Flood Management in Integrated River Basin Development

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Abstract
Integrated river basin development aims at the optimum use of basin water resources to best meet all of the water needs of the basin. It is a tool that can be used to address issues related to both the positive and negative aspects of floods and droughts in a basin. Effective flood management needs to consider the whole basin as a hydrological unit as well as to consider what is the most appropriate approach for the sustainable development of water resources. It also requires careful consideration of any methods that can be used to conserve floodwater for use in the dry season while reducing flood losses. Experience has shown that a judicious mix of both structural and non-structural measures can increase any benefits that would accrue from structural measures alone. While work will continue on measures for physical flood protection such as dams, reservoirs, flood embankments, and anti-erosion structures; it will be necessary to augment these with non-structural measures like flood-forecasting and flood plain zoning in order to minimise losses.

This paper deals with flood management in the development of river basins. Various aspects of flooding and its management by both structural and non-structural measures are discussed, together with the experience gained in adopting these measures in India during the last five decades and case studies.

Integrated River Basin Development

A river basin is the most appropriate hydrological unit around which to focus management and planning of water resources. Within a river basin, comprehensive account can be taken of all the supplies of water: precipitation, interbasin transfers, and surface and ground water storage (and their variation and demands including spatial, temporal, and sectional variations). Social, environmental, legal, policy, and other objectives and constraints have to be taken into account, in addition to economic objectives and technical and physical constraints. Integrated river basin development aims at the optimum utilisation of basin water resources to best meet all of the water needs of the basin. At the same time it should also minimise the negative impacts of natural occurrences such as floods and droughts and in so doing, create a suitable balance between water supply and demand in the river basin. In order to do this properly both the supply to the basin (water resources) and the demands from it (including irrigation, power, domestic and industrial water requirements, and minimum flow requirements for navigational, ecological, and religious purposes), need to be assessed. In assessing the demands for water, it is also necessary not only to take into account the increase that will result from the growth in population but also the increase that usually accompanies the shift from traditional rural to modern urban life.

The United Nations Water Conference held in Mar-del Plata, Argentina, in 1977 recommended the formulation of a master plan for countries and river basins to provide a long-term perspective for planning, including resource conservation. The International Conference on Managing Water Resources for Large Cities and Towns, held in Beijing, China, from 18-21 March 1996, also recommended that the river basin be taken as the basic unit for water resources management.

As a result of the variation in time and space for the demand and supply of water, in India a lot of water goes to waste during the rainy season that could be utilised during the dry season. The excessive and unregulated supply of water during the monsoon creates havoc and wastes water. Equally, during the dry period so little water is available that even the most essential demands for drinking water can hardly be met. The hope is that a proper river basin development plan will preserve the monsoon flow and release it during the dry period in a regulated way. In this way flood management is an important component of river basin development.

Flood Problems

Floods continue to plague many parts of the world causing phenomenal losses. About 86% of the total world land area is occupied by the river basins of large and small rivers. Historical records of water stages and floods are not available for all of this land area; however, the recording of flood discharge data started in around 1500 AD and a large flood of about 1400 cumecs was recorded for the Danube in 1501. Very large floods exceeding 50,000 cumecs have been recorded in the Amazon (Brazil); Lena (USSR); Yenisey (USSR); Brahmaputra, Ganges, Godavari, and Narmada (India); Ganges (Bangladesh); Yangtze-Kiang (China); Mekong (Cambodia); Mississippi (USA); and Irrawaddy (Myanmar). Some important historic floods are listed in Table 1.

Table 1: Some important historic floods

Country	River (gauge station)	Date	Flood discharge (cumecs)	Drainage area (sq.km)
Australia	Budekin (Clare)	17.02.1968	27,043	
Bangladesh	Brahmaputra (Jamuna) Ganges (Hardinge bridge)	01.08.1955 not available	93,500 70,790	530,000 1,073,070
Brazil	Amazon (Obidos)	22.05.1944	227,000	4,688,000
Myanmar	Irrawaddy	1877	62,700	360,000
China	Yangtze-Kiang	Not available	84,950	Not available
Egypt	Nile (Aswan)	Not available	13,500	3,000,000
Ghana	Volta (Senchi)	1963	14,272	394,095
India	Godavari (Dowleswaram) Brahmaputra (Pandu) Narmada	17.09.1959 Not available Sept. 1970	88,350 73,620 70,790	314,684 934,990 98,420
Cambodia (Khmer)	Mekong (Kratie)	1939	75,700	646,000
Madagascar	Mangoky (Banian)	09.01.1956	14,800	Not available
USA	Mississippi (Columbus) Ohio (Cairo)	27.02.1937 04.02.1937	70,792 55,218	2,387,950 528,300
USSR	Lena (Kusur) Yenisey (Igarka) Volga (Volgograd) Amur (Kombomolsk)	11.06.1944 03.06.1937 29.05.1926 1876	194,000 132,000 51,900 50,000	2,430,000 2,440,000 1,350,000 1,700,000
Zambia	Zambezi (Kariba)	05.03.1958	16,990	633,040

