Introduction

We know that water is necessary, both for sustainable human development and for the healthy functioning of the planet’s ecosystem. Availability of freshwater globally however, is limited. Out of the 2.7 per cent of a total amount of 1 400 million km$^3$ of freshwater, the major portion occurs in the form of permanent snow cover or deep aquifers and only a small fraction is available for use.

Although India has to support 16 per cent of the world’s population and 15 per cent of livestock, we have only 2.4 per cent of the land and 4 per cent of the water resources of the world. Out of about 4 000 km$^3$ of precipitation in a year, as much as 3 000 km$^3$ comes as rainfall in a short monsoon period of three to four months from June to September. The distribution of the water thus available is not uniform and is highly uneven in both space and time. The average annual water resource potential of the country is estimated to be 1 869 km$^3$. Due to hydrological, topographical and geological limitations, however, only 690 km$^3$ of surface water can be utilized by conventional storage and diversion structures. The annual recharge of groundwater is 433 km$^3$.

Two major problems faced by the country are drought and floods, which are discussed in the succeeding paragraphs:

Floods and drought

Today, droughts and floods are a common feature and their co-existence poses a potent threat, which cannot be eradicated but has to be managed. Transfer of the surplus monsoon water to areas of water deficit is a potential possibility. This would also help create additional irrigational potential, the generation of hydropower, as well as overcoming regional imbalances.

The recurrence of drought and famines during the second half of the 19th century necessitated the development of irrigation to give protection against the failure of crops and to reduce large-scale expenditure on famine relief.

Floods in India

Floods are recurrent phenomena in India. Due to different climatic and rainfall patterns in different regions, it has been the experience that, while some parts are suffering devastating floods, another part is suffering drought at the same time. With the increase in population and development activity, there has been a tendency to occupy the floodplains, which has resulted in damage of a more serious nature over the years.

Often, because of the varying rainfall distribution, areas which are not traditionally prone to floods also experience severe inundation. Thus, floods are the single most frequent disaster faced by the country.

Flooding is caused by the inadequate capacity within the banks of the rivers to contain the high flows brought down from the upper catchments due to heavy rainfall. Flooding is accentuated by erosion and silting of the river beds, resulting in a reduction of the carrying capacity of river channels; earthquakes and landslides leading to changes in river courses and obstructions to flow; synchronization of floods in the main and tributary rivers; retardation due to tidal effects; encroachment of floodplains; and haphazard and unplanned growth of urban areas. Some parts of the country, mainly coastal areas of Andhra Pradesh, Orissa, Tamil Nadu and West Bengal, experience cyclones, which are often accompanied by heavy rainfall leading to flooding.

Area prone to flood

In 1980, Rashtriya Barh Ayog (National Commission on Floods) assessed the total area liable to flooding in the country as 40 million hectares (ha), which constitutes one-eighth of the country’s total geographical area. The Working Group on Flood Control Programme set up by the Planning Commission for the Tenth Five Year

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Plan put this figure at 45.64 million ha. About 80 per cent of this area, i.e. 32 million ha, could be provided with a reasonable degree of protection.

Damage from floods

More significant than the loss of life and damage to property is the sense of insecurity and fear in the minds of people living in the floodplains. The after-effects of flood, such as the suffering of survivors, spread of disease, non-availability of essential commodities and medicines and loss of dwellings, make floods the most feared of the natural disasters faced by humankind.


Flood-prone areas are shown in the map on the page opposite.

Drought

Drought is a recurrent natural feature which results from the lack of precipitation over an extended period of time (e.g. a season or several years). It is a temporary deviation of rainfall and moisture conditions from the mean, thus differing from aridity and seasonal aridity. It is a creeping phenomenon and, unlike other hazards, can last for months and, in severe cases, years. Drought affects virtually all climatic regions and more than one-half of the Earth is susceptible to droughts every year. Regions with higher variability of rainfall and runoff are more vulnerable. Depending on the likely impact, the phenomenon of drought can be categorized in several ways, such as meteorological, hydrological and agricultural. The spatial extent of drought is much greater than for any other hazard and is not limited to basin or political boundaries. Long-lasting droughts lead to degradation of soil, plant and animal habitats and social disruption.

