Training Course

Climate Change and its Impact on Water Resources

[May 17 - 21, 2010]

LECTURE - 11

IMPACT OF CLIMATE CHANGE ON HYDROPOWER GENERATION

By

SHARAD K. JAIN

Organised by

National Institute of Hydrology
Roorkee- 247 667
&
Indian Institute of Technology
Roorkee -247 667

IMPACT OF CLIMATE CHANGE ON HYDROPOWER GENERATION

1.0 CLIMATE CHANGE

Climate change is defined as "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods". Global warming is shorthand for "climate change," and the term is correct if we realize that it's referring to the average temperature of the Earth over years and decades; not to the temperatures at particular times and places. "Climate change" is a much better term because much more than warming is involved, although the changes first begin with the earth's warming.

Global warming can cause changes in patterns of rainfall. It can lead to more snow piling up in places such as Antarctica and Greenland, and it can even include some parts of the Earth growing colder. There is no doubt that the amount of carbon dioxide in the air -- a "greenhouse" gas -- has increased. This increase in a greenhouse gas is bound to "force" the climate in one direction or another with a general warming being one of the effects. Climate scientists also have strong reasons to say that as humans continue adding gasses to the air, warming is likely to continue through this century.

A schematic view of the components of global climate system is given in Fig. 1.

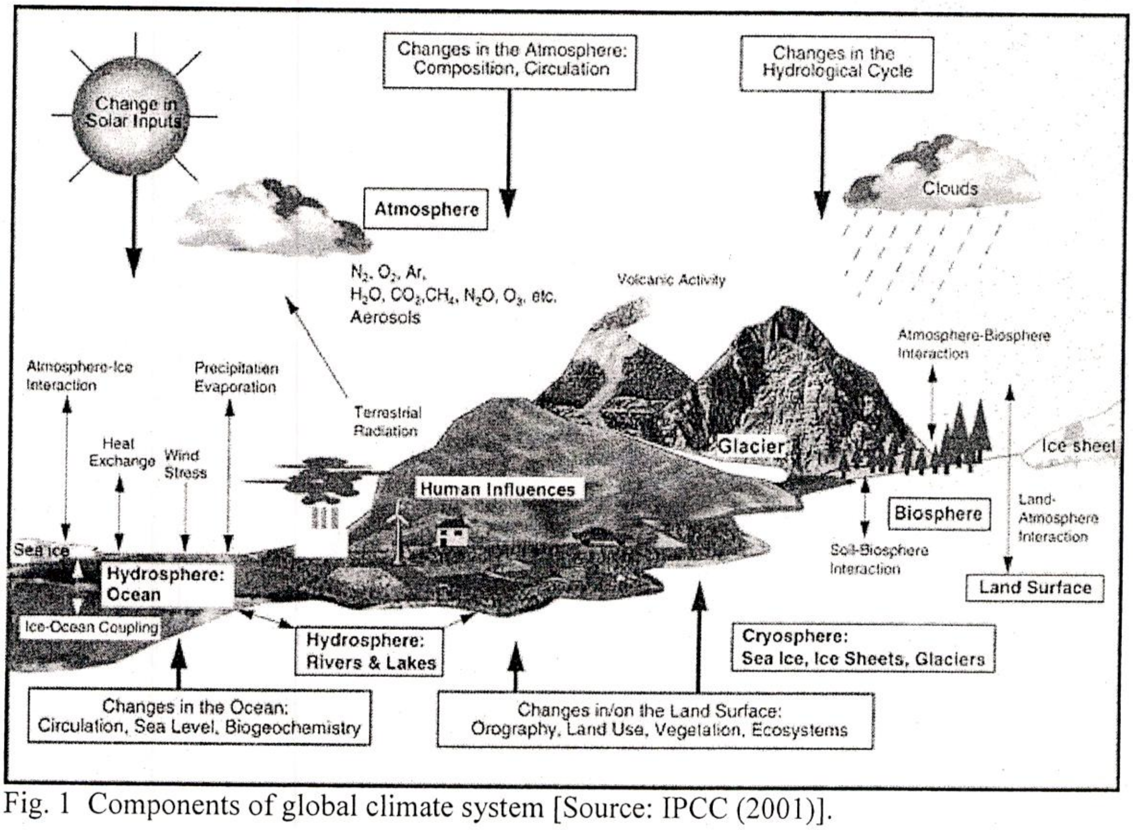

Fig. 1 Components of global climate system [Source: IPCC (2001)].

