

# **REAL TIME FLOOD FORECASTING - INDIAN EXPERIENCES**

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## **ABSTRACT**

The real time flood forecasting is one of the most effective non- structural measures for flood management. For formulating the flood forecast in the real time, the observed meteorological and flow data are transmitted to the forecasting station through the different means of data communication which include telephone, wireless and network of telemetry stations etc. The collected meteorological and flow data in real time are then used into the calibrated & validated real time flood forecasting model to forecast the flood flow and corresponding water levels for different lead periods varying from few hours to few days depending on the size of catchment and purpose of the forecast. The structure of the model should be simple and it should not have excessive input requirements, but at the same time the forecasted flood must be as accurate as possible.

Different types of real time flood forecasting techniques and models have been suggested and used by many investigators. These can be broadly classified into (i) deterministic models, (ii) stochastic and statistical models and more recently (iii) Artificial Neural Network (ANN) and fuzzy logic techniques. In India the various flood forecasting centers are using different forecasting models, based on the availability of hydrological and hydro-meteorological data, basin characteristic, computational facilities available at the forecasting stations, warning time required and purpose of forecast. Some of the commonly used methods by various forecasting stations include: (i) simple correlation based on stage-discharge data, (ii) co-axial correlation based on stage, discharge and rainfall data etc, (iii) net work model wherein the lateral flows from different sub-basins are calculated using unit hydrograph approach and successive routing through different sub-reaches is carried out using river flood routing techniques, and (iv) hydrologic models (at selected places). The recent techniques like ANN and fuzzy logic are being currently used by the academicians and researchers for the development and testing.

In this lecture brief description of various real time flood forecasting models and techniques being used in India are presented. The limitations of the techniques are discussed. The status of the real time flood forecasting in India including those of the arid and semi-arid basins is presented. The present gaps in the application of real time flood forecasting techniques in India are highlighted.

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## 1.0 INTRODUCTION

Some time immemorial, floods have been responsible for loss of crops and valuable property and untold human misery in the world, India has been no exception. An area of more than 40 million ha. in India has been identified as flood prone. India, which is traversed by a large number of river systems, experiences seasonal floods. It has been the experience that floods occur almost every year in one part or the other of the country. The rivers of North and Central India are prone to frequent floods during the south-west monsoon season, particularly in the month of July, August and September. In the Brahmaputra river basin, floods have often been experienced as early as in late May while in Southern rivers floods continue till November. On an average, floods have affected about 33 million persons between 1953-2000. There is every possibility that this figure may increase due to population growth and developmental works taken up in the flood plains.

Flood occurs due to natural as well as man made causes. Major causes of floods in India include intense precipitation, inadequate capacity within riverbanks to contain high flows, and silting of riverbeds. In addition, other factors are land slides leading to obstruction of flow and change in the river course, retardation of flow due to tidal and backwater effects, poor natural drainage, cyclone and heavy rainstorms/cloud bursts, snowmelt and glacial outbursts, and dam break flow.

For minimizing the losses due to floods, various flood control measures are adopted. The flood control measures -which should more correctly be termed as "Flood Management" can be planned either through structural engineering measures or non-structural measures. Wise application of engineering science has afforded ways of mitigating the ravages due to floods and providing reasonable measure of protection to life and property. Such measures comprise multipurpose reservoirs and retarding structures which store flood waters, channel improvements which increase floods carrying capacity of the river, embankments and levees which keep the water away from floods prone areas, detention basins which retard and absorb some flood water, floodways which divert flood flows from one channels to another and over all improvement in the drainage system. Various engineering measures could ultimately protect a large portion of such flood prone areas. Till 1985 about 13 million ha. of land has been covered by some measures of flood protection. The large back-log of unconstructed, though economically feasible, flood control projects will take quite some time to be cleared in view of the shortage of funds allocated and allocatable to flood control sector. Further, no systematic study has been taken up particularly in India to examine the efficacy of these structures on river flow regimes during the period of flood. This would in turn mean that many areas would remain unprotected for a considerable time thus calling for measures to ensure, meanwhile, flood loss mitigation.