During a severe drought in 1917/1918, the Jhelum River in Kashmir dried up completely. Out of the 328 million ha geographical area of India, 107 million ha (nearly one-third), spread over administrative districts in several states, is affected by drought. It includes about 39 per cent of cultivable land and about 29 per cent of our population. India has experienced 22 major droughts during the last 131 years. The 2002 drought, one of the severest in India, affected 56 per cent of its geographical area, the livelihoods of 300 million people and 150 million cattle in 18 states. The Government of India had to provide relief amounting to about US$ 4 500 million.

Water-resources development in India

India’s population of about 1 billion (2001 census) is expected to stabilize at about 1.6 billion by 2050. This would require some 450 million tonnes of food grain annually. The basic needs for water of rural and urban populations and cattle, as well as industry and environment and ecological management, also have to be met, taking into account land-use policies, degradation of water resources, depletion of aquifers, etc. To this end, long-term planning of the utilization of the country’s water resources is required to meet the various competing demands on a sustainable basis. The strategy for mitigating the effects of drought and floods is the optimal development of scarce water resources.

After independence, planned development of water resources was taken up mainly through the creation of storage projects, as well as extension, renovation and modernization of existing projects. So far, storage capacity of some 213 billion m³ has been created in the country and projects under construction will increase this to 289 billion m³. A further 108 billion m³ is expected to be created through projects under consideration.

Institutional arrangements

At the central level, the Union Ministry of Water Resources is responsible for development, conservation and management of water as a national resource, i.e. for general policy on water resources development and for technical assistance to the states on irrigation, multipurpose projects, groundwater exploration and exploitation, command area

<table>
<thead>
<tr>
<th>Flood damage</th>
<th>Maximum</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area affected</td>
<td>17.5 million ha (1978)</td>
<td>7.63 million ha</td>
</tr>
<tr>
<td>Crop area affected</td>
<td>10.15 million ha (1988)</td>
<td>3.56 million ha</td>
</tr>
<tr>
<td>Population affected</td>
<td>70.45 million (1978)</td>
<td>32.92 million</td>
</tr>
<tr>
<td>Houses damaged</td>
<td>3 507 542 (1978)</td>
<td>1 234 616</td>
</tr>
<tr>
<td>Heads of cattle lost</td>
<td>618 248 (1979)</td>
<td>91 242</td>
</tr>
<tr>
<td>Human lives lost</td>
<td>11 316 (1977)</td>
<td>1 560</td>
</tr>
<tr>
<td>Damage to public utilities</td>
<td>US$ 705 million (1998)</td>
<td>US$ 126 million</td>
</tr>
<tr>
<td>Total damage</td>
<td>US$ 1 255 million (1998)</td>
<td>US$ 307 million</td>
</tr>
</tbody>
</table>
development, drainage, flood control, water-logging, sea-erosion problems, dam safety and hydraulic structures for navigation and hydropower. It also oversees the regulation and development of inter-state rivers. These functions are carried out through various central organizations. Urban water supply and sewage disposal is handled by the Ministry of Urban Development, while rural water supply comes under the purview of the Department of Drinking Water under the Ministry of Rural Development. The subject of hydro-electric and thermal power is the responsibility of the Ministry of Power. Pollution and environment control comes under the purview of the Ministry of Environment and Forests.

Water being a state subject, the state government has primary responsibility for use and control of this resource. The administrative control and responsibility for development of water rest with the various state departments and corporations.

National water policy

The National Water Policy adopted by the National Water Resources Council in April 2002 highlights the provisions for project planning, surface- and groundwater development, irrigation and flood control.

Irrigation plays a major role in increasing the production of food grains. The policy provides following directives for irrigation management:

- Irrigation planning either in an individual project or in a basin as a whole should take into account the irrigability of land, cost-effective irrigation options possible from all available sources of water and appropriate irrigation techniques for optimizing water-use efficiency. Irrigation intensity should be such as to extend the benefits of irrigation to as large a number of farming families as possible, keeping in view the need to maximize production;

- There should be close integration of water- and land-use policies.