Fig. 2 shows the concentration of CO_2 at the famous Mauna Loa observatory from 1960 onwards.

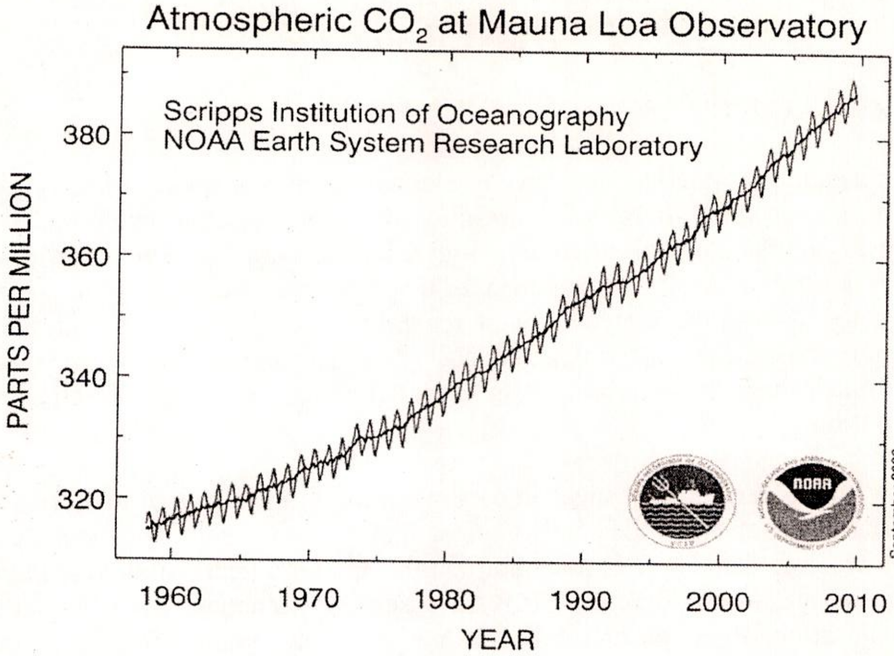

Fig. 2 Concentration of CO_2 at the Mauna Loa observatory, 1960-2009 [Source: co2now.org].

2.0 IMPACT OF CLIMATE CHANGE ON WATER RESOURCES

Access to water plays a key role in development – it sustains human life, both through direct consumption and use in agriculture (for food security) and industrial activities. While water availability for drinking purposes is essential, it cannot be separated from wider water resource management issues. Its use for industrial purposes is important to fuel economic growth, and competing demands from households, agriculture and industry can cause conflict over water availability and use. Today, more than one billion people still lack access to safe water, while over two billion lack safe sanitation.

The changes to the hydrological cycle will deteriorate the availability of water for human populations, in terms of quantity, quality and accessibility of water supplies. These conditions will be further exacerbated by increasing natural disasters and their impacts on water for human populations.

2.1 Changes in Quantity of Water

Many of the world's countries already struggle under existing water stress from pressures such as irrigation demands, industrial pollution and water borne sewerage. These pressures will be significantly exacerbated by climate change, which for many regions will result in reduced rainfall and increasing temperatures, further reducing the availability of water for drinking, household use, agriculture and industry. As these competing demands intensify under climate change, effective governance for balancing water demands will become essential, particularly in the face of strong pressures to prioritise industrial uses over other uses such as drinking supplies. Estimates based on only a moderate climate change show that by 2025 the proportion of the world's population living in countries of significant water stress will increase from approximately 34 percent (in 1995) to 63 percent. For example, in Africa's large catchment basins of Niger, Lake Chad and Senegal, the total available water has already decreased by 40-60 percent, and desertification has been aggravated by lower than average annual rainfall, runoff and soil moisture, especially in

Northern, Southern and Western Africa. The consequences for water supply include smaller flows in springs and rivers, and decreasing groundwater levels.