Flooding Problems in Selected Countries

In China, the occurrence of annual rainfall over a relatively short period of time, and the fact that the population and property are concentrated in flood prone areas, contribute to the occurrence of flood disasters. Floods in Hong Kong are particularly severe as they result from of a critical combination of two factors: heavy rainfall and an abnormal rise in sea level as a result of storm surges during typhoons. Although the urbanised metropolitan areas are relatively free from flooding, significant flood problems are being experienced in the low-lying areas of the rural districts in the New Territories. As a result of recent developments in those areas, natural flood plain storage has been reduced and as a result flooding is becoming more frequent and severe.

In Japan, the rapid urbanisation of river basins has reduced the water retaining and retarding capacities of the land, increased the volume of flood flows, reduced the time of flood concentration, and increased the danger of flood disasters. These facts are compounded with the reality that about 50% of the population and 70% of the nation's assets are located in flood prone areas that occupy only 10% of the total land area. The flood potential in Japan now ranks amongst the highest for any industrialised country.

Flood damage in the Lao People's Democratic Republic is caused primarily by the overflowing of the Mekong River, which brings heavy floods, and secondarily by the overtopping of its tributaries. The frequent flooding of the Vientiane Plain and the southern region caused by the overflow of the Mekong River and its tributaries routinely inflicts significant damage on important cultivated areas. Flash floods occur in many small steep catchments in the northern and southern regions of the country. The city of Vientiane and its surrounding area can be flooded for periods of about two weeks. The cost of the damage to this urban, and the surrounding rural, areas can amount to tens of millions of dollars.

Kuala Lumpur, the capital of Malaysia, has routinely suffered flooding caused by overflow from the Klang River (and its tributaries) since the city was first founded. The rapid urbanisation of the city itself and the bowl shaped topography of the adjacent area are mostly to blame for this frequent flooding.

In the Philippines, the annual damage resulting from flooding is enormous in both social and economic terms. The flood situation is aggravated by the uncontrolled development taking place on flood plains, the exploitation of basin watersheds, the sedimentation of waterways, and the reduction in wetland storage areas owing to rapid urbanisation. Despite improvements in flood protection measures, flood problems continue to grow and associated flood damage persists; these are mainly the result of partially implemented schemes and still insufficient protection measures.

The Republic of Korea has frequently suffered flooding in some of its major cities. As a result, many lives are lost, large populations are displaced, and property damage amounting to millions of dollars is suffered annually. The insufficient capacity of pumping stations, insufficient secondary drainage facilities, and rapid urbanisation of previously rural areas are all partly to blame.

Floods constitute a severe hazard to the people of Thailand and impede economic growth in flood affected areas. On average, Bangkok suffers significant flood damage once every five years; overland flow and local drainage problems, often prolonged by high water levels in the Chao Pharaya river, commonly cause this flooding. Rural areas in Thailand also routinely suffer considerable flooding.

Vietnam experiences many flood catastrophes throughout the country. The magnitude of flooding in urban and rural areas is such that it poses a significant problem, especially in areas where existing levee systems have failed.

In India, any area that has at any time been subjected to flooding is henceforth designated a flood prone area, unless measures have been taken to effectively protect it. The Rashtriya Barh Ayog (National Commission on Floods 1980) designated 40 mha to be natural flood prone areas in the country. Of these, about 32 mha can be provided with a reasonable degree of protection. Data from1953 to 2000 show that annually a mean area of 7.56 mha has been affected by floods, with a range from 1.46 mha (1965) to 17.5mha (1978). On average, floods affected about 33 million people between 1953 and 2000, and in future many more may be affected as a result of population growth in affected areas. Many cities, including Delhi and some state capitals, are among the places that have been affected by floods in the past (IRS 2001).

Causes of Flood

The major causes of floods are:

- inadequate capacity of a river to contain high flows within its banks;
- river bank erosion and silting of river beds;
- landslides leading to obstruction of flow and changes in the river courses;
- simultaneous flooding in a main river and its tributaries so that high flood flows occur in all rivers at the same time;
- retardation of flows due to tidal and backwater effects resulting in the stagnation of floodwater;
- poor natural drainage in flood prone areas;
- cyclones and associated heavy rainstorms/cloudbursts; and
- snowmelt and glacial lake outbursts.

Floods: Some Typical Phenomena

Flash Floods

Flash floods are characterised by a very fast rise and fall of flows of small volume and high discharge, which can cause great damage because of their suddenness. They occur in hilly regions and sloping lands where heavy rainfall and thunderstorms or cloudbursts are common. Severe flash floods in Arunachal Pradesh and Himachal Pradesh in India during the year 2000 are discussed below as examples. Large reservoirs downstream of flash flood prone areas can usually absorb the resultant flood wave, impeding the progression of the flood (IRS 2001).