- Water allocation in an irrigation system should be done with due regard to social equity and justice. Disparities in the availability of water between head-reach and tail-end farms and between large and small farms should be obviated by adoption of a rotational water distribution system and supply of water on a volumetric basis subject to certain ceilings and rational pricing;

- Concerted efforts should be made to ensure that the irrigation potential created is fully utilized. For this purpose, the command area development approach should be adopted in all irrigation projects.

The following provisions exist in National Water Policy 2002 as regards flood control and moderation:

- There should be a master plan for flood control and management for each flood prone basin;

- An adequate flood cushion should be provided in water-storage projects, wherever feasible, to facilitate better flood management. In highly flood-prone areas, flood control should be given overriding consideration in reservoir-regulation policy, even at the cost of sacrificing some irrigation or power benefits;

- While physical flood-protection works like embankments and dykes will continue to be necessary, increased emphasis should be laid on non-structural measures such as flood forecasting and...
Irrigation developments and protection against droughts

River-valley projects serve a basic necessity of a country whose economy is based largely on agriculture. Irrigation and power are crucial inputs for increased productivity. A high priority has, therefore, been given in the national planning process to the creation of river-valley projects ever since India gained independence. The prominence given to river-valley projects in India’s successive five-year plans is consequent to the contribution to the prosperity of the country by water-resources projects.

As stated earlier, of all natural disasters, drought affects the greatest number of people in the world, especially in India. The occurrence of drought cannot be prevented but being well prepared for its likely occurrence can lessen its impacts. Droughts have two basic components: climatic (decrease in precipitation) and demand (use of water). In responding to droughts, governments tend to concentrate most of their efforts on reducing the demand for water, although there are limited options for controlling the climatic component. Thus, drought-planning strategies should have a clear objective and purpose; involve stakeholder participation; have a good inventory of resources; identify groups at risk; be able to integrate science and technology with policy; publicize the proposed plan and invite public responses; and have an appropriate education programme. The long-term measures for drought mitigation would normally include creation of ground- and surface-water storages, integration of small reservoirs with major reservoirs, integrated basin planning; inter-basin transfer of water, etc. Long-term adaptation involves the development of community-based natural resources management plans, developed and implemented through a participatory approach, and making full use of traditional knowledge.

Thus, most measures focus on management, re-allocation and distribution of existing water resources and on establishing priorities accordingly for different uses. Commonly known means adopted for combating drought and promoting development are:

- Improving national capabilities, including training and human resource development, for assessing water resources and determining water use on a continuing basis and for the planning and management of these resources;
- Conserving water resources and optimizing their use;
- Augmenting the supply of water locally by exploiting surface- and groundwater, taking into account long-term trends, the future demands of local communities and other needs;
- Augmenting the supply of water by transfers from more permanent surface-water sources (lakes and rivers) and from groundwater resources in arid and semi-arid areas and/or long-distance transfers from humid areas if practically and economically possible—and environmentally acceptable.

Many major, medium and minor water-resources projects have been constructed over the past six decades. As a result of this development, the irrigation potential of India increased from about 23 million ha in 1951 to about 102 million ha in 2006, resulting in increased production of food grains from 51 million tonnes to about 212 million tonnes, making the country self-sufficient.

The cultivable area of the country is estimated to be about 186 million ha, of which about 142 million ha is under cultivation. With growing population and industrialization putting pressure on land, it is expected that cultivated area will stabilize at about 140-145 million ha. As irrigated agriculture is more productive than non-irrigated agriculture, it is imperative to irrigate more land in
order to meet the country’s future needs for food and fibre.

Sustained efforts so far have ensured considerable progress, but there is still a long way to go to ensure water for all in adequate quantity and quality. The problems are further compounded by fresh issues that have surfaced over the last few years.

Approach to drought management

The behaviour of the monsoon is usually erratic and uncertain in India. Kharif (summer crop) production depends on the quantum and distribution of rainfall. The behaviour of monsoon is broadly classified as:

- Normal season with normal onset, cessation and distribution of the monsoon;
- Delayed onset of the monsoon;
- Normal onset but early withdrawal of the monsoon;
- Normal onset and cessation but prolonged drought period in between (inter-spell dry period);
- Flood/excess rains;
- Uneven distribution of rain.