2.2 Changes in Quality of Water

The quality of existing water supplies will become a further concern in some regions of the globe. Water acquires most of its geochemical and biochemical substance during its cycle from clouds to rivers, through the biosphere, soils and geological layers. Changes in the amounts or patterns of precipitation will change the route/ residence time of water in the watershed, thereby affecting its quality. As a result, regardless of quantity, water could become unsuitable as a resource if newly-acquired qualities make it unfit for the required use. For example, in areas with relatively high water tables, or under intensive irrigation, increased evaporation due to higher temperatures will raise the concentration of dissolved salts. Further, increased flooding could raise water tables to the point where agrochemicals/ industrial wastes from soil leach into the groundwater supply. Likewise, higher ocean levels will lead to salt water intrusion in coastal groundwater supplies, threatening the quality and quantity of freshwater access to large populations.

2.3 Changes in Accessibility of Water

As water quantities decrease and quality deteriorates as a result of intensification of the hydrological cycle, competition for available resources will intensify. Demand for agricultural and domestic water in particular increases significantly at hotter and drier times of the year. Agriculture has always been the dominant end-use of diverted water; this will only intensify with increasing needs for irrigation brought on by higher temperatures and reduced precipitation, coupled with increasing populations. Meanwhile, demands of industry are expected to become a greater issue in the competition for dwindling resources; in the event of decreasing water tables as a result of climate change, industrial needs will be forced to compete with agricultural and domestic water supply sources, and could lead to conflict.

2.4 Natural Disasters

The increase in natural disasters, primarily floods and droughts, will further exacerbate issues over water availability and water quality. Of particular concern are increased risks from flooding. IPCC has projected that flooding and landslides pose the most widespread direct risk to human settlements from climate change. The UNFCCC predicts that "a future of more severe storms and floods along the world's increasingly crowded coastlines is likely, and will be a bad combination even under the minimum scenarios forecast". Beyond the immediate and apparent devastation caused by flooding, including loss of life and livelihoods, flooding has major impacts on water resources, and hence humans.

2.5 Impacts on Agriculture and Food Security

The predicted changes in quantity, quality and accessibility to water will have important consequences for human populations, through impacts to agriculture and food security, health, economic activity, and conflict over water resources.

Agriculture will be one of the hardest-hit sectors by climate change, reinforcing the unequal distribution of impacts. In addition to pressures caused by population growth and intensified agriculture, warmer temperatures will lead to increased water evaporation, intensifying the need for irrigation precisely as water becomes even less available. It is predicted that water withdrawal for agriculture will rise from 2600 km^3 in 2000 to 3200 km^3 by 2025.

Increasing supply for irrigation will simply not be feasible in many regions, particularly where irrigation capacity is not sufficiently developed to accommodate changing precipitation patterns. In sub-Saharan Africa, for example, where up to 90 percent of agriculture is rain fed, the sector accounts for 70 percent of employment and 35 percent of GNP, and changes in rainfall will have a significant social and economic impact. Meanwhile, it is estimated that a temperature increase of 2-3.5 °C in India could result in a decline in farm revenues of between 9 and 25 percent. According to estimates, for every degree Celsius of night time temperature increase, there is at least a 10 percent decrease in rice production for the African region. While some areas will benefit from longer growing seasons (such as northern Asia), changes in water regimes will render other areas unsuitable for traditionally-grown products, and others areas will become susceptible to new forms of crop and livestock diseases. In regions already affected by food shortage and famine, this could cause further disruptions in food supply.