Flash Flooding in the Siang River in Arunachal Pradesh – June 2000
In Arunachal Pradesh the Siang river (also known as the Tsang-Pho in Tibet and Brahmaputra in Assam) experienced flash flooding on the 11th and 12th of June 2000.

There was no heavy rainfall or cloudburst preceding the flood. All of a sudden floodwaters entered the Gelling area from its source: the Tsang-Pho river. The water level rose rapidly; with a rise of 3.2 m in one hour and total rise of 5.3 m in nine hours, but receded quickly thereafter. This flash flood inundated vast areas in four districts on both sides of the river including the Passighat Township causing considerable losses. The flood was caused by a breaching of a natural dam caused by landslides within the Tibetan Plateau area of the upstream catchments.

Flash flooding in the Sutlej river in Himachal Pradesh – August 2000
A flash flood was experienced in Himachal Pradesh in the night of 31 July to 1 August 2000. The discharge in the Sutlej river at the Rampur site rose sharply from 1,527 cumecs (54,000 cusecs) to 5,092 cumecs (180,000 cusecs) between 03:00 hrs and 05:30 hrs. Discharge at Suni downstream of the above site rose from 1,827 cumecs (64,600 cusecs) to 6,082 cumecs (215,000 cusecs) in 2 hours, but the water level receded very quickly thereafter. This flash flood caused widespread damage to life and property in the Kinnour district, where it washed away almost all the bridges and their surrounding villages. Rampur, another town downstream, also suffered heavy damage. Further downstream, this flood, which had a huge discharge but small total volume, was absorbed by the Bhakra reservoir; the reservoir level increased only marginally. A lake outburst or the failure of a landslide blockade in the upstream catchments in the Tibetan plateau area of China is suspected to be the cause.

Littoral Drift in River Estuaries

The flood problems of deltaic regions are attributed to various causes including the flatter slopes of drains and backflow due to tides. Littoral drift of sand, in the form of sand dune formations, and the consequent choking of river outfalls into the seas, is a specific problem in deltaic regions. The Biccavole and Tulabhaga drains in the Godavari Eastern delta, and the Panchnadi, Lower Kowsika, Vasaltippa, and Kunavaram drains in Godavari Central delta in India are some of the problem reaches. Straight cuts into the sea with to make the slopes steeper or outfall reaches shorter are sometimes considered effective measures to address this problem.

Snowmelt/Glacial Lake Outbursts/Natural Landslide Dam Failure

Snowmelt is a gradual process and does not usually result in major flooding. Glacier melt is usually slower than snowmelt and is not capable of causing severe flooding. But some glaciers hold large quantities of bound water in impound lakes, which may be suddenly released when ice jams melt resulting in a glacial lake outburst flood (GLOF). The rivers originating in the Himalayas are also fed by snowmelt from glaciers. In 1929, an outburst of the Chong Khundam glacier (Karakoram) caused a flood peak of over 22,000 cumecs at Attock. A glacial lake outburst is suspected to be the cause of the Sutlej river flash flood in 2000. Similar effects can occur when a natural dam, caused, for example, by a landslide, breaches.

Cyclones and Storm Surges in Coastal Areas

Floods in coastal areas can be caused by rainstorms, which are generally associated with low-pressure systems like well-marked lows, depressions, or tropical cyclones. During the past 109 years (1891–2000) over 1000 tropical cyclones and depressions originating in the Bay of Bengal and the Arabian Sea moved across the Indian subcontinent. Passage of such storms in quick succession over a river basin invariably leads to severe flooding. The soil is generally fully saturated after the passage of the first storm, which means that the rainfall from any subsequent storm will most probably lead to flooding. In India, coastal areas of Andhra Pradesh, Orissa, Tamilnadu, and West Bengal generally experience cyclones and extensive flooding as a result. The flood in the coastal belt of Orissa in October 1999 that resulted from a super cyclone combined with heavy rainfall is an example of one of the worst cases.

Cloudbursts

Sudden unexpected heavy rains resulting from particular climatic conditions, known as cloudbursts, can also cause flooding. During the year 2000, the coastal districts of Andhra Pradesh in India experienced floods of this type. A cyclonic circulation during monsoon conditions can also cause cloudbursts that lead to flooding. In July 1981 this type of situation developed over East Rajasthan (a traditionally a dry area) and many stations around Jaipur recorded more rain in three days than is usually experienced in the entire year. Annual rainfall in East Rajasthan varies from 550 mm to 700 mm. During the cloudburst the daily rainfall was 250-590 mm (2-day rainfall of 430-800 mm and 3-day rainfall of 450-900 mm) and this excessive precipitation led to flooding.