The preparations for dealing with such situation, which is necessary to maintain from year to year, are:

- Early warning;
- Early response;
- An efficient intelligence system;
- Timely maintenance of the irrigation system and adoption of a crop stabilization strategy;
- An effective programme of relief works by advance shelf of projects of the works by different departments
- Pre-positioning of adequate foodstuff and their delivery;
- Alternate arrangements for drinking-water supply;
- Construction of deep wells and bore wells and repair of those which are defunct and continuous repair of hand pumps.

Initiative taken for drought management

From 1900 to 2002, droughts in India resulted in 2 750 430 deaths and affected some 900 million people, apart from huge financial losses. It is the creeping effect of drought over long periods and its severity that sensitized the Government of India to treat the problem from several angles—scientific, technological, economic, social and environmental. Some of the initiatives taken for drought management by the Government are:

- Enhancement of the capabilities of long-range forecasts to climate modelling and weather forecasting;
- In 1989, the National Centre for Medium Range Weather Forecasting started to forecast weather on a medium-term basis (3-10 days in advance);
- Monitoring of storage position of reservoirs: 76 important reservoirs of the country having a total live storage capacity of 131.22 billion m³ are being monitored. A further 49 have also been identified for inclusion in the monitoring system, which will increase storage capacity of the monitored reservoirs to 156.69 billion m³, i.e. about 74 per cent of the total capacity of 213 billion m³ created so far;
- Efforts are under way to improve the efficiency of the irrigation system;
- The National Agricultural Drought Assessment and Monitoring System became operational in 1989;
- The National Centre for Disaster Management was set up in 1995 to undertake human-resource development, research, building a database and providing information services and documentation on disaster management;
- Many programmes to prevent/mitigate drought in the long term;
- Supporting research to provide solutions to drought-related problems;
- Setting-up of a National Data Bank under the All India Co-ordinated Project on Agrometeorology at the Crop Research Institute for Dry Land Agriculture, Hyderabad;
- Setting-up of a National Disaster Management Authority.

The new Drought Risk Management Programme under formulation aims to build on the previous Programme’s experience to reduce the vulnerabilities of communities to drought through community-based approaches and appropriate risk management and better decision-support systems at state and district levels.

Approach to flood management

Approaches to dealing with floods may be any one or a combination of the following available options:

- Attempts to modify the flood
- Attempts to modify the susceptibility to flood damage
- Attempts to modify the loss burden
- Bearing the loss.

The main thrust of the flood protection programme undertaken in India so far has been an attempt to modify the flood in the form of physical (structural) measures to prevent the floodwaters from reaching potential damage centres and modify susceptibility to flood damage through early warning systems.
Structural measures

The following structural measures are generally adopted for flood protection:

- Embankments, flood walls, sea walls
- Dams and reservoirs
- Natural detention basins
- Channel improvement
- Drainage improvement
- Diversion of flood waters.

Of these measures, embankments are the most commonly undertaken in order to provide quick protection with locally available material and labour. The major embankment projects taken up after independence are on the rivers Kosi and Gandak (Bihar), Brahmaputra (Assam), Godavari and Krishna (Andhra Pradesh), Mahanadi, Brahmani, Baitarni and Subarnarekha (Orissa) and Tapi (Gujarat). These embankments play an important role in providing reasonable protection to vulnerable areas. Realizing the great potential of the reservoirs in impounding floodwaters and regulating the flows downstream for flood moderation, flood control has been sought to be achieved as one of the objectives in multipurpose dams. Reservoirs with a specifically allocated flood cushion have been constructed on the Damodar system in Jharkhand and the Hirakud and Rengali dam in Orissa. However, many other large storage dams, e.g. Bhakra dam, without any earmarked flood storage, have also helped in flood moderation.

During the post-independence period, multi-purpose projects such as the Damodar Valley Corporation (DVC) reservoirs, the Bhakra-Nangal project, Hirakud dam, Nagarjunasagar project etc., have been constructed to increase food production, energy generation, drinking-water supply, fisheries development, employment generation, flood moderation, etc. These large dams have played a significant role in reducing damage by way of flood moderation. One of the important flood moderation examples achieved by dams is that of Damodar Valley, where four reservoirs were constructed with flood management as one of the objectives. During the 2000 monsoon, DVC reservoirs saved the life and property of people from a possible disaster through flood moderation.