2.6 Other Impacts

The health implications of changes to water supply are far-reaching. Currently, more than 3 million people die each year from avoidable water-related disease, most of whom are in developing countries. The effects of climate change on water will exacerbate the existing implications of water shortages on human health, as follows:

- Water-borne diseases: result from the contamination of water by human/ animal faeces, or by urine infected with pathogenic viruses/ bacteria, both of which are more likely to occur during periods of flood and therefore intensify with the projected increases in natural disasters under climate change.
- Water-washed diseases: those resulting from inadequate personal hygiene as a result of scarcity or inaccessibility of water (including many water-borne diseases and typhus).
- Water-based diseases: those caused by parasites that use intermediate hosts living in/near water (e.g. guinea worm).
- Water-related diseases: borne by insect vectors that have habitats in/near water (such as malaria). For example, malaria has recently appeared in Nairobi and the highlands of Kenya, illustrating the expanding range of mosquitoes due to warmer temperatures.
- Water-dispersed diseases: infections for which the agents proliferate in fresh water and enter the human body through the respiratory tract.

Reductions in water quantity and quality will require people, particularly women and children, to spend increased time gathering water, detracting from employment and educational opportunities. A greater proportion of household income may need to be spent on water delivered from private sources, such as tankers, to supplement lack of water locally. Further, water is a key input to industrial uses, and decreases in water availability will reduce the amount of industry and hence inputs to the local economy.

3.0 CLIMATE CHANGE IN INDIA

As far as climate change in India is concerned, it is expected that temperatures may increase throughout India and particularly in Northwest and Southeast. As a consequence, evapotranspiration may increase. Another consequence is that there may be more glacial melt for some years, followed by recession of glaciers and less melt later on. Summer monsoon precipitation may increase throughout, but this would be more marked in the Northeast. No significant increase /some decrease in winter precipitation is likely. Rainfall variability may increase and the date of onset of summer monsoon may become more variable. Finally, more extreme rainfall events are likely.

Glacier melt in the Himalayas is projected to increase which may lead to more flooding and rock avalanches from destabilised slopes. This will be followed by decreased river flows after two to three decades as the glaciers recede (Fig. 3). Freshwater availability in Central, South, East and South-East Asia, particularly in large river basins, is projected to decrease due to climate change which, along with population growth and increasing demand arising from higher standards of living, could adversely affect more than a billion people by the 2050s.

4.0 METHODOLOGY TO STUDY CLIMATE CHANGE IMPACTS ON HYDROLOGY

To identify the initiatives that water industry need to undertake to overcome the adverse impacts of climate change on water resources, it is important to determine impacts of climate change on various hydrological variables. To that end, the following methodology can be followed:

- General circulation models (GCMs) are used to simulate future climate under assumed climatic (including GHG emission) scenarios.
- GCM outputs are downscaled to the appropriate scales of hydrological models by applying techniques such as statistical downscaling or regional climate models.
- Hydrologic models are employed to simulate effects of climate change at regional and local scales.
- Outputs from these models serve as inputs to water management models that give more details about the performance of hydro-infrastructure such as a hydro power plant.