Human Activities

Human activities, whether inadvertent or intentional, can also sometimes lead to flooding. Sudden breaches in dams or reservoirs can cause devastating floods. There are many examples of dams in diverse places around the world that have failed for a variety of reasons. These failures include the following.

- The Puentes Dam in Spain (69m high, 291m long, masonry gravity): constructed in 1791, failed in 1802 due to internal erosion, leading to the abandonment of the project.
- The Gallians Dam in the USA (29m high, 210m long, masonry gravity): constructed in 1910 failed in 1957 due to submersion.
- The Banqiao dam in China (24.5m high, 2.02 km long, earthfill), constructed in 1956, failed in 1975 due to insufficient capacity of spillway and submersion.
- The Machhu-II dam in India (24.7m high, 3.9 km long earthfill/concrete gravity) constructed in 1972, failed in 1979 due to overtopping and pressure of silt. The failure caused severe damage to the town of Morbi downstream.

With the construction of dams, the chances of flooding in the downstream reaches are reduced to a great extent. This creates a false sense of security and people tend to occupy more and more of the flood plains thereby reducing the actual carrying capacity of the river. As a result, even small releases from the reservoirs sometimes create flood situations in the downstream flood plains. Reservoirs like the Damodar and Ukai in India, where there has been large-scale encroachment of the flood plains downstream, are prime examples. When embankments protect flood plains, a false sense of security also prevails and the fact that a flood beyond the design frequency can overtop the embankment is often overlooked. Some examples of such cases are cited below.

The drainage capacity of the Lower Damodar river has deteriorated considerably since the construction of the Damodar Valley Corporation (DVC) reservoir. Measures for relieving the surface drainage congestion in the lower basin could not be taken up simultaneously with the upland storage. The moderation of the flood peak encouraged further encroachment into the channel waterway downstream, and this tendency could not be controlled. The cumulative result of these factors has been that although the outflow has been reduced to <25% of the inflow, flooding still occurs in the lower basin. The problem becomes more acute, when release from the reservoirs occurs simultaneously with uncontrolled runoff from the catchment.

The Ukai dam is the terminal dam on the river Tapi, harnessing a catchment area of about 62,000 sq. km up to the dam site. The Ukai dam was designed to reduce the peaks of incoming floods and has a large storage space reserved for flood control, thereby providing considerable relief to the downstream areas. Over the years, however, the downstream reach of the Ukai dam (near the city of Surat) experienced flooding whenever there was excessive release of water from Ukai dam. The flooding was due to a number of developments including considerable reduction in the safe carrying capacity of the river channel, extensive encroachment of flood plains around the city of Surat, silting of the river channel, and the effect of tides. When the dam was constructed in the seventies, a design discharge of 24,045 cumecs (850,000 cusecs) was considered safe for the river Tapi in the Surat city area. As a result of subsequent developments and human activities in the areas downstream of the dam, especially around Surat itself, the safe discharge capacity was reduced to about 11,315 cumecs (400,000 cusecs). During the last 5-6 years, the Ukai reservoir has twice experienced high inflows as a result of flood conditions in the upstream reaches. The dam authorities were forced to release more than19,802 cumecs (700,000 cusecs). The result was extensive inundation of low-lying areas in and around the city of Surat. State government authorities are proposing various measures to solve the problem, one of which includes a proposal for real-time automatic data transmission and inflow/ flood forecasts.

Positive and Negative Effects of Floods

Since time immemorial, floods have been responsible for the loss of human life, cattle and other farm animals, crops, and valuable property all over the world. Floods also adversely affect communication systems like roads, railways, and telecommunications; it is generally agreed that floods have caused untold misery to humankind. While there are several negative effects of floods, there are a few positive effects also. One positive effect is that floods can deposit silt, which acts as a fertiliser and eventually increases crop production after the flood recedes. In some cases, however, floods deposit coarse sand, which is harmful to production. Another advantage is that floodwaters recharge the aquifers on riverbanks. This water can be drawn after the floods and used for irrigation and drinking water. In Delhi, this component is used to maintain a significant portion of the domestic water supply.

Flood Control Vs. Flood Management

In the middle of the 20th century, flood problems drew attention in South Asia. In India, the earlier approach had been to control flooding by structural measures, specifically by the construction of flood embankments and anti-erosion structures for the protection of riverbanks. Flood cushions were also provided in some reservoirs. However, it was soon realised that even though flooding could be reduced using these measures, it would never be possible to totally control floods. It was also recognised that it would not be possible to provide permanent protection to all flood prone areas for all magnitudes of floods. Providing protection would involve factors as diverse as the topographic limitations of the region as well as financial investment – and would entail prohibitively high cost of construction and maintenance.