Up to 2005, 34,398 km of new embankments and 51,318 km of drainage channels were constructed. In addition, 2,400 town protection works were completed and 4,721 villages were raised above flood levels. Barring occasional breaches in embankments, these works gave reasonable protection to an area of some 16.5 million ha.

Non-structural measures

Non-structural measures include:

- Flood forecasting and warning
- Floodplain zoning
- Flood fighting
- Flood proofing
- Flood insurance.

A brief description of the most important measure, i.e. flood forecasting, and the progress made so far is given below.

Flood forecasting and warning network in India

Of all the non-structural measures for flood management which rely on the modification of susceptibility to flood damage, the one which is gaining increased/sustained attention of planners and acceptance by the public is flood forecasting and warning, which enable forewarning as to when the river is going to use its floodplain, to what extent and for how long. As for the strategy of laying more emphasis on non-structural measures, a nationwide flood forecasting and warning system has been established by the Central Water Commission.

Flood forecasting and flood warning in India commenced in a small way in the year 1958 with the establishment of a unit in the Central Water Commission, New Delhi, for flood forecasting for the river Yamuna at Delhi. This has now grown to cover most of the flood-prone interstate river basins. The Central Water Commission is currently responsible for issuing flood forecasts at 173 stations, of which 145 are for river stage forecast and 28 for inflow forecast. On average, about 6,000 flood forecasts are issued every year with a maximum of 7,943 forecasts in 1998. The forecasts issued by the Central Water Commission have been consistent with about 96 per cent accuracy as per the present norms of the Central Water Commission. A forecast is considered to be reasonably accurate if the difference between forecast and corresponding observed level of the river lies within ±15 cm. In the case of inflow forecasts, variations within ±20 per cent are considered acceptable, as a result of which the flood-forecasting and warning services have rendered immense benefit to those in flood-prone areas.

Modernization of flood forecasting services

The Central Water Commission is making a constant endeavour to update and modernize forecasting services on a continuous basis to make flood forecasts more accurate, effective and timely. Initiatives being taken for modernizing flood forecasting services are:

- The establishment and modernization of the flood forecasting network, including inflow forecast through automated data collection and transmission; use of satellite-based communication systems through very small aperture terminals; and improvement of forecast formulation techniques using computer-based catchment models;
- Development of a decision-support system for flood
forecasting and inundation forecast model for the Mahanadi basin and flash flood forecasting for Sutlej basin;

• Development of a real-time flood-forecasting system for the Brahmaputra and Barak basin, envisaging data collection through automatic sensors and transmission through satellite and forecast formulation using a computer-based mathematical model.

Disaster management in India

India has traditionally been vulnerable to natural disasters on account of its unique geoclimatic conditions. Floods, droughts, cyclones, earthquakes and landslides have been recurrent phenomena. About 60 per cent of the landmass is prone to earthquakes of various intensities; over 45 million ha are prone to floods; about 8 per cent of the total area is prone to cyclones and 68 per cent of the area is susceptible to drought. In the decade 1990-2000, an average of about 4 344 people lost their lives and 30 million were affected by disasters every year. The loss in terms of private, community and public assets was astronomical.

Over the past couple of years, the Government of India has effected a paradigm shift in its approach to disaster management. The new approach derives from the conviction that development cannot be sustainable unless disaster mitigation is built into the development process. Another cornerstone of the approach is that mitigation has to be multi-disciplinary, spanning all sectors of development. The new policy also emanates from the belief that investments in mitigation are much more cost-effective than expenditure on relief and rehabilitation.

Disaster management occupies an important place in this country’s policy framework, as it is the poor and the underprivileged who are worst affected by calamities/disasters.

The steps being taken by the Government emanate from the approach outlined above. This has been translated into a National Disaster Framework (roadmap) covering institutional mechanisms, a disaster prevention strategy, early warning systems, disaster mitigation, preparedness and response and human resource development. The expected inputs, areas of intervention and agencies to be involved at the national, state and district levels have been identified and listed. There is now, therefore, a common strategy underpinning the action being taken by all the participating organizations/stakeholders.

Institutional and policy framework

The institutional and policy mechanism for carrying out response, relief and rehabilitation has been well-established since independence. These mechanisms have proved to be robust and effective.

