in size was observed for many glaciers of Pamir- Alay. It was expected that the changes can alter flows of river Amudarya and inflows into Aral sea. Satellite pictures of snout of Zarafshan glacier have shown that the glacier has degraded rapidly. It was reported that during the period 1908 to 1986, the glacier has receded by almost 1 km. Investigations conducted on Abramov glacier from 1850 to 1984 have shown that its lower boundary has gone upwards by 80 m and the volume of ice has decreased by 630 million cubic metres. It is felt that such climatic changes can result in relocation and change of glaciation in Pamir.

4.3 Possible Impacts of Climate Change in India

Climate change poses serious threat to every part of the world especially the developing countries which are trying to ensure food security to the people. South Asian countries including India will be particularly vulnerable to climate change impacts. The impacts of climate change on the tropical Asian region are expected to be significant. Since the capacity of the developing countries including India to cope with and adapt to the climate variability is limited, the climate change and its impact on water resources is going to be all the more important. This problem will be further compounded as water resources in the tropical regions are vulnerable to increasing demand resulting from population growth, urbanization, industrialization and agriculture.

India signed the UNFCCC in 1993 and initiated concerted efforts on several fronts with the relevant obligations under the UNFCCC, including the submission of initial national communication. In order to fulfill the requirements of the UNFCCC, the Indian government, through its various institutions and resources, has strengthened its researches on the

(i) science of climate system and climate change
(ii) impact of social and economic development and
(iii) response strategies

The topographic and geographic location of India, which influences the climate of the region, not only have a great variety of natural resources, including surface and ground water availability, forestry and vegetation but also have a very rich collection of flora and fauna.

Climate variability and climate change assume great importance for the Indian subcontinent. Changes in the present climate system may affect a wide variety of ecosystems and socio economic sectors in the country with corresponding impacts on water resources, agriculture, forestry and other sectors.

The magnitude of projected changes in temperature, rainfall and carbon dioxide in future for different parts of the world, including India as simulated by various general circulation models has been compiled by IPCC (1998). According to this, by 2010 the CO_2 level will increase to 397 – 416 ppm from the 2000 level of 368 ppm. This is expected to increase further to 605 – 755 ppm by the year 2070.

Studies show that the heating up of India will not be uniform across the country. The winters of north and northwest India may be warmer by more than 2 °C by middle of 21st century and there could be a cooling by about 1 °C in the north east India. Besides increase in temperature, climate change is also likely to affect rainfall not only in terms of magnitude but also its distribution in time and space. There is considerable uncertainty in the projected magnitudes of change in rainfall and temperature for India (Table 5).

Table 5: The expected magnitude of change in climate factors in south Asia by 2010 to 2070 A.D. due to global warming

Climatic factors	Rabi		Kharif	
	2010	2070	2010	2070
Temperature increase °C	0.3 to 0.7	1.1 to 4.5	0.1 to 0.3	0.4 to 2.0
Rainfall change in the southwest monsoon region %	0	- 10 to + 10	0	0 to + 10

Source : IPCC 1998 a

The mean temperature in India is projected to increase by 0.1 °C to 0.3 °C in kharif and 0.3 °C to 0.7 °C in rabi by 2010 and 0.4 °C to 2.0 °C in kharif and 1.1 °C to 4.5 °C in rabi by the year 2070 (IPCC, 1998 a). Mean rainfall is projected to change by + 10% or – 10 % by 2070. Some studies have also indicated the possibility of a decline in monsoon rainfall over north and central plains of India in the decades to come. At the same time there is an increased possibility of climate extremes such as the timing of the onset of monsoon, intensities and frequencies of droughts and floods.

Simulation studies by Lal et al (1992) using Hamburg global coupled atmosphere ocean circulation model indicated the possibility of an increase of rainfall in parts of northern India while decrease in rainfall in parts of peninsular India. It was also reported that more frequent heavy rain storms would occur in the north east region of the country which could result in frequent flash floods in the region. The authors, however, did not find any change in the likely dates of onset of monsoon or the inter annual variability of monsoon.

IPCC (2001) and Lal et al (2001) have recently updated these scenarios. The area averaged annual mean warming by 2020 is now projected to be between 1.0°C to 1.4 °C and between 2.23 °C to 2.87 °C for 2050. It is again confirmed that kharif rainfall would increase and rabi rainfall may decrease in some areas. Semi arid regions of western India are expected to receive higher than normal rainfall as temperatures soar, while central India will experience a decrease of between 10 to 20 per cent in winter rainfall by the 2050.

Analysis of recent weather data indeed indicated a warming trend at many places in India. According to Edward Goldsmith, internationally known environmentalist and editor of "The Ecologist" published from London, the temperatures in India by the year 2080 may rise by as much as 7 °C.

Studies at the Indian Institute of Tropical Meteorology IITM, Pune (India) have shown that the country wide mean maximum temperature has increased by 0.6 °C and the mean minimum temperature has decreased by 0.1 °C. Studies by IITM on Indian monsoon rainfall have not shown any systematic trend. On the other hand spatial and sub seasonal pattern analysis of 306 rainfall stations spread all over India showed that 18 stations in west coast and central peninsula showed increasing trends in rainfall and 13 in north east and northwest peninsula and northeast India showed declining trends.

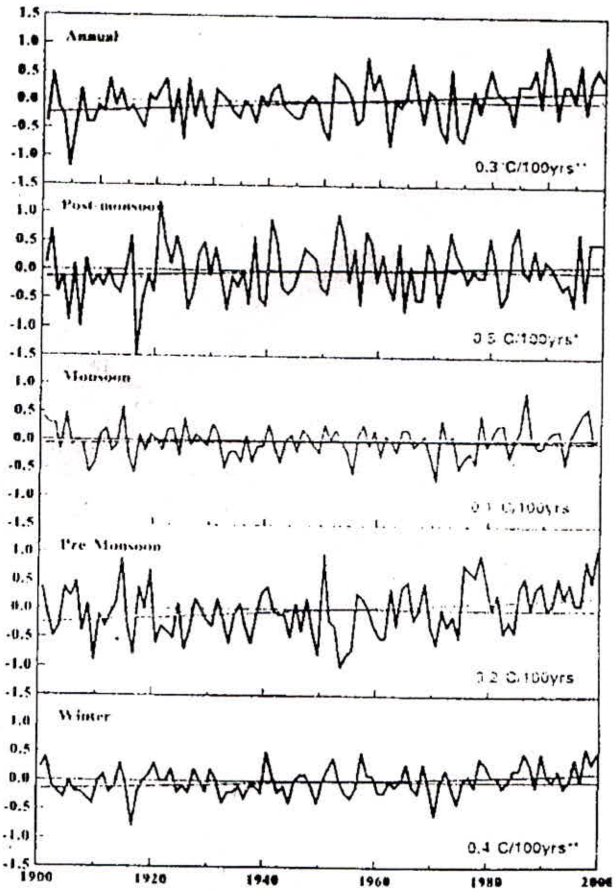

Figure 8: Seasonal and annual time series of all India surface temperature

In the figure 8 (ICRP Bulletin, January 2002) the time series of all India surface temperatures for the four seasons and annual based on data from 34 stations for the period 1901 – 2000 are shown. It may be seen that there is 0.3 °C rise over a period of 100 years in the annual temperature. Also, warming is noted during the post – monsoon (October – December) and winter (January – February) while there is no change in the temperatures during the monsoon season (June – September).