Experience also showed that the loss of life and property could be reduced considerably by using non-structural measures such as reliable advance warning about incoming floods, flood proofing, and flood plain zoning. People can move to safer places in an organised manner as soon as advance flood warnings are received, and moving them to safer places can save valuable property and cattle. Hence, the practical approach that is now widely adopted in flood management, and which can provide a reasonable degree of protection against flooding at a reasonable economic cost, is a combination of both structural and non-structural measures.

Flood Management Strategy

Flood Management activities can be broadly classified in four major categories.

- Modifying the floods in order to keep the flood waters away from developed and populated areas by decreasing runoff, increasing channel capacity, or containing, diverting, or storing flood waters
- Modifying susceptibility to flood damage by keeping people and developed areas out of flood hazard areas or by insuring that such developed areas are flood-proof
- Modifying the loss burden by reducing the financial and social impact of flooding by providing post flood assistance and insurance
- Bearing the losses

All these measures for flood management can be classified as either structural or non-structural measures. Measures taken up under 'modifying the flood' are mostly physical measures and are termed 'structural measures', while those under the other three headings are mainly 'non- structural measures'.

Structural Measures

Flood management in the form of physical measures to prevent the floodwaters from inflicting damage usually involves one of the following.

- Dams and reservoirs
- Embankment and flood walls
- River bank protection and anti-erosion structures.
- Natural detention basins
- Channel improvement
- Drainage improvement
- Diversion of flood waters
- Catchment area treatment/afforestation

Non-Structural Measures

Non-structural measures strive to keep people away from floodwaters. One must always bear in mind; however, the stark reality that flood plains belong to the river and that floods, commonly perceived only as a curse, can be turned into a blessing in disguise if properly prepared for. Flood plains can be used judiciously and shared with developed areas by vacating and permitting use of the land by the river whenever the situation calls for it. This approach allows the flood plains to be utilised and reduces the disaster dimension, while retaining its beneficial effects.

Non-structural measures are very cost effective and can be readily implemented. In recognition of the fact that it may not be possible to halt human encroachment in flood plains areas, the main thrust is now on non-structural flood management measures. Non-structural measures can be grouped broadly as follows.

- Flood forecasting and advance warning
- Flood plain zoning
- Flood proofing
- Disaster preparedness and response planning
- Disaster relief
- Flood fighting
- Flood insurance

Flood Forecasting and Advance Warning

Flood forecasting and advance warning is gaining the greatest attention of planners as the approach of choice when considering non-structural measures to modify the susceptibility to flood damage, and is gaining acceptance with the public as well. Flood forecasting forewarns the resident population when the river is going to use its flood plain, to what extent, and for how long. In 1959, the Government of India laid the foundation for a strategy of laying more emphasis on non-structural measures by establishing a nationwide flood forecasting and warning system under the Central Water Commission (CWC). The network now consists of more than 500 hydrometeorological data observation sites (with wireless facilities) and 159 flood forecasting stations (134 for river stage forecasting and 25 for inflow reservoir forecasting). The stations operated by the CWC are located mainly on major interstate rivers. The state governments of the individual states often supplement these with their own efforts by providing reliable advance information/warning about impending floods. Advance warning helps in preventing the loss of human lives and moveable property and in reducing human misery to a considerable extent. With advance warning, people, cattle, and valuable moveable property can be removed to safe places upland of the areas that will be inundated.

Dissemination of Flood Warnings

Advance flood warning, by disseminating flood-forecast information, is the most common non-structural measure of flood management. The important considerations for advance flood warning include

- accuracy of the flood forecast;
- timeliness of the advance warning; and
- proper dissemination of the advance flood warning.

The importance of the first two are well known and are undertaken during the formulation of the flood forecast. Equally important, however, is dissemination to the right user since it is the public that is the end user of these warnings. Flood warnings are disseminated by telephone, wireless network, police wireless, flood telegrams, fax, and special messenger. Advance flood warnings are generally disseminated to the following.

Flood control rooms – State governments usually have control rooms in the capital as well as at the administrative headquarters. Advance flood warnings are passed on to these control rooms and it is their responsibility to inform all concerned to take necessary action.

Civil authorities/revenue authorities – These authorities are generally in charge of announcing warnings through loudspeakers in the areas that are likely to be affected. They are also generally in charge of disaster preparedness for the area and for transporting people and chattels to safer places. In the event of flooding, these authorities are also responsible for providing relief measures such as boats, drinking water, food packets, fodder for cattle, and medicines.

Engineering authorities – Advance flood warnings are provided to the engineers in charge of structures such as dams, reservoirs, flood embankments, anti-erosion works, railways, roads, and bridges in areas likely to be affected in order to enable them to take precautionary measures for the safety of the structures.

Important and strategic establishments – Oil refineries, power stations, coalmines, factories, and other industrial units located in the areas likely to be affected are also issued flood warnings.