At the national level, the Ministry of Home Affairs is the nodal ministry for all matters concerning disaster management. The Central Relief Commissioner in the Ministry of Home Affairs is the nodal officer to coordinate relief operations for natural disasters. The Central Relief Commissioner receives information relating to forecasting/warning of a natural calamity from the India Meteorological Department or the Central Water Commission of the Ministry of Water Resources on a continuous basis.

National Crisis Management Committee (NCMC)

The Cabinet Secretary, who is the highest executive officer, heads the NCMC. Secretaries of all the ministries/departments concerned, as well as organizations, are members of the Committee. The NCMC gives direction to the Crisis Management Group as deemed necessary. The Secretary, Ministry of Home Affairs, is responsible for ensuring that all developments are brought promptly to the notice of the NCMC. The NCMC can give directions to any ministry/department/organization for specific action needed for meeting the crisis situation.

Crisis Management Group (CMG)

The Central Relief Commissioner in the Ministry of Home Affairs is the Chairman of the CMG, comprising senior officers (called nodal officers) from various concerned Ministries. The CMG’s functions are to review every year contingency plans formulated by various ministries/departments/organizations in their respective sectors and measures required for dealing with a natural disaster, coordinate the activities of the central ministries and state governments in relation to disaster preparedness.
and relief and to obtain information from the nodal officers on measures relating to above. In the event of a natural disaster, the CMG meets frequently to review relief operations and extend all possible assistance required by the affected states to overcome the situation effectively. The Resident Commissioner of the affected state is also associated with such meetings.

Control Room (Emergency Operations Centre)

An Emergency Operations Centre (Control Room) exists in the nodal Ministry of Home Affairs, which functions round the clock, to assist the Central Relief Commissioner in the discharge of his duties. The activities of the Control Room include collection and transmission of information concerning natural calamity and relief, keeping close contact with governments of the affected states, interaction with other central ministries/departments/organizations in connection with relief, maintaining records containing all relevant information relating to action points and contact points in central ministries etc., and keeping up-to-date details of all concerned officers at the central and state levels.

Contingency Action Plan

A national Contingency Action Plan (CAP) for dealing with contingencies arising in the wake of natural disasters has been formulated by the Government of India and is periodically updated. It facilitates the launching of relief operations without delay. The CAP identifies the initiatives required to be taken by various central ministries/departments in the wake of natural calamities, sets down the procedure and determines the focal points in the administrative machinery.

State relief manuals

Each state government has relief manuals/codes which identify the role of each officer in the state for managing natural disasters. These are reviewed and updated periodically, based on the experience of managing the disasters and the needs of the state.

Funding mechanisms

The policy and funding mechanisms for providing relief assistance to those affected by natural calamities are clearly laid down. They are reviewed by the Finance Commission appointed by the Government of India every five years. The Finance Commission makes recommendations regarding the division of tax and non-tax revenues between the central and state governments and also regarding policy for provision of relief assistance and their share of expenditure thereon. A Calamity Relief Fund has been set up in each state as per the recommendations of the 11th Finance Commission. The size of the Calamity Relief Fund was fixed by the Finance Commission after taking into account the expenditure on relief and rehabilitation over the past 10 years.

Cyclone forecasting

Tropical cyclones are intense low-pressure systems which develop over warm sea. They are capable of causing immense damage due to strong winds, heavy rains and storm surges. The frequency of a tropical cyclone in the Bay of Bengal is four to five times more than in the Arabian Sea. About 35 per cent of initial disturbances in the northern Indian ocean reach tropical cyclone stage, of which 45 per cent become severe.

The India Meteorological Department is mandated to monitor and give warnings of tropical cyclones. The monitoring process has been revolutionized by the advent of remote-sensing techniques. A tropical cyclone intensity analysis and forecast scheme has been worked out, using satellite image interpretation techniques which facilitate storm surge forecasting. The meteorological satellite has made a tremendous impact on the analysis of cyclones.

Case studies—impact of water development on flood and drought management

Dams and reservoirs have played a major role in moderating flood-peaks and providing safeguards for drought mitigation. Case-studies of two such projects are presented below:

Hirakud Reservoir

The Hirakud Dam Project is built across the River Mahanadi about 15 km upstream of the town of Sambalpur in the state of Orissa. It is the first post-independence major multipurpose river valley project in India.