In figure 9 the all India mean surface air temperature anomalies for the period 1881 to 1997 as analysed by Lal (2001) are shown. It can be seen from the figure that there is in, general, a near normal or rising temperature trend after 1980.

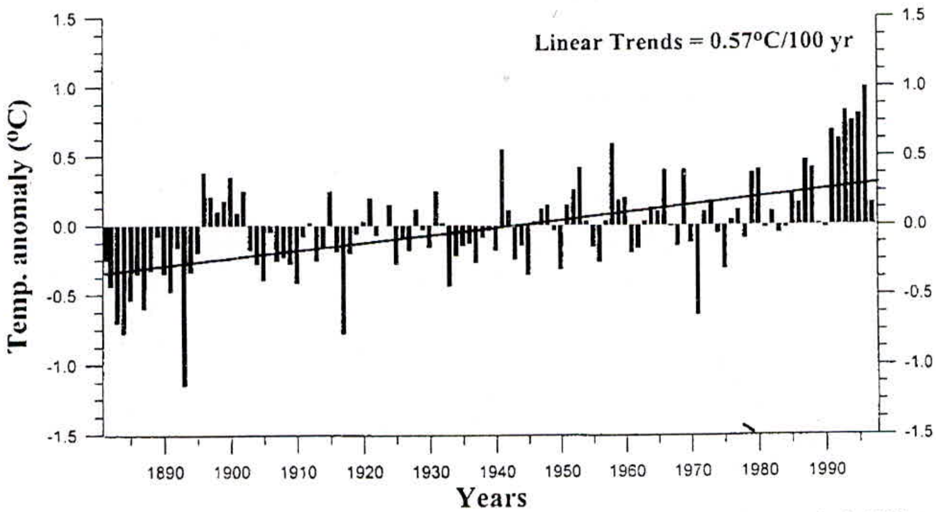

Figure 9 : All India mean surface air temperature anomalies for the period 1881 to 1997 (Lal, 2001)

Prakasa Rao et al (2005) studied the critical maximum and critical minimum temperature days for 103 well distributed stations in India for a period of30 years from 1971 to 2000. The important conclusions are as follows:

- In peninsular India (south of 20 deg N)during March – May and November - January 60 to 70 % of the stations were found to be having an increasing trend in the critical maximum temperature days coupled with increasing night temperature
- In summer about 40 % of north India (north of 20 deg N) have shown increasing critical maximum temperature days while night temperatures increased for about 80 % stations. In winter 79 % stations have shown increase in critical maximum temperature days
- In summer 30 % stations in north east India have shown increasing trend in critical maximum temperature days while critical minimum temperature days increase at 70 % stations. In winter 63 % stations recorded increase in critical maximum temperature days and 77 % recorded increase in critical minimum temperature days

- 60 to 70 % of coastal stations have shown increasing trend in critical maximum and critical minimum temperature days in summer. In winter 80 to 90 % stations recorded increase in critical maximum and critical minimum temperature days

Studies conducted on changes in rainfall and air temperatures over northwest India showed that there is a marginal increase in the rainfall by 141 mm in the past 100 years (Pant and Hingane, 1988) and more so in the irrigated belts of Ganganagar region during the past three decades (Rao, 1996).

Most of the studies clearly pointed out that the rainfall fluctuations in India have been largely random over a century with no systematic change detectable either at annual or seasonal scale (Figure 10).

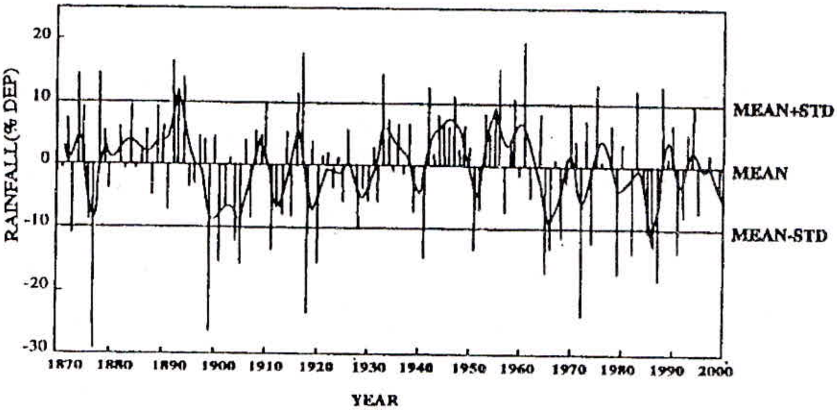

Figure 10: All India summer monsoon rainfall series (1871- 2000)

4.3.1 Impact on water resources

India is a country with a changing water management structure and priorities. It is having regions with increasing levels of water scarcity, floods and water quality problems, compounded by population growth and issues of social and economic development. The annual requirement of water for various uses is shown in Table 6.

Additional stresses on water resources arising from potential climate change will exacerbate these problems. It is predicted that runoff in rivers in central Indian plains may decline due to decline in summer monsoon season rainfall. Alteration in CO_2, temperature and water availability and seasonal distribution of rainfall at regional level caused due to global climatic change are likely to have an impact on production and productivity. Droughts which have been frequent in different parts of India have affected agricultural production and yields.

Table 6: **Annual requirement of water for various uses (in billion cubic metres)**

Sl. No.	Different Water Users	2000	2025	2050
1	Irrigation	541	910	1072
2	Domestic use	42	73	102
3	Industries	8	22	63
4	Power generation	2	15	130
5	Other uses	41	72	80
	Total	634	1092	1447

Source: Central Water Commission

In many parts of India, requirements of water for agriculture and other uses during dry season are significantly higher. Nearly 70 % of the dry season flow of rivers originating from Himalayas is contributed by snow and glacial melt. If climate change alters the temperature and pattern of precipitation in the Himalayas, it could seriously affect the dry season flow.

Mountain glaciers are melting at an alarming rate due to global warming. In fact, some of the Himalayan glaciers are the fastest retreating glaciers globally due to the effects of global warming. "The rapid melting of Himalayan glaciers will first increase the volume of water in rivers, causing widespread flooding. But in a few decades this situation will change and the water levels in rivers will decline, meaning massive economic and environmental problems for people in northern India, western China and Nepal" said Jennifer Morgan, Director of the WWF's global climate change programme.

4.3.2 Sea level rise

The Centre for Science and Environment, India (2002) suggests that low lying areas of Goa, Gujarat and Maharashtra may be worst affected by sea level rise which could flood land (including agricultural land). The effect of sea level rise in the coastal states of India is given in Table 7.