It has also been recognized that permanent protection of all flood prone areas for all magnitude of floods by such structural means is neither possible nor feasible because of various factors such as financial constraints, cost-benefit criteria or topographic limitations of the region. Real time flood forecasting and flood plain zoning are some of the important non-structural measures adopted for the management of the flood. The process of estimating the future stages or flows and its time sequence at selected

vulnerable points along the river course during floods may be called “Real Time Flood Forecasting”. Real time flood forecasting systems are formulated for issuing the flood warning in real time in order to prepare the evacuation plan during the flood. Experience has shown that loss of human life and property etc. can be reduced to a considerable extent by giving reliable advance information about the coming floods. The people could be moved to safer places in an organized manner as soon as the flood warnings are received. Valuable moveable property and cattles could be saved by transferring them to places of safety. The effectiveness of real time flood forecasting systems in reducing flood damage would depend upon how accurately the estimation of future stages or flow of incoming flood and its time sequence at selected points along the river, could be predicted. The rivers of alluvial plain exhibit the meandering, shifting of the course and unstable cross sections due to the problem of sediment transport. These hydraulic changes in the river behavior complicate the issue of adopting the suitable measures for flood management.

The magnitude and severity of the floods, caused by excessive rainfall in the river catchments, depend upon the nature and extent of rainfall and the characteristics of the specific watersheds. For example, intense and shorter duration rainfall or cloud burst in small steep catchments or in hilly catchments (having basin area  $< 1200 \text{ km}^2$  and time of peak  $< 6$  hours) results in flash floods of shorter time periods, whereas the heavy rainfall of longer duration in the large catchments may generate the floods which sustain for longer periods. Suitable real time flood forecasting techniques are required to forecast such floods. The accurate real time flood forecasts are required to be issued well in advance in order to provide sufficient time, known as lead time, for evacuating the people from the areas likely to be affected by the flood. The lead time available for flash flood forecasts are very small. It makes the implementation of evacuation plan very difficult during the flood.

The techniques available for real time flood forecasting may be broadly classified in four groups: (i) deterministic modeling, (ii) stochastic modeling, (iii) statistical modeling and (iv) computational techniques like Artificial Neural Network (ANN) and fuzzy logic. The deterministic models are based on either index catchment models or conceptual catchment models. Such models tend to simulate the basin response to hydrological events and do not fully utilize information collected during an event. Further the deterministic models were originally developed for design studies, and their formulation has not been influenced by the need to incorporate hydrological information in real time. As a consequence, these models cannot readily be updated, and may prove difficult to re-initialize following telemetry or computer breakdowns. For example, a forecast from a conceptual model is often made of contributions from a number of stores (reservoirs), the contents of which have to be specified in order to initialize the model, which is clearly not practical in a real time context. The similar difficulties are also encountered in unit hydrograph models (which were primarily developed to meet design objectives) as the necessary separation of base-flow and storm runoff is difficult to invoke in real time. The inherent weaknesses of deterministic hydrological models for real time applications have provided to look into stochastic time series models with structures more suited to real time forecasting. The time series models and their applications to real time flow forecasting were evolved in 1970's and have been successfully applied for real time forecasting. The statistical models involve the

development of the relationships correlating the flood characteristics of forecasting station and upstream gauging station considering the various other factors influencing the floods. The ANN and fuzzy logic based models, which have the potential for the real time flood forecasting, are capable of considering the inherent non-linear ties in the rainfall-runoff process

Depending on the availability of hydrological and hydro-meteorological data, basin characteristic, computational facilities available at the forecasting stations, warning time required and purpose of forecast, different flood forecasting techniques are being used in India. Some of the commonly used techniques include: (i) simple relation developed correlating the stage-discharge data, (ii) co-axial correlation diagram's developed utilizing the stage, discharge and rainfall data etc, (iii) event based hydrological system models for small to moderate sized catchments, (iv) net work model consisting of the sub-basins and sub-reaches for the large sized catchments, and (v) hydrologic models (at selected places). The stochastic models have been mostly applied by researchers and academician for real time flood forecasting. However, their applications are restricted only at few places. The application of the computing techniques such as ANN and fuzzy logic are currently in the development stage and being mostly used by the academicians and researchers.