The project provides 155 635 ha of kharif (summer crop) and 108 385 ha of rabi (winter crop) irrigation. The water released through the powerstation irrigates a further 436 000 ha of Culturable Command Area in the Mahanadi delta. Installed capacity for power generation is 307.5 MW. Besides, the project provides flood protection to 9 500 km² of delta area. The gross capacity of Hirakud dam is about 8 105 million km² and the spillway capacity is 4 595 m³/s.

Hirakud reservoir has no earmarked flood storage. The entire available storage during monsoon is utilized for flood moderation and subsequently used for irrigation purposes and hydropower generation. Hirakud dam was to provide adequate flood protection to the delta from all but extraordinary floods. Mahanadi delta has witnessed many high floods which caused extensive damage, as in 1834, 1855, 1866, 1872, 1933 and 1937. With the construction of Hirakud dam, the swollen waters of Mahanadi in the monsoon period have been tamed to a great extent. In the 90 years before the construction period during (1866-1957), 27 years witnessed high floods...
in the delta whereas, in the post-construction period during the last 41 years (1959-1998), floods in the delta were reported in only 7 years.

Out of 24 events, in the absence of Hirakud dam, a peak flood at the head of the delta would have exceeded the catastrophic value of 33,980 m³/s on 19 occasions against the five times it actually exceeded due to flood moderation provided by Hirakud dam.

From the above, it can be seen that about 10-30 per cent flood moderation has been achieved by Hirakud dam.

**Bhakra dam**

The Bhakra project consists of a 225.55 m high dam on the Sutlej River, with a reservoir area of 168.35 km² at full storage level, as well as thousands of kilometres of canals and several inter-basin diversions. The gross capacity of Bhakra is 9,621 million m³ and spillway capacity is 8,512 m³/s. The installed generation capacity is 1,354 MW. The dam, built between 1947 and 1963, brought irrigation to some 2.8 million ha to the states of Punjab, Haryana and Rajasthan. The dam also envisages catering to irrigation and hydropower needs and has dramatically improved the economy of the area. The deserts of Rajasthan have been converted into a food bowl with the availability of water through the Rajasthan Canal whose source is the Bhakra dam.

The explosive growth in agricultural production in the late 1960s and 1970s in Punjab and Haryana is attributed to the Bhakra project. Prior to its construction, the irrigation area was less than 0.8 million ha, which, after the project, increased to about 5.5 million ha. The project was credited with single-handedly relieving India of dependency on foreign food aid and creating food self-sufficiency. In the process, the project has almost become a legend in India and is regularly cited to justify large dam-based irrigation projects. It generates 7,000 million units of electricity every day and has made electricity available at affordable rates.

**Conclusions**

India is a developing country which needs to take a balanced view of development. India has a long history of irrigation development. It continued at a slow pace until partition. Since independence, the Government has given highest priority to irrigation to offset severe food deficit and consequent import of food grains. Countrywide programmes were taken up for surface- and groundwater resources development through large and medium river valley projects. National water policy has been a good step in evolving national consensus on the planning, development and
There is an imperative need for harnessing and utilizing riverwater for irrigation supplies, generation of power and flood control on a sustained basis through these development projects. Reasonable protection has been provided to about one-third of the flood-prone areas of the country. Despite significant outlay on flood control, flood protection and catchment protection works, it has been found that there is no complete solution to providing total protection. Flood cushions in the reservoirs and flood embankments have provided good solutions for recurring floods and have provided relief to large-scale flood damage. Flood forecasting provided by the Central Water Commission has played a significant role in minimizing flood damage and saving human lives. For addressing natural calamities such as floods and drought, there is a need to make full use of existing schemes and priority needs to be given to the implementation of schemes that will help overcome the conditions created by the calamity. A major scheme, namely Bharat Nirman, to bring 10 million ha under assured irrigation over a period of four years (2005-2009) through completion of ongoing major, medium and extension renovation and modernization projects, the repair, renovation and restoration of water bodies and groundwater development for irrigation has been taken up by the Government of India. Note: The views expressed in the article are those of the authors and not necessarily those of the Central Water Commission.