Table 7: Effect of 1 m sea Level Rise on Coastal Areas in India

State/Union Territory	Total Area (million hectares)	Area Inundated (million hectares)	Percentage
Andhra Pradesh	27. 504	0. 055	0. 19
Goa	0. 370	0. 016	4. 34
Gujarat	19. 602	0. 181	0. 92
Karnataka	19. 179	0. 029	0. 15
Kerala	3. 886	0. 012	0. 30
Maharashtra	30. 771	0. 041	0. 13
Orissa	15. 571	0. 048	0. 31
Tamil Nadu	13. 006	0. 067	0. 52
West Bengal	8. 875	0. 122	1. 38
Andaman and Nicobar Islands	0. 825	0. 006	0. 72

The increased sea level will also result in salt water intrusion turning coastal aquifers into saline water which would further reduce availability of fresh water in the coastal areas.

4.3.3 Agriculture yields

Under climate change scenario, the onset of summer monsoon over India is projected to be delayed and often uncertain. This will have a direct effect on not only the rain fed crops but also water storage will be affected putting stress on water availability for irrigation

Agriculture will be adversely affected not only by an increase or decrease in the over all amounts of rainfall, but also by shifts in the timing of the rainfall. There are conflicting views of impact on crop yields. Many studies have reported the possibility of an increase in crop yield, bio mass production, leaf area, photosynthetic rates. Ramakrishna et al (2002) estimated that a 2° C temperature rise in Rajasthan would reduce production of pearl millet by 10 to 15 per cent. Yet another study has calculated that rice yields could drop as much as 15 to 42 per cent and wheat yields by 1.8 to 3.4 per cent. (CSRE, 1998)

4.3.4 Vulnerability and resilience

The vulnerability of India and Indian states to climate change was assessed by Brenkert and Malone (2005). The vulnerability – Resilience Indicator Prototype was used to account for India dietary practices and fresh water resources. Results have shown that nine states in India which are mostly inland were found to be moderately resilient to climate change, principally because of low sulfur emission. Six states with coast line namely Gujarat, Goa, Kerala, Tamilnadu, Orissa and west Bengal are found to be more vulnerable.

Chapter - V
Modelling Climate Change and its Impacts

5.1 Modelling Climate Change Impact

If a climate change is contemplated in the near future, how much of the population and human activity will be affected on the globe is a topic of research of several specialists in different fields of discipline. A number of studies showed that different climate and environmental changes during the past 100 years over various regions in the world were experienced. Almost all numerical experiments on climate modeling in different countries of the world point towards temperature rise in the lower troposphere, atmosphere cooling in the upper troposphere and stratosphere. The short term transient scenarios of climate changes, say during next 10 – 20 years, are less definite and are generally beyond the resolution of most GCM models but there are enough indications to suggest a modest increase in CO_2 and temperature.

According to the results from the analysis through 'Parallel Climate Model' developed by the Department of Energy, USA, the geographical patterns of future heat waves will relate directly to the average climate change associated with increased greenhouse gases. From 2080 to 2099 the largest increases in heat wave severity are predicted to occur in the western and southern United States and in the Mediterranean. Other areas that are currently not as susceptible to heat waves, including northwest North America, France and Germany would also experience increased heat wave severity, the results suggest. The level of green house gas emissions used as input to the model are from 'business as usual' scenario which assumes little by way of any policy intervention to mitigate the green house gas emissions in the 21st century by the concerned nations.

Palmer and Raissanen (2002) analysed the modeled differences between the control run with twentieth century levels of CO_2 as an ensemble with transient increase in CO_2 and calculated for around the time of CO_2 doubling (61- 80 years from present). They found a considerable increase of the risk of a very wet winter in Europe and a very wet monsoon season in the Asian monsoon region.

According to Prof Meinrat Andreae of the United Kingdom, new computer models indicate the possibility of global temperatures in the future could be much hotter than scientists have predicted. Improvements in air quality will lead to a decrease in aerosols, small particles that act as a brake on impact of GHGs.

Impact and adaptation assessments are increasingly using climate projections from regional climate models to achieve greater spatial details in climatic scenarios. Guidance on the use of regional models for impact and adaptation assessment studies is available with the IPCC's Data Distribution centre.

5.2 Impacts on Precipitation and Water Resources

Due to climate change there are likely to be significant changes in seasonal rainfall patterns and other factors controlling stream flow. The possible impacts of climate change on the hydrological regime include: increase in summer evaporation, more rain storms caused by increased convective precipitation in summer months, increased intensity of tropical storms and increased monsoon rainfall in the tropics. The rate and timing of snow melt is likely to change. (IPCC, 1990)

The prediction of extreme events for future climate is highly uncertain. Based on global simulations and for a wide range of scenarios, global average water vapour concentration and precipitation are expected to increase further during the twenty first century while precipitation extremes are projected to increase more than the mean with consequences for flood risk.

During the past twenty years, hydrologists from many countries have extensively studied hydrologic consequences of future scenarios of climate change. The studies are based on various methods which can be grouped as follows :

(i) Time series analysis of runoff and meteorological parameters to study the long term variations and trends
(ii) Use of GCMs and Regional Circulation Models
(iii) Use of deterministic hydrological models

GCMs are indeed playing a crucial role in constructing possible scenarios pertaining to various levels and trends of carbon dioxide in the atmosphere. In addition to indicating average temperature changes GCMs also show the type of changes in synoptic weather conditions which could occur. Hydrological models are used to estimate the hydrological response to an expected climate change. The underlying idea is that variations in key climatic parameters such as precipitation and temperature produce significant changes in the hydrological regime of a basin. Predicted changes in precipitation and temperature deduced from General Circulation Models (GCM) are used as input to well known hydrological simulation models to study the impact.

To investigate the consequences of climate change on the water budget in small catchments, it is necessary to know the change of local precipitation and temperature. General Circulation Models (GCM) cannot provide as yet regional climatic parameters because of their coarse resolution and imprecise modelling of precipitation. Therefore, downscaling of precipitation and temperature has to be carried out from GCM grids to a small scale of few square kms. A model concept for simultaneously downscaling of precipitation and temperature from a GCM grid to a regional resolution of few square kms was developed by Bardossy and Caspary (2000)

Khaliq and Cunnane (1997) investigated the effect of a range of climate change scenarios on rainfall extreme values using a rainfall cluster model (Modified Bartlett-Lewis Rectangular Pulse Model). The selected scenarios were based on more or less stormy conditions and more or less rainfall cell intensity. The rainfall cluster model was applied to 38 years of hourly rainfall data of the month of March at Shannon Airport, Ireland for simulating rainfall sequences. The authors concluded that climate change affects quantiles of lower return periods more than those of higher return periods. Thus from flooding point of view climate change could have a proportionately much larger effect on urban and agricultural drainage systems, which are usually designed to accommodate low return period floods than on large flood retaining structures which are designed to much larger return periods.

Roulin et al (2000) studied the impact of climate change on water resources in Meuse basin Belgium and France using perturbed series of meteorological data with the climate change simulated by GCM. The results from the perturbed series were compared with those from the unperturbed observed series of meteorological data. The results indicated increased winter precipitation leading to flooding and reduced summer precipitation which might lead to droughts.

Kite et al (2000) used the Semi-distributed Land Use Runoff Process (SLURP) model to investigate the effect of 2 x CO_2 scenario on water availability in the Gadiz basin in western Turkey. The results indicated reduction in annual water flow by more than 100 million cubic metres. Studies have shown that the climate change may lead to changes in availability of ground water as a consequence of changes in occurrence of precipitation.