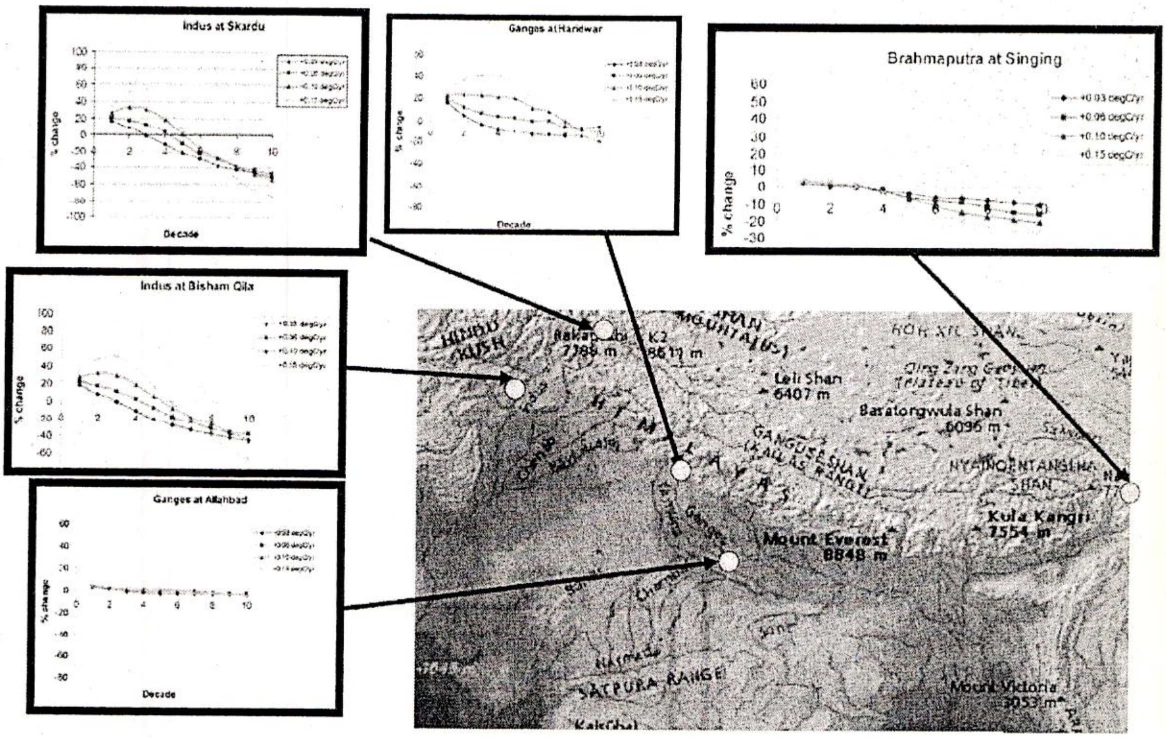

Fig. 3 Impacts of climate change on flows of north Indian rivers [Source: World Bank, 2005].

5.0 CLIMATE CHANGE AND HYDROPOWER GENERATION

Hydropower generation follows a simple concept: water falling under gravity turns blades of a turbine, which is connected to a generator. Basic elements of potential water power are river flow and available head or fall. Hydropower projects may be classified in two major types: Run-of-river (ROR) schemes and storage based schemes. Hydropower stations with storage capacities will have advantage of accommodating increased seasonality in hydrological series and thus the ROR schemes will be more vulnerable to climate change.

Climate change may influence hydropower generation through changed water availability and distribution. If water quantity is reduced, less power will be generated and vice-versa. Further, if flows are concentrated in fewer months, there will be more chances of spill, and less hydropower will be generated. Further, if the precipitation in higher reaches is reduced, less hydropower can be generated in a cascade system of plants.

Climate change could also induce a timing mismatch between energy generation and energy demand. Additionally, higher inflows in monsoon time could lead to greater spillage and less overall energy generation. These and the other potential effects can be studied using an optimization/simulation model of catchment and reservoir system.

5.1 Impacts of climate change on river flow

Climate change will have wide-ranging effects on the environment, and on socio-economic and related sectors, including water resources, agriculture and food security, human health, terrestrial ecosystems and biodiversity and coastal zones. Changes in rainfall pattern are likely to lead to severe water shortages and/or flooding. Melting of glaciers can cause increasing in river discharge, flooding and soil erosion.

Many catchments and rivers are heavily modified by human activities, which will complicate the effect of global warming. The most obvious human interventions are structures and procedures to manage the water (particularly reservoir and interbasin transfer) and abstraction from and return to water courses (all have direct impacts, intentional and unintentional on river flows). Human activities also effect catchments land use, and these also can have significant effect on river regimes and water quality of the river. Land use decisions may be affected by global warming, farmers may alter cropping patterns or crop mixes (or at the extreme, abandon land or cultivate new land), different amounts of agricultural chemicals may be applied, and a policy of afforestation for carbon sequestration would affect catchment water balances.