Press, radio and television – Flood warnings are also sent to the press, and to radio and television stations, so that they can publish/announce appropriate warnings to the public. In India, during the flood season, the stations of All India Radio and local television channels reserve a particular time slot every evening and/or morning for flood news including advance flood warnings. The general public is aware of this and they know that they can get reliable information in time.

Flood signals – In areas prone to frequent flooding, a system of light signals can be used to indicate impending danger. For example, a yellow signal can indicate a minor warning such as may be needed when a flood occurs within the river, whereas a red signal can indicate a more serious threat such as when a large area is likely to be inundated. Such a system is in practice in the Damodar basin in India.

Village administration, schools and hospitals – In the case of particular villages, advance flood warnings are sent not only to the central flood control rooms and civil authorities, but also directly to the gram panchayat (village administration), schools, hospitals, and dispensaries among others.

Indian Experience over Five Decades

After the disastrous flood experienced in 1954, a national programme of flood management was launched in India. During the last five decades, different approaches to flood management, both structural and non-structural, have been adopted in different parts of the country. Various methods of flood protection, both long-term and short-term, have also been adopted depending on the nature of the problems and local conditions. Between 1954 and 2000, 33,630 km of new embankments and 37,900 km of drainage channels have been constructed, 2,337 town protection works completed, and 4,713 villages elevated above flood levels. Barring occasional breaches in embankments, these works have given satisfactory protection to an area of about 15.81 mha. Apart from these works, reservoirs with specific flood cushions have been constructed on the Damodar basin to provide protection to areas downstream. Storage structures constructed on the Mahanadi (at Hirakud), Sutlej (at Bhakra), Brahmani (at Rengali), and Tapi (at Ukai) rivers, and a number of major and medium reservoirs, have helped greatly in reducing the intensity of flooding in downstream areas. The flood-forecasting network, which was started in 1959, has also played a significant role in reducing loss of life and moveable property and in alerting authorities to take appropriate advance action. Flood forecasting networks cover most of the flood prone areas in the country. Advance flood warnings (6 to 48 hours before the event) help civil authorities take appropriate preventive measures, which include moving the population, and asking engineering authorities to take measures for the safety of structures including dams and embankments. The major reservoirs in the country are given inflow forecasts. These inflow forecasts are used to determine the reservoir outflow and have helped in moderating floods and reducing flood damage downstream.

Some important examples of the experience in India over the last five decades are discussed below.

Flood Moderation by Dams and Reservoirs

The Damodar Valley Reservoirs

The most important example of flood moderation by dams and reservoirs in the country is that of the Damodar valley, where a chain of reservoirs was constructed with the main objective of flood management. The CWC has inflow forecasting stations on all the dams in the valley. Inflow forecasting, based on gauge and discharge data upstream and rainfall data in the catchment, is used to provide 24hr advance warning to the reservoir authorities. Inflow-outflow figures from the Maithon, Panchet, and other reservoirs during the past years show that tangible flood moderation has been achieved.

The monsoon of 2000 provides a good example. During this period, the Damodar valley reservoirs helped to moderate floods and saved numerous lives and considerable property from possible disaster. West Bengal faced a very grim flood situation in the districts of Birbhum, Murshidabad, Nadia, and 24 Parganas (North) as a result of unprecedented heavy rainfall both in quantity and intensity. A vast reservoir was erected that reached from the high bank of the Ganga-Padma to the right bank of the Bhagirathi along a stretch of 25 to 50 km covering the whole of Murshidabad and Nadia districts and about 40 % of Birbhum, Burdhwan, and 24 Parganas (North) districts. The average annual rainfall in the districts of Birbhum, Burdwan, Murshidabad and Nadia is around 1300 mm; between the 18th and 23rd September 2000, total rainfall values of between 333 mm and 1629 mm were recorded in different parts of the Ajoy Basin, Massanjore Dam catchment, Tilpara Barrage catchment, and Damodar basin areas. The inflow into the Maithon and Panchet Reservoirs started rising on the 19th of September. By the 21st, the inflow at Maithon had increased to 5,092 cumecs (180,000 cusecs) and at Panchet to 4,045 cumecs (143,000 cusecs) necessitating the outflows to be increased to 1,980 cumecs (70,000 cusecs) and 849 cumecs (30,000 cusecs), respectively. By this time, the Maithon reservoir had used 50% of its flood cushion, and Panchet 22%. The reservoir levels rose sharply necessitating the encroachment of even higher levels in these reservoirs. For three hours, the Maithan reservoir used up to 80% of its flood cushion. As the inflows started decreasing, the release was kept at 1,980 cumecs (70,000 cusecs) from Maithan reservoir and 1,414 cumecs (50,000 cusecs) from Panchet. On the 22nd, however, the inflows again started increasing. The Maithan reservoir had to use 100% of its flood cushion for three hours, and the Panchet reservoir 58%. The inflow to the Maithan reservoir reached a peak of 7,581 cumecs (268,000 cusecs) necessitating the release of 4,950 cumecs (175,000 cusecs), while that to the Panchet reservoir dropped to 764 cumecs (27,000 cusecs). The inflows to both reservoirs decreased slowly thereafter. The extent to which the potential flooding was moderated by these reservoirs (in a situation in which the downstream area was already under flood) can be estimated from the above description.