Moin et al (2000) studied the impact of climate change on the runoff and ground water in the Grand river basin in Ontario, Canada. The effect of climate change was found to be increase in the total flow and base flow during winter months January and February as against the high flow normally experienced in the months of March and April. The other impact of climate change is non accumulation of precipitation as seasonal snow and the almost immediate melting of precipitation received as snow and its availability as runoff in the winter months. Studies have also indicated that the mountain glaciers are known to respond to climatic changes more quickly than the polar glaciers.

Nigel Arnell of University of Southampton. U. K. had carried out a study of impact of climate change on water availability for three scenarios. River runoff was simulated across the globe at a spatial resolution of 0.5° x 0.5° latitude and longitude using a macroscale hydrological model run firstly with the observed 1961 – 1990 global climate, followed by scenarios derived from the Hadley Centre predictions with an unmitigated emissions scenario and scenarios leading to CO_2 concentration being stabilized at 550 ppm and 750 ppm. Increasing CO_2 concentrations may affect evaporation rates directly by reducing stomatal conductance. The findings from the study indicated that with unlimited emissions by the 2080s, there are large changes predicted in the availability of water from rivers. Substantial decreases are seen in Australia, India, southern Africa, most of South America and Europe and the Middle East. Increases are seen across North America, Central Asia and central eastern Africa.

An emissions scenario leading to stabilization of CO_2 at 750 ppm generally slows down the rate of change in river flows compared to an unmitigated emissions scenario, by about 100 years. Stabilisation at 550 ppm delays the change further particularly in South America and Asia.

5.2.1 Studies for Indian Basins

The major river systems of the Indian sub-continent namely Brahmaputra, Ganga and Indus which originate in the Himalayas are expected to be more vulnerable to climate change because of substantial contribution from snow and glaciers into these river systems (Singh and Naresh Kumar, 1997).

Studies on climatic variability and its impact on water resources were carried out by imposing climate change scenarios and linking them to hydrological models. The studies have shown that increase in the temperature by 1.5° C will increase the risk of floods in the Ganga and Brahmaputra plains (Siedel et.al, 2000). The effect of climate change on the runoff for Ganga and Brahmaputra is shown in figure 11 and figure 12 respectively.

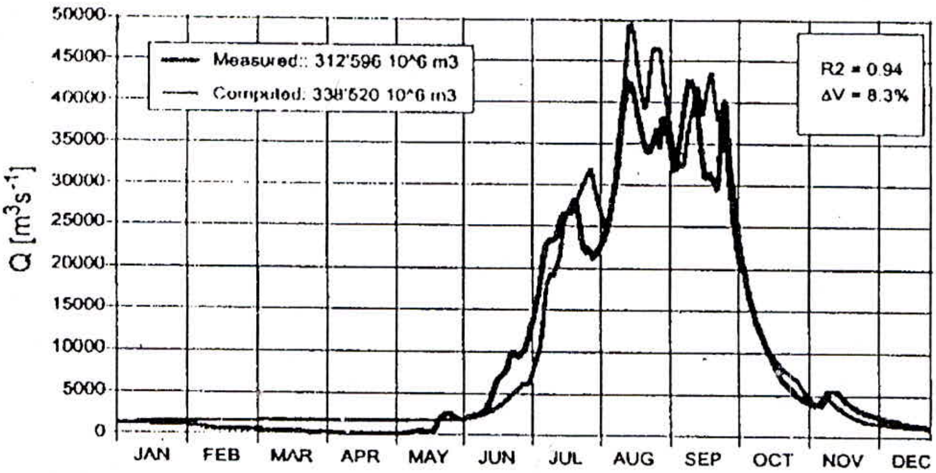

Figure 11 : Comparison of the runoff in the Ganga river computed with the data of 1995 with the climatic scenario recommended for the region (Temperature + 1.5° C Summer precipitation + 10%) Siedel et.al. (2000)

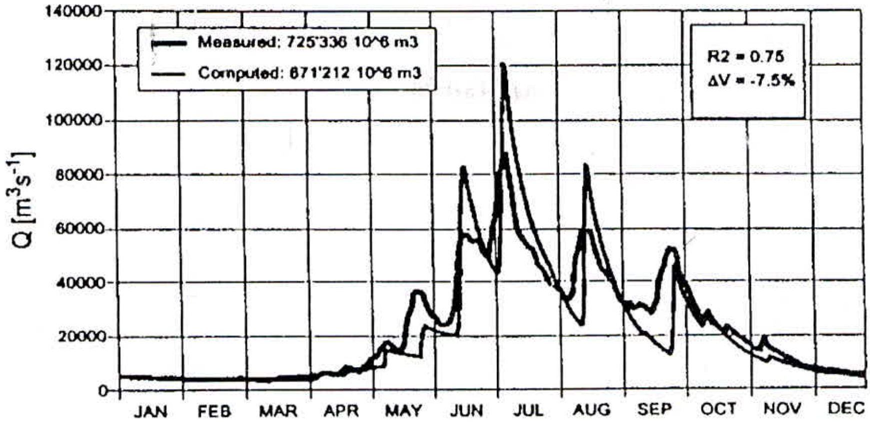

Figure 12 : Comparison of the runoff in the Brahmaputra river computed with the data of 1995 with the climatic scenario recommended for the region (Temperature + 1.5^0 C Summer precipitation + 10%) Siedel et.al. (2000)

Lal and Chander (1993) analysed the output obtained from athe European Community Hamburg coupled ocean-atmosphere climate (ECHAM3) model (spatial resolution of 300 km x 300 km) and had studied the changes in hydrological parameters namely precipitation , soil moisture, evaporation and runoff on a seasonal and annual basis for the Indian sub-continent in warmer world. The results, though, were having low confidence level due to the resolution of the climate model, could qualitatively provide the changes in the hydrological parameters for the Indian sub-continent. Also, studies by Lal and Chander (2000) indicated that warming could result in more runoff in the north east and central plains during monsoon though, not much change could be seen in the flows during winter season.

Mehrotra (1999) carried out sensitivity analysis using disaggregated GCM output and a conceptual rainfall runoff model for the Damanganga (Gujarat), Sher and Kolar sub basins in Naramada basin and Hemavati in Cauvery basin. It was seen that while monsoon and annual runoff is expected to decrease due to the projected climate changes in Damanganga, annual runoff is expected to increase in Sher and Kolar sub basins.

An assessment of the implications of climate change for hydrological regimes and water resources using scenarios developed from Hadley Centre Model Simulations indicates that by the year 2050, the average annual runoff in the river Brahmaputra will decline by 14 per cent. Studies have indicated that the impact of snow melting in the high Himalayas will lead to flood disasters in Himalayan catchments. Impacts will be observed more in the western Himalayas as the contribution of snow to the runoff of major rivers on the western side is about 60 per cent as compared to 10 per cent on the eastern side (IPCC, 2001).