Thus mostly statistical approach is used to formulate the real time flood forecast in India. Event based net work model and multi-parameter hydrological models are applied for some of the pilot projects during the implementation of the International projects. Flash Floods occur in the arid and semi-arid regions. However, no system is evolved for flash flood forecasting. Some sort of flood warning arrangement had existed in a few states of the country, but these were largely aimed at transmitting information on flood levels from upstream points to the areas lower down. Such warnings have limited utility in as much as they did not indicate the likely levels and the time of arrival of floods at the vulnerable places. Further, they did not often give adequate advance notice.

## **2.0 FLOOD PROBLEMS IN INDIA**

Main problems in India with respect to floods are inundation, drainage congestion due to urbanization and bank erosion. The problems depend on the river system, topography of the place and flow phenomenon. Being a vast country, the flood problems in India may be visualized on regional basis. However, for the sake of simplicity, India may be broadly divided into four zones of flooding, viz. (a) Brahmaputra River Basin, (b) Ganga River Basin, (c) North-West Rivers Basin, and (d) Central India and Deccan Rivers Basin. Flooding in these zones is presented in following subsections.

### **a. Brahmaputra River Basin**

The first zone belongs to the basins of the rivers Brahmaputra and Barak with their tributaries. It covers the States of Assam, Arunachal Pradesh, Meghalaya, Mizoram, northern parts of West Bengal, Manipur, Sikkim, Tripura and Nagaland. The catchments of these rivers receive large amount of rainfall. As a result of this, floods in this region take place very often and are severe by nature. The general tectonic up wrapping of North-East region has also significant effect on river Brahmaputra. Almost all Northern

tributaries of Brahmaputra are affected by landslides in the upper catchment. Further, the rocks in the hills, where these rivers originate are friable and susceptible to erosion and thereby cause exceptionally high silt charge in the rivers. In addition, the region is subject to severe and frequent earthquakes causing numerous landslides in the hills, which upsets the regime of the rivers. Important problems in this region are flood inundation due to spilling of banks, drainage congestion due to natural as well as man-made structures and change of river flow. In recent years, the erosion along the banks of the Brahmaputra was enormous and has become a serious concern among the water resources engineers.

Main problems of flooding in Assam are inundation caused by spilling of the rivers Brahmaputra and Barak as well as their tributaries. In addition, the erosion along the Brahmaputra is a serious problem. In Northern parts of West Bengal, the rivers Teesta, Torsa and Jaldakha are in floods every year and inundate large areas. During flooding, these rivers carry large amount of silt and have a tendency to change their courses. The rivers in Manipur spill over their banks frequently. The lakes in the territory are filled up during the monsoon and spread to large marginal areas. In Tripura, flood problems are the spilling and erosion by rivers.

## **b. Ganga River Basin**

The Ganga and its many tributaries (the Yamuna, the Sone, the Ghaghra, the Gandak, the Kosi and the Mahananda) constitute the second zone. This zone covers Uttaranchal, Uttar Pradesh, Bihar, south and central parts of West Bengal, parts of Haryana, Himachal Pradesh, Rajasthan, Madhya Pradesh and Delhi. The normal annual rainfall of this region varies from about 60 cm to 190 cm of which more than 80 per cent occurs during the South-West monsoon. The rainfall increases from west to east and from south to north.