The variability in extreme discharges for climate change conditions increases with respect to the simulations for current climate conditions. This variability results both from the stochasticity of the precipitation process and the differences between the climate models. The total uncertainty in river flooding with climate change (over 40%) is much larger than the change with respect to current climate conditions (less than 10%). However, climate changes are systematic changes rather than random changes and thus the large uncertainty range will be shifted to another level corresponding to the changed average situation. The impact of climate change on local discharge variability is investigated in the Suir River Catchment which is located in the south-east of Ireland shows that different behavior in the evolution of return levels of extreme discharge events: Strong increases.

5.2 Hydropower Generation

Hydropower generation follows a simple concept: water falling under the force of gravity turns the blades of a turbine, which is connected to a generator. The rotating generator produces electricity. The pre-historic man was aware of the energy contained in falling water. One of the earliest devices to utilize this energy was the water wheel. The Romans used the energy of falling water to do many useful things. They had constructed paddle wheels that turned with the river flow and lifted water to troughs built higher than river level. Before 2000 B.C., the Egyptians and the Greeks knew how to harness the power of river currents to turn wheels and grind grain. More efficient water wheels were built for milling grain in the middle ages. The basic elements of potential water power are river or stream flow and available head or fall through which the stream flow may be utilized in the development of power (power plant).

5.3 Hydropower Potential

Before any power plant is contemplated, it is essential to assess the inherent power available from the discharge of the river and the head available at the site. Let P (mkg/sec) be the potential power for a stream having a head of H (m) and a discharge carrying capacity of Q (m^3/sec). The theoretical potential power can be expressed as:

$$P = wQH\,(m\,kg/\sec) \qquad (1)$$

where w, the specific weight of water = 1000 kg/m^3. This expression written in term of "horse power" and kW would be :

Horse power
$$P = \frac{1000\,QH}{75} = 13.33\,QH \qquad (2)$$

kW
$$P = 0.736(13.33)\,QH = 9.81\,QH \qquad (3)$$

The total energy (in kWHr) that can be produced is:

$$E = \frac{P}{3600} = \frac{9.81\,QH}{3600} = 0.002725\,QH \qquad (4)$$

The total kilowatt-hours of energy computed in equation (4) is assuming 100% efficiency in conversion of potential to electrical energy. Considering the efficiency of the plant, the energy generated is given by:

$$E = 0.002725\,QHe$$

where e is the plant efficiency.

5.4 Hydropower in Past, Present and Future

Hydropower projects have been built successfully for over a hundred years. During this period societal attitudes and needs have changed and science has made good progress. This impacted on the planning, construction and operation of hydropower projects. The first generation hydropower plants were wooden water wheels used for motive power. Around 1880 the first small single purpose hydroelectric plants were built. Over the years more and more projects became multipurpose, making best use of dam projects for irrigation, hydropower, water supply, and flood control. With progress in technology and increasing electricity demand, the maximum size of hydro projects increased. After World War II the pace at which hydro plants were built accelerated, first in the industrialized world and China, and 10–15 years later also in developing countries. Worldwide, most hydro projects were commissioned between 1955 and 1985.

Electricity generation from hydropower makes a substantial contribution to meeting today's increasing world electricity demands. In the mid-1990s hydropower plants accounted for about 19% (or approx. 2500TWh/a) of total electricity production worldwide and produced 31,62,165 GWh of energy worldwide in 2007 (International Energy Agency, 2010). The role of hydropower, along with other renewable energy sources, is expected to become increasingly important in future. World production of hydroelectricity has grown steadily by about 2.3% per year on average since 1980 (European Commission, 2000).