Gosain et al (2002) used distributed hydrological modeling to quantify the impact of the climate change on the water resources of India. The study determined the present water availability of different river basins without incorporating any man made changes like dams, diversions etc. The same frame work was then used to predict the impact of climate change on the availability of water resources with the assumption that the land use shall not change over time. The analysis revealed that the GHG scenario may deteriorate the conditions in terms of severity of droughts and intensity of floods in various parts of the country. Also, a general reduction in the quantity of the available runoff due to climate change was predicted.

5.3 Impact on Groundwater

Hydrologists studying ground water flows have often neglected climate controlled variation in inflow to and outflow from the aquifers. There is need to know how the variations in inflow affect ground water availability as aquifer systems are developed to and beyond their natural limits because of increased chance that future climate change will affect ground water availability and because of increased need to maintain outflow to perennial streams and riparian areas.

Hanson, R.T of the U. S. Geological survey, San Diego, USA had carried out a study to determine the effects of climate variations of differing time scales on recharge to and discharge from aquifers. The study was carried out on selected watersheds from coastal California to the Rio Grande Rift, USA. The study attempted to address the fundamental issues of how climate forcings affect groundwater/surface water interaction and provide basis for delineating recharge and discharge estimates for local ongoing applications.

5.4 Impact on snow and glacier melt.

Temperature increase associated with global warming will increase the rate of snow melting and consequently snow cover is liable to decrease. Glaciated catchments reach their highest discharge values in hot summers, when glaciers show large areas of bare ice and deliver a high basic load of melt water. Large responses are expected in the annual hydrologic regime of rivers where a significant proportion of the runoff is from melt of snow cover and from wastage of ice in heavily glacierised basins. In short term, there may be increase in water flow in many rivers which, in turn, may lead to recurring floods. In the long term, however, receding snow line would result in reduced water flow in rivers.

Climate change effects on the hydrological behaviour of snow fed rivers has been studied by various researchers though limited studies have been carried out to study the depletion of snow cover under warmer climatic conditions.

Runoff models under global warming scenarios project a higher and earlier peak of spring runoff from snow melt and reduced flow in summer (Rango and Martinec, 1998). Rango and Martinec (1994) also examined the influence of changes in temperature and precipitation on snow cover using snow melt runoff model (SRM).

Singh and Kumar (1997) carried out detailed study on the effect of different climatic scenarios on different components of runoff for a highly snow fed river in the western Himalayas.

Using WiFS data of Indian Remote Sensing satellite IRS-1C, Kulkarni et al (2002) studied the effect of global warming on snow ablation pattern in the Beas and Baspa (Satluj) basins in western Himalayas. The results from the study suggested that warmer winter is causing snowmelt in the higher altitude zone. Melting and retreat of snow cover was observed even in the months of December and January at an altitude of 5400 m. Snow cover was observed retreating early, in the months of January and February at elevation of 4200 m. This was reported to be due to high temperatures during winter months. The authors further reported that the average stream runoff of Baspa river in December during the period 1966 to 1992 has gone up by nearly 75 %.

Hagg and Braun (2005) studied the effect of climate change and consequent de-glacierisation on river stream flow for three glaciers in Central Asia. These were Tayuksu glacier region in Kazakhstan, Abramor glacier in Kyrgyzstan and glacier No. 1 in China. The study was carried out by simulating runoff using HBV – ETH model.

Singh and Bengtsson (2005) studied the effect of increase in temperature from 1 to 3° C on the depletion of snow covered area in the Sutluj basin (upto Bhakra Dam). It was seen that increase in temperature from 1 to 3° C enhanced the melting area of snow over the melt season by 2.7, 5.1 and 7.2%, respectively.

Using a simple surface energy budget model Keller and Goyette (2005) studied snowmelt under different temperature increase scenarios for two high altitude stations in the eastern parts of the Swiss Alps. In order to infer the impact of climate change, three temperature scenarios were used with 2 x CO_2 simulation: first with rise of mean temperature, second allowing for an increase in maximum temperature only and the third with an increase in minimum temperature only. The results have shown that even a small temperature increase may have a significant influence on mountain snow, which has an important impact on mountain bio systems. The sensitivity analysis showed that an increase in temperature enhances the melting speed of the snow during the snow season. Also, the runoff peaks occur earlier in the year. The maximum snow depth diminished.

5.5 Impact on Agriculture

The relationship between agriculture and climate is well known. Climate influences plant life and can inhibit, stimulate, alter or modify crop performance. Its components rainfall, temperature, solar radiation, wind and humidity independently or in combination during critical stages are known to significantly affect crop growth and productivity. Climate change has serious implications for food security through direct and indirect effects on crops, live stock, fisheries and pests. Most crops in India, even in irrigated environment are quite sensitive to climatic variability.

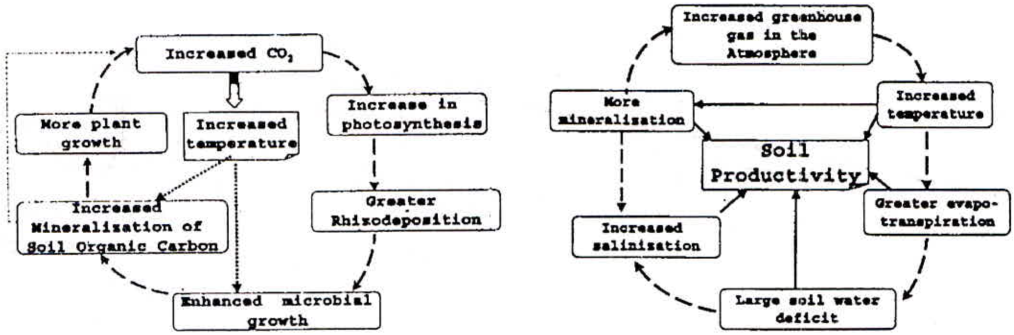

Figure 13 : Impact of CO_2 emission and global warming on soil productivity

The IPCC (1990) projected an increase of 0.1 to 0.3^{0}C by 2010 and 0.4 to 2.0^{0}C by 2020 in south Asia which may result in decrease in cereal production and increase in rainfall by 5 to 15% in the region. Climatic change studies over the Jodhpur region revealed that rainfall and air temperatures were favourable but the increase in human (+400%) and livestock (+127%) population were the main causative factors for accentuating the adverse effect of drought and desertification in the region (Rao and Miyazaki, 1997).

Attri (2000) had modeled the impacts of climate change on different crops by projecting climate during 2040 – 2049 with temperature rise coupled with enhanced CO_2 levels. Wheat yield enhancement of the order of 29 – 37 % and 16 – 28 % were noted for an increase of T_{max} 1. 0° C and T_{min} 1.5° C as compared to current climate. Further increase of temperature (T_{max} 2. 0° C and T_{min} 2.5° C) has resulted in reduction of yield.

In the past few years the havoc climate change can wreak on Indian agriculture has been seen. Since 2004, the Indian Council of Agricultural Research ICAR has been supporting research on the "Impact, adaptation and vulnerability of agriculture to climate change". The research is being carried out across 14 centres of ICAR and agricultural universities. It is aimed to identify areas and crops which are particularly vulnerable to climate change and identify ways to minimize the impact.

Recent studies in USA, China and Japan on maize, rice, soybean and wheat indicated that the effect of increase in ozone levels was more important than that of carbon dioxide. Increase in ozone levels showed drastic decrease in crop yields. This is important as the ozone level is expected to go up in Europe, China, USA, India and most of the middle-east countries in the next fifty years. A British scientist predicted that the changes in the climate will have effects on tropical countries like India.

5.6 Impact on Forests

Climate is an important determinant of the geographical distribution, composition and productivity of forests. Therefore, changes in climate could alter ecosystems.

Ravindranath and Sukumar (1998) discussed the impacts of two climate change scenarios on tropical forests in India – one involving green house gas forcing and the other incorporating the effects of sulphate aerosols. The first scenario associated with increased temperature and rainfall could result in increased productivity, migration of forest types to higher elevations and transformation of drier forest types into moist forest types. The second scenario involving modest increase in temperature and decrease in rainfall in central and northern India could have adverse effects on forests.

Using climate scenarios generated by the ECHAM3 climate model for forests in Kerala (south India), Achanta and Kanetkar (1996) found that the soil moisture is likely to decline and in turn reduce teak productivity from 5.40 m^3/ha to 5.07 m^3/ha The study has also shown that the prodiuctivity of moist deciduous forests could decline from 1.8 m^3/ha to 1.5 m^3/ha.

5.7 Impact on Arid Areas

Dry lands respond quickly to the climate fluctuations. According to the recent IPCC assessment report (2001) many dry land areas could become even hotter and drier over the 21st Century.

The following future climate changes and impacts in many dry land areas are predicted (Rind et al 1990; Le Houerou, 1992)

(i) Dry land temperatures are projected to increase by 2° C to 5° C for the doubling of green house gases concentrations which are expected to occur in the middle of the 21st century.
(ii) Increase in evapotranspiration rates will overwhelm any changes in rainfall. Soil moisture levels will decrease and droughts will become more frequent according to many models
(iii) Changes in temperature, precipitation and soil moisture are likely to deteriorate surface conditions, particularly in dry land areas that are prone to desertification processes.

5.8 Climate and Emission Scenarios

According to a study carried out by Swart et al (2002), the radiative forcing associated with most 450 ppm stabilization scenarios is generally below the range of SRES (Special Report on Emission Scenarios, IPCC, 2000) base cases and should, therefore, receive additional attention in order to cover the full range of radiative forcing associated with reference and stabilization cases. The authors recommended a stylized emissions profile to be analysed for stabilization of the CO_2 concentration at 450 ppm, based on the global profiles of the lower post – SRES 450 ppm analysis.

In its Third Assessment Report the IPCC (2001) concluded that not many studies especially in developing countries have been done regarding the potential impacts of green house gas induced climate change. Where studies have been conducted, they often assume different scenarios of climate change, different economic and social projections and different base lines. This often led to inconsistency in the use of climate and emission scenarios which has in turn resulted in difficulties in comparing and integrating the results to build a regional or global picture of impacts and adaptation options. IPCC, therefore, established a Task Group on Scenarios for Climate Impact Assessment (TGCIA) in 1998. Its purpose is to facilitate the provision of scenarios (both climate and socio-economic) for impacts and adaptation researchers about what data on scenarios are now available and to encourage use of them (Parry, 2002).

5.9 Integrated climate modeling

Climate forecasts can be used to better manage climate sensitive sectors such as agriculture and water resources. There is need to have an integrated climate model by adapting GCMs coupled with regional circulation models to predict future climatic conditions under different emission scenarios. To offset the impact of occurrence of extreme events due to impact of climate change, improved climate forecasts should be integrated into water resources decision models to provide adaptive and robust operational management policies. A crop model can also be integrated along with seasonal forecasts and GCMs to produce short and long term estimates of yields of principal crops. A schematic of an integrated climate model is shown in figure 14.

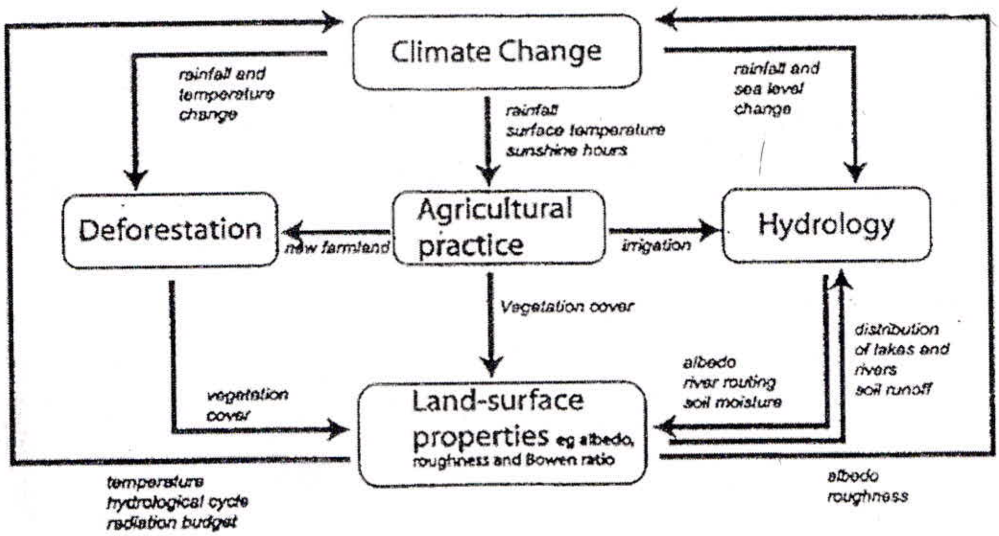

Figure 14: Schematic representation of integrated climate modeling

The model concept (figure 15) developed by Bardossy and Caspary (2000) incorporates linkages with hydrological models for assessing changes in vegetation and crops and water management models for assessing impact on availability of water for irrigation, domestic water supply and water quality.