The flood problem is mostly confined to the areas on the northern bank of the Ganga River. The damage is caused by the northern tributaries of the Ganga by spilling over their banks and changing their courses. Though the Ganga is carrying huge discharges (57,000 to 85,000 m<sup>3</sup>/s), the inundation and erosion problems are confined to some specific places only. In general, the flood problem increases from west to east and from south to north. In the north-western parts of the region, there is the problem of drainage congestion. The drainage problem also exists in the southern parts of West Bengal. The problem becomes acute when the main river, in which the water is to be drained, already has high water level. The flooding and erosion problem is serious in Uttar Pradesh, Bihar and West Bengal. In Rajasthan and Madhya Pradesh, the problem is not so serious. In Bihar, the floods are largely confined to the rivers of North Bihar and are an annual feature. Most of the rivers (e.g. the Burhi Gandak, the Bagmati, the Kamla Balan, other smaller rivers of the Adhwra Group, the Kosi in the lower reaches and the Mahananda at the eastern end) spill over their banks causing considerable damage to crops and dislocating traffic. High floods occur in the Ganga occasionally causing considerable inundation of the marginal areas in Bihar.

In Uttar Pradesh, the flooding is frequent in the eastern districts, mainly due to spilling of the Rapti, the Sarada, the Ghaghra and the Gandak. The problem of drainage congestion exists in the western and north-western areas of Uttar Pradesh, particularly in Agra, Mathura and Meerut districts. Erosion is experienced in some places of the left

bank of Ganga, on the right bank of the Ghaghra and on the right bank of the Gandak. In Haryana, flooding takes place in the marginal areas along the Yamuna and the problem of poor drainage exists in some of the south western districts. In Delhi, a small area along the banks of the Yamuna is subject to flooding by river spills. In addition local drainage congestion is experienced in some of the developing colonies during heavy rains. In the south and central part of West Bengal, the Mahananda, the Bhagirathi, the Ajoy, and the Damodar cause flooding due to inadequacy in river channels and the tidal effect. There is also the problem of erosion of the banks of rivers and on the left and right banks of Ganga, upstream and downstream, respectively, of the Farakka barrage.

### **c. North-West River Basins**

This is the third zone and comprises of basins of North-West rivers such as the Sutlej, Ravi, Beas, Jhelum and Ghaggar. In comparison to the two zones mentioned above, the flood problem in this zone is relatively less. The major problem is that of inadequate surface drainage which causes inundation and water logging.

Another cause for flood has been the water logging in the irrigated area and changes in river regimes due to increased ground water levels. At present, the problems in Haryana and Punjab are mostly of drainage congestion and water logging. The Ghaggar River used to disappear in the sand dunes of Rajasthan after flowing through Punjab and Haryana. The Jhelum floods occur frequently in Kashmir causing a rise in the level of the Wullar Lake thereby submerging marginal areas of the lake.

### **d. Central India and Deccan Rivers Basin**

Important rivers in the fourth zone are the Narmada, the Tapi, the Mahanadi, the Godavari, the Krishna and the Cauvery. These rivers have mostly well defined stable courses. They have adequate capacity within the natural banks to carry the flood discharge except in their lower reaches and in the delta area, where the average bed slope is very flat. The lower reaches of the important rivers on the East Coast have been embanked.

This region covers all the southern States namely Andhra Pradesh, Chhattisgarh, Karnataka, Tamil Nadu, Kerala, Orissa, Maharashtra, Gujarat and parts of Madhya Pradesh. The region does not have very serious problems except for some of the rivers of Orissa (the Brahmani, the Baitarni, and the Subarnarekha). The Delta areas of the Mahanadi, Godavari and the Krishna rivers on the east coast periodically face flood and drainage problems, in the wake of cyclonic storms.

The Tapi and the Narmada are occasionally in high floods affecting areas in the lower reaches of Gujarat. Flood problems in Andhra Pradesh is confined to spilling by the smaller rivers and the submergence of marginal areas along the Kolleru Lake. Rivers like Budameru and the Thammileru not only overflow their banks along their courses to Kolleru Lake but also cause a rise in the level resulting in inundation of adjoining lands.

In Orissa, damage due to floods is caused by the Mahanadi, the Brahmani and the Baitarani which have a common delta. Water from these rivers intermingles in the delta and results in a very high water level, which cause severe flooding in the region. The coastal districts are densely populated and receive heavy precipitation in the Eastern Ghat

region. The silt deposited constantly by these rivers in the delta area raises the flood water level and, the rivers often overflow their banks or break through new channels causing heavy damage. The lower reaches of the