Looking into the future, there are good reasons to expect a revival for hydro in the medium to long term because:

- The depletion of oil and natural gas deposits will lead to higher generation costs for thermal plant in the future, putting hydro in a relatively better position.
- By offsetting thermal generation, hydropower is a leading technology in efforts to reduce greenhouse gases. With the introduction of carbon trading, thermal plant will become more expensive, improving the chances of hydro development.
- HVDC (high voltage direct current) transmission over long distances is becoming cheaper and electricity networks are getting interconnected and growing, improving the prospects for large scale hydro plants in remote areas.
- The ancillary services in electrical networks that can be provided by hydro are increasingly acknowledged and financially rewarded. This adds to the revenues and makes hydro more attractive.
- Due to the growth of the world population, especially in developing countries, new dams will have to be built for irrigation and water supply. The addition of a hydropower component to these projects is economical and has practically no additional environmental or social impacts.
- It is widely believed that, as part of the long-term changes in the energy sector, hydrogen is the fuel of the future. Remote hydro can become one of the major carbon-free financially viable producers of electricity.

5.5 Impact of Climate Change on Hydropower: Brief Review

Hydropower generation depends on availability of water and effective head. The climate change has significant contribution to changes in rainfall intensity and distribution. These changes lead to change in discharge and effective head that caused a change in hydropower production. A search of literature showed only limited studies that have investigated the impact of climate change on hydropower generation.

Lehner et al. (2005) reviewed the potential of hydroelectric power generation in Europe in terms of present, mid-and long-term prospects. Assessments of European hydropower potential presented in the study are based on flow calculations as provided by Water GAP (Water-Global Assessment and Prognosis) model. This model provides a study of current and the future climate and the water use conditions to the river flow time series. The model allows for the analysis of the combined effects of climate change and the demographic, socio-economic and technological trends in large-scale discharge regime. Water GAP model consists of two main components: the Global Hydrology Model and the Global Water Use Model. The Global Hydrology Model simulates the characteristic macro-scale behavior of the terrestrial water cycle and estimates of natural water availability that is defined as the total river discharge, which is a combination of surface runoff and groundwater recharge. The Global Water Use Model consists of four submodels which calculate the water use for household-sector, industry, irrigation, and livestock.

The main results of the model simulations can be summarized as follows:

- Based on climate projections from two different GCMs and a set of scenarios, for the future water use, it is likely that there will be increased availability of water in north and northeast Europe and decrease availability in parts of southern and southeastern Europe.
- Reduction of water resources could occur due to a shift towards a drier climate or a significant increase in water use by humans. The latter is assumed to have a significant effect in Eastern Europe.
- Results from GCM projections for 2070 for Scandinavia and northern Russia show an increase in developed hydropower potential of 15-30% and above. Areas most vulnerable to decline in hydropower potential are Portugal and Spain in the southwest of Europe and Ukraine, Bulgaria and Turkey in the southeast, with decreases of 20-50% or more. In the western and central Europe, the United Kingdom and Germany, a stable developed hydropower potential will be noticed compared with other European countries.
- For the whole of Europe, the gross hydropower potential is estimated to decline by about 6% by the 2070s, while the developed hydropower potential shows a decrease of 7–12%.

Harrison and Whittington (2002) developed a model to assess the relationship between climate change and viability (technical and financial) of the hydro development. Batoka Gorge scheme that is planned on the River Zambezi was used as a case study to validate the model and predict impact of climate change on river flows, electricity production and financial performance. Harrison and Whittington (2002) used three different scenarios of climate change (all available from the IPCC Data Distribution Center). Two of them are HadCM2 GCM and HadCM2-S developed by the Hadley Center in the UK Meteorological Office, HadCM2-S combines the effects of aerosols which have a tendency to cool the atmosphere. The third scenario is the ECHAM4 GCM developed by the Max Planck Institut fur Meteorologie. All the data used to represent the conditions projected for the 2080s and consists of changes in rainfall and temperature relative to the control results which represent the current conditions. Comparison between GCM simulation with the current scenario and potential future climate will illustrate the sensitivity of the case study schemes to climate change.