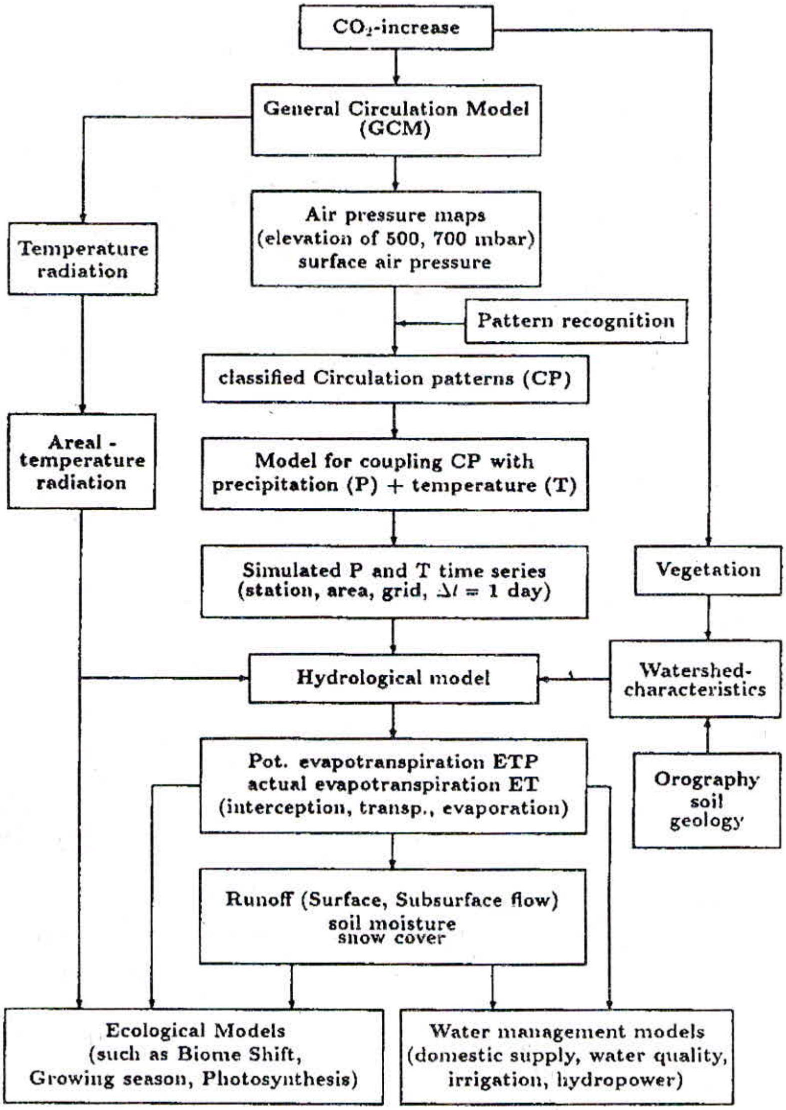

Figure 15: Model concept for downscaling of precipitation and temperature from a GCM grid to a regional resolution

Chapter - VI
Effects of Climate Change Happening Already

6.1 Warming Trends

Observed changes in temperature, precipitation, snow cover, glaciers, sea level and extreme weather conditions confirm that the global warming is a reality. Some people still point to the uncertainties about the extent to which human behaviour contributes to climate change. Consensus in the scientific community on climate change has grown over the recent years. It is felt that the problem is more serious than it was thought to be some years ago and there is growing unanimity about the initial effects of climate change, which are now becoming visible through changes in temperature, precipitation and extreme weather events.

There is a fair degree of agreement that continuing build up of heat absorbing gases in the atmosphere is causing global climate change. Climatic changes which are expected to occur in the near future are already showing their impacts.

There have been reports of effects of global warming in recent years. Global surface warming over the last two decades of the twentieth century has been nearly 0.5° C. The year 1998 was said to be the warmest ever, heightened by a strong El- Nino. All the four years 2001 – 2004 recorded high temperatures with 2002 being the second hottest after 1998. The British Meteorological office report dated 14th October 2005 indicates that the year 2005 could as well turn out to be the third if not the second warmest year after 1998. The trend adds weight to the concern among many scientists that the world is heating up and human activity including burning of fossil fuels and generation of GHGs is playing a major part.

Over the past 50 years 40 per cent of the arctic ice cap has melted. In Antarctica, the ice caps have shown large cracks and slowly, it is melting and breaking away from the main cap and floating as ice bergs.

The Guardian Newspaper (2005) reported of a study carried out by U. S. Scientists and published in the journal "Science" which found that lakes in two large swaths of Siberia are shrinking in size. According to the study, in the area between Ural mountains and the arctic mining town of Norilsk, the number of lakes reduced from 10882 in 1971 to 9712 in 1997, a decline of 11 percent. The scientists concluded that the ultimate effect of continued climate warming on high altitude perma frost controlled lakes and wet lands may be their widespread disappearance.

6.2 Hurricanes in Atlantic

U.S. Meteorologists warn that the world has shifted gear into a cycle of increased hurricane activity that may last 20 years. On the basis of analysis of data collected from actual storms, climatologist Kerry Emanuel of the Massachusetts Institute of Technology has shown for the first time that major storms spinning in both the Atlantic and the Pacific since the 1970s have increased in duration and intensity by about 50 per cent. These trends were said to be closely linked to increases in global average atmospheric temperatures during the same period (Times of India, 2005).

In 2004, four major hurricanes (Charley, Ivan, Jeanne and Frances) hit the southern U.S. Coast. Of these Ivan caused major mud slides in the ocean floor. In 2005 category 4 hurricane Dennis struck in July hurting mainly the Caribbean islands. Then came hurricane Emily also of category 4 which hit mainly Cuba and Mexico. The southern states of USA have been affected by a series of severe hurricanes Katrina, Ophelia and Rita in close succession during last week of August to 3rd week of September 2005. Katrina and Rita were category 5 hurricanes with Katrina causing maximum damage to life and property in southern Texas and New Orleans, Louisiana. In the first week of October 2005, tropical storm Stan which touched hurricane level for some duration has devastated Mexico and Central America. During 20 – 23 October 2005, Hurricane Wilma, eighth tropical storm of hurricane category since August 2005, hit the Yucatan peninsula in Mexico, Cuba and, Florida State in USA. Environmental groups claim, implausibly, that global warming is responsible for these events.

6.3 Accelerated Glacier Melting

The U S based World Watch Institute reported in 2000 that in 1999, the Indus recorded high water levels because of glacial melt. The report warned that "first signs" of the disastrous effects of human induced global warming are already becoming perceptible.

According to the results of the study released by World Wide Fund for Nature (WWF) in March 2005, the Himalayan glaciers were receding 10 – 15 metres per year on an average. It is reported that the Gangotri Glacier is receding at an astonishing 23 metres per year.

Two of Greenland's largest glaciers are retreating at an alarming rate. Speaking at the meeting of American Geophysical Union in San Francisco, USA in December 2005, Prof Gordon Hamilton of the University of Maine's Climate Change Institute mentioned that one of the glaciers Kangerdlugssuaq is currently retreating at the rate of 9 miles (11. 5 km) per year compared to 3 miles (4.8 km) per year in 2001. The other glacier Helhelm is retreating at about 7 miles (10.2 km) per year as compared to 4 km (6.4 km) earlier. Melting of Greenland ice and calving of icebergs from glaciers is responsible for 7 % of the annual rise in global sea level. (Times of India, December 2005)

Alaska's Columbia glacier has shrunk 9 miles (11.5 km) since 1980. It is expected that it will lose another 11 to 12 km in the next 15 to 20 years.

6.4 Tropical Storms in Indian Ocean

The frequency of monsoonal cyclonic disturbances in the north Indian Ocean has shown a significant decreasing trend during the twentieth century, registering about fifty percent reduction from beginning to the end of the century. The number of cyclones has been declining since 1985 (Singh, 2001)

Frequency of heavy rainfall (more than 70 mm in 24 hrs) during southwest monsoon showed increasing trend over certain parts of the country namely Andaman and Nicobar Islands, Lakshadweep, west coast and some pockets in central and north west India, while most of other areas in the country showed decreasing trend. However, during other seasons (winter, pre-monsoon, post-monsoon) a general decreasing trend of rainfall was noted (De, 2001).

During the southwest monsoon of 2005, states of peninsular India namely Chattisgarh, Gujarat, Maharashtra, Madhya Pradesh, Orissa and Andhra Pradesh received heavy precipitation under the influence of a variety of weather systems while states in Northern India faced long dry spells during July and August which are the principal rainy months of the southwest monsoon.