Flood Moderation by the Hirakud Reservoir

The Hirakud reservoir has no earmarked flood storage capacity. The entire available storage is utilised during the monsoon season for flood moderation and subsequently used for irrigation. The Hirakud dam benefited flood control in the Mahanadi delta area in two ways. Firstly, it was intended to prevent damage to land and property, which had been estimated roughly at Rs.1.2 million per year (1947 values). Secondly, it was intended to provide land fit for irrigation and cultivation that could not otherwise be used because of periodic flooding. It was also intended to provide substantial flood relief to the town of Sambalpur. The Mahanadi delta periodically experiences high floods, most notably, the floods of 1834, 1855, 1866, 1872, 1933, and 1937, which caused extensive damage. With the construction of the Hirakud dam, the swollen waters of the Mahanadi river during the monsoon period have been tamed to a great extent. In the 90 years prior to construction (1868-1957), there were 27 years with high floods in the delta; but there has only been flooding in 7 of the 41 years since construction (1959-1998).

Flood Moderation by Other Reservoirs

The Bhakra and Beas dams, while not specifically designed for flood moderation, also absorb peak floods and help in moderating flooding. The example of flash flooding in the Sutlej River in Himachal Pradesh was discussed above.

The Ukai multipurpose project was planned for irrigation, hydropower, and flood control. The Ukai reservoir also provides considerable flood relief to the downstream areas, especially to the city of Surat, by using the flood cushion and by moderating releases.

Other reservoirs in which flood moderation is envisaged are the Rengali dam and Bhimkund project in Orissa, the Baigul reservoir in Uttar Pradesh, the Subernarekha multipurpose dam in Bihar, and the Kangsaboti reservoir in West Bengal. India has about 400 large dams with a total reservoir capacity of more than one million cu.m, but with the exception of the Damodar Valley (1867 million cu.m), and the Ukai (1332 million cu.m), few reservoirs have either a provision for flood storage or a specific flood cushion. In spite of this, all the major dams also moderate peak flow in addition to providing other benefits, and in so doing do help to reduce flood damage to people downstream.

Effectiveness of Embankments

Kosi Embankment

Flood embankments on both banks of the Kosi river, which were mostly completed as early as 1957, give flood protection to approximately 213,840 ha (528,000 acre) of land in the Darbhanga and Saharsa districts of Bihar. Before construction of the embankments, the kharif (monsoon) crops on this land were always in peril and even the sowing of rabi (winter, dry season, crops) was sometimes affected by standing water and excessive moisture. Severe damage was also experienced by property like buildings and orchards. This embankment project has prevented flooding and has had the following identifiable benefits:

- reduction of flooding and waterlogging and consequent improvement;
- reclamation of large areas of land for cultivation;
- construction of a network of surfaced roads and other communication systems; and
- opening of various industries/factories.

In addition to the obvious benefits to the state of Bihar from the project, the neighbouring country of Nepal is also benefiting. This project provides Nepal with some measure of flood protection, stability of the river in the upstream, and to some extent better information in times of floods, in addition to the normal benefits from the irrigation facility.

Gandak Embankment

Prior to 1954, the Gandak river was provided with some marginal embankments on both its banks in the districts of Chapra, Siwan, Gopalganj, East and West Champaran, and Muzaffarpur in Bihar. These embankments have served satisfactorily for over a century and will continue to provide substantial flood control over the Gandak in its lower reaches in Bihar. However, the discontinuity in the embankment posed intermittent problems to the people living in its lower reaches. To overcome these, embankments were planned in the discontinuous reaches with a view to arresting large floods within the embankments and providing security and relief to the people in Bihar and Eastern Uttar Pradesh. Eventually the entire length of the Gandak river up to Hajipur was embanked along the eastern bank . A comparative study performed by the Ganga Flood Control Commission showed a considerable decline in damage suffered after the embankments were completed.

Yamuna Embankments in Delhi

The Yamuna river has embankments on both its sides in the reach near Delhi which are intended to provide flood protection to the population and to agricultural land. However, as a result of breaches in the embankments during high floods, the protected area is occasionally flooded. After the severe flood of 1978, the embankments were strengthened and raised giving additional protection to Delhi against flood. There was some apprehension that such strengthening and raising of the embankments would further accentuate the flood problem requiring further raising of the embankments. Studies of gauge and discharge at different river sections after construction of these additional embankments showed no perceptible rise of flood level as compared to pre-embanked periods. They indicate that during high floods, scouring of the bed and banks takes place restricting the rise in flood level, and during falling floods silting of the bed and sides, thereby keeping the regime more or less in its original state.