6.0 FRAMEWORK TO STUDY IMPACT OF CLIMATE CHANGE ON HYDROPOWER GENERATION

The following framework is suggested to study the impact of climate change on hydropower generation:

1. Collect hydrological and meteorological data for the study area along with feature of the reservoir and hydropower plant.
2. Carry out modeling of the catchment area of the hydropower plant. A large number of models are available and the main purpose behind the modeling will be to simulate the inflows to the project. The model should be able to realistically account for the changes in the meteorological and other inputs to the catchment.

3. Construct the likely future climate scenarios in terms of precipitation, temperature and other meteorological variables.
4. Using the model calibrated for the catchment, determine the inflows to the reservoir under the different climatic scenarios.
5. Simulate the operation of the hydropower plant to determine firm energy, firm power, or hydroelectric energy generated by the project under the different scenarios along with the associated reliabilities.
6. Inter comparison of the results of different scenarios will yield the impact of climate change on hydropower generation by the project.

7.0 THE FUTURE

For the future, the IPCC predicts that warming will continue at an accelerated pace, with global mean surface temperature climbing by somewhere between 1.4 and 5.8 C during the 21st century. The primary cause will again be human activity, particularly fossil fuel use and deforestation leading to further increases in atmospheric carbon dioxide concentration.

Unless huge reductions are made in fossil fuel use, the atmospheric CO_2 concentration, now at 370 ppm (a level that has not been exceeded during the last 420,000 years), is expected to reach 560–1,000 ppm by the end of this century. This will raise heating due to greenhouse gases to at least 3 W per m^2 and average global temperatures a further 1.4–5.8 °C. The Panel projects that the 21st century warming will be much larger than that observed during the 20th century and larger than the increase in any century during the last 10,000 years; faster over land than over the oceans; unevenly distributed over land areas, with North America and northern Central Asia warming 40% faster than the global mean, while southeast Asia in summer and South America in winter will warm more slowly.

Anticipated effects of the 21st century warming include:

- A rise in global mean sea level by 10 to 88 cm;
- Continued retreat of glaciers and icecaps and further decreases in Northern Hemisphere snow cover and sea-ice extent;
- An increase in the mass of the Antarctic ice sheet because of greater precipitation, but a decrease in mass of the Greenland ice sheet;
- A weakening of the ocean thermohaline circulation which transports heat from the tropics to high latitudes of the Northern Hemisphere.

For the 22nd century and beyond, the IPCC predicts that:

- increases in atmospheric concentrations of GHGs will take centuries to reverse, even if emissions cease entirely;
- even if atmospheric GHG concentrations are stabilized at present levels, global mean surface temperatures will rise at a rate of a few tenths of a degree per century for hundreds of years;
- rising global mean temperature will result in a continual rise in sea level due to thermal expansion of the ocean;
- ice sheets will react to climate warming and contribute to sea level rise for thousands of years after the climate has been stabilized;
- specifically, a 3 °C local rise in temperature, sustained for millenia, would result in the melting of virtually the entire Greenland ice sheet causing a 7 metre rise in sea level;

- a warming over Greenland of 5.5 °C for 1000 years would likely result in a 3 m rise in sea level due to melting of the ice sheet;
- melting of the West Antarctic ice sheet could contribute up to 3 m to sea level rise over the next 1000 years.

The Panel further predicts that warming during the 21st century may result in the complete, and possibly irreversible, shut down of the thermohaline circulation.

Further Reading

Harrison, Gareth P., and Whittington, H. W. (2002). Susceptibility of the Batoka Gorge hydroelectric scheme to climate change. Journal of Hydrology, 264, 230–241.

Lehner, B., Czisch, G., et al. (2005). The impact of global change on the hydropower potential of Europe: a model-based analysis. Energy Policy, 33, 839-855.

Reports of IPCC and many other relevant publications are available at IPCC web: www.ipcc.ch

Web site of Ministry of Environment and Forests also gives useful information and details about India's initiatives: http://www.envfor.nic.in/cc/index.htm

*** **** ***