Mumbai recorded the highest rainfall of 944 mm in 24 hrs on 26th July which surpassed the earlier record of 370 mm observed on 5th July, 1974. At the beginning of the north east monsoon season of 2005 – 06 heavy rains occurred in Karnataka and Tamilnadu. It is reported that Chennai had recorded 210 mm in 5 hrs in the early hours of 27 October 2005.

Chapter - VII
Concluding Remarks

Global climate change is a reality, a continuous process and needs to be taken seriously even though there are large uncertainties in its spatial and temporal dimensions. The world today faces two challenges in order to be able to deal effectively with the effects of climate change. The first is to reduce carbon dioxide emissions drastically by moving over to renewable technologies as soon as possible. The second is to prepare to deal with the impacts of climate change that are already inevitable due to existing levels of greenhouse gases in the atmosphere. The UNFCCC agreed to in 1992 and the 1997 Kyoto protocol, the two international agreements to deal with global warming, have not succeeded in reducing GHG emissions. The developed countries, where per capita emissions of carbon dioxide are much higher due to higher usage of fossil fuel, are unwilling to compromise on their life styles by reducing consumption of fossil fuels.

India's participation in the US Asia-Pacific initiative on climate change is in continuation of the India-USA energy dialogue. With India's energy needs expected to rise with expanding economic activity, it is imperative that India also take part in initiatives that seek to reduce emissions with least costs.

Since climate is the least manageable, it is imperative to focus attention on the natural resources such as water, soil, nutrients and vegetation to offset the negative impacts of climate change. It need not be overemphasized that increase in incidence of extremes such as floods and droughts would cause increased frequency and severity of disasters.

The changes in snow melt runoff and its timing will have direct impacts in hydropower generation and impose requirements for alternative power sources.

The estimates of water availability and the maximum flood that the spill ways are designed to discharge will become unreliable. There is, therefore, need for developing a reliable hydrological data base and research must be strengthened to predict possible hydrological changes and impact on water resources.

Human induced climate change may not result in smooth linear changes. The increased concentration of GHGs in the atmosphere could set in motion large scale high impact, non-linear and potentially abrupt changes in physical and biological systems over the coming decades to millennium (Pachauri, 2005). As the environmentalists have been demanding, there has to be a decrease in carbon dioxide emissions and a shift to using renewable energy.

Irrespective of the likelihood of abrupt changes and climate related catastrophes, the scale and nature of human induced climate change requires the immediate inclusion of the impacts of climate change in our preparedness to protect human lives and property. Adopting appropriate mitigation strategies for limiting climate change impacts in the Indian sub-continent is easier said than done and requires careful intervention coupled with the right blend of alternate technology. It is also necessary to re-evaluate existing scientific methods of analyzing hydrological processes in the light of expected climate changes. The design criteria for dams may require re-evaluation to incorporate the likely effects of climate change in the respective regions. It is, of course, customary in hydrologic design practices all over the world to include a greater degree of uncertainty. According to Kite (2000) there may be a small component of change due to increase in green house gases. For the design of most water resources projects, the uncertainty due to climate change falls within normal design safety factors.

The threat to Himalayas can be diluted by draining the lakes formed by melting glaciers, before they reach dangerous levels. The governments concerned should take steps to protect the Himalayas from the effects of climate change.

The receding glaciers are only a part of a greater environmental melt down. We need desperately to rethink our energy use and consumption patterns, failing which the future energy requirements will be difficult to cope with.

Change in agricultural technologies offer good promise for adapting to climate change. Water and nutrition management has to be redefined in various agro-ecologies to meet the climate change. Management – climate predictor links are an important and growing part of agricultural extension. Linking agricultural management to seasonal climate predictions, if they can be made with certain degree of reliability, can allow management to adapt to climate change.

Policy makers are interested in the near term implications of long term climate objectives and strategies to achieve these objectives. The IPCC (2001c) in its synthesis report notes that a final decision on what constitutes dangerous anthropogenic interference with the climate system, and the associated level and timing of stabilization of green house gases, depends on socio – political rather than merely scientific considerations. Policy planning has to be integrated with long term social and technological changes so as to make a realistic effort at mitigation. As more information becomes available over time, the decisions could be adjusted in a sequential decision making process.

The IPCC's Third Assessment Report contained a brief summary of currently detectable early effects of recent warming, particularly at high altitudes. An important conclusion from this was that it is now possible to discern some effects. It will be necessary to extend this type of analysis to a wide range of regions and exposure fields across the world. It is important that some key gaps in current knowledge be filled. Amongst these are estimates of impacts in developing countries, estimates under differing amounts of emissions reduction and the need to ensure consistency in the use of climate and emissions scenarios. We need research in these areas.

In the Indian context, it is important that the knowledge on climate impact on hydrology is absorbed into water resources management policies to overcome the adverse impacts due to recurring floods and droughts. As suggested by Mitchell and Ericksen (1991), the best preparation for the uncertainties associated with resource management in terms of climate change may be to increase preparedness for extreme events. This would allow better coping with expected changes and additional resilience in management systems to deal with uncertainties in terms of severity, timing or location

Reliable and long term hydro-meteorological data especially from the higher elevations in Himalayas are needed to study the impacts of climate change on the hydrology and water resources of the Himalayas region in order to plan for future needs of water.

Climate information and skilful climate forecasts have the potential not only to help cope with climate fluctuations but also to assist in adapting to long term climate change. There is, therefore, an imminent need to promulgate the use of modern hydrological monitoring and data transfer techniques and to propagate knowledge of the relationship between global processes and regional hydrology.

A few aspects of climate change and their impacts have been discussed. There are many more aspects of climate change and their impacts. In view of the importance of these impacts on society and the national economy it is imperative that a multi disciplinary coordinated research is undertaken involving all those concerned. Even with significant progress, the routine use of climate information and forecasts effectively for real time benefits is still in early stages. To make this vision a reality, further research and development are essential.

7.1 Issues for Research

The following research issues need to be addressed:

- Improving the capability of climate prediction models to give more reliable forecasts of temperature and precipitation in different climatic zones
- Pilot studies in each climate zone are to be initiated to monitor climate change and its impact on water resources
- Study the severity and vulnerability of hydrologic hazards under the influence of projected climate change
- Developing models for improved stream flow forecasts for operational time periods with inputs from climate forecasts and appropriate downscaling procedures
- Use of long term climate forecasts for water resources planning and management
- Developing Decision Support Systems to evolve strategies for adapting agriculture and water resources systems to short and long term climate changes
- Developing pragmatic operation policies to adapt to impacts of climate change.

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INDIAN NATIONAL COMMITTEE ON HYDROLOGY (INCOH)

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India's participation in IHP-VI program

	Theme	Selected Focal Area
1.	Global Changes and Water Resources	Integrated assessment of water resources in the context of global land based activities and climate change
2.	Integrated Watershed and Aquifer Dynamics	Extreme events in land and water resources
3.	Land Habitat Hydrology	Dry lands
4.	Water and Society	Raising public awareness on water interactions
5.	Water Education and Training	Continuing education and training for selected target groups

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