Dibrugarh Town Protection Works

Dibrugarh town in Assam has faced problems of acute erosion since its inception. The devastating earthquake of 1950 further aggravated the problem and led to the erosion of one-sixth of the town in the 1954 flood alone. Such severe devastation drew the attention of the central and state governments and planned protection works were undertaken thereafter. The work comprised a 24 km dyke system, a 22 km drain through the town, stone/timber spurs, permeable and semi-permeable piles, and bank revetments from upstream of Maijon to Mohonaghat. Later, due to the shifting of river erosion upstream, the protection works consisted of stone bars, bank-heads, revetments, land spurs, and permeable spurs constructed in the reach upstream of the Maijon stone spur. The 24 km dyke system was constructed in stages between 1954/55 and 1979/80 and was designed to prevent water spilling into the town and adjoining area. A 14 km drain was constructed through the town and outfalling into the river in 1956/57 to provide some relief from the water congestion that resulted from the dyke construction. The drain was later extended to about 22 km.

In 1991, the Central Water Commission evaluated the performance of the flood protection work. The study showed that the anti-erosion work had helped to divert the main current towards the north, thereby reducing erosion in the town and downstream areas. Similarly, the system of dykes was functioning well and was adequately checking the spillage of flood water into Dibrugarh and its suburbs providing a sense of security to the local population. However the floods of 1988 alerted the population to the necessity of regular monitoring and further raising and strengthening of these embankments. There is an urgent need to carry out flood plain zoning in the protected areas and to regulate development activities in the town and its adjoining areas. The gradual shifting of development activities from the present vulnerable areas of the town to comparatively safer higher areas will also help to reduce flood damage potential.

Performance of Flood Forecasting in India

According to the present norms of the CWC, a forecast is considered to be reasonably accurate if the difference between the forecast and the actual observed levels of a river lies within ±15 cm. In the case of inflow forecasts, a variation within ± 20 % is considered acceptable. Between 1991 and 2002, an average of about 6,000 flood forecasts per year were issued, with a maximum of 7,943 issued during 1998. The number of forecasts each year and proportion of accurate forecasts is shown in Table 2.

Table 2: Accuracy of Flood Forecasts in India

Year	No of forecasts issued	Accuracy of forecast	
		No. of forecasts within ±15 cm, or ±20 %	% of accurate forecasts
1991	6603	6225	94.3
1992	4764	4567	95.9
1993	6643	6438	96.9
1994	7476	7087	94.8
1995	6417	6189	96.4
1996	6467	6266	96.9
1997	5465	5263	96.3
1998	7943	7775	97.9
1999	7055	6826	96.8
2000	6510	6315	97.1
2001	5463	5342	97.8
2002	4241	4151	97.9

The forecasts issued by the CWC and warning services provided have rendered immense benefit to the people in the flood prone areas.

Like the river stage forecasts, the inflow forecasts issued by the CWC have also been consistent. They have provided adequate warning to the authorities in charge of dams and barrages, and have led to systematic operation of the reservoirs and optimum utilisation of water resources for flood management. However, while the above criteria for accuracy may be reasonable in the case of large rivers, they may have to be revised and modified for small rivers in areas prone to flash floods, since in small hilly catchments a rise of even one metre can occur within a short time. Similar considerations regarding volume of inflow can lead to different yardsticks for different inflow forecasting stations.

Conclusions

A river basin is the most appropriate hydrological unit for the planning and management of water resources. Integrated river basin development aims at the optimum use of basin water resources to best meet all of the water needs of a basin. It is a tool that can be used to address issues related to both the positive and the negative aspects of floods and droughts in a basin. Effective flood management needs to consider the whole basin and requires that methods that can reduce flood losses should be considered and used where appropriate. There should be a master plan for flood management for the basin. Sound watershed management through extensive soil conservation, catchment area treatment, and construction of check dams should be promoted to reduce the intensity of flooding. Adequate flood cushions should be provided in water storage projects wherever feasible to facilitate better flood management.

A judicious mix of structural and non-structural measures would optimise the benefits that accrue from structural measures alone. An extensive network of flood forecasting stations should be established to issue timely warnings to settlements in flood plains. Flood plain zoning and strict regulations on the location of settlements and economic activities in flood zones will help minimise loss of life and property. While physical flood protection work like embankments and dykes will continue to be necessary, the emphasis should be on non-structural measures such as flood plain zoning, to minimise losses and reduce the recurring expenditure on flood relief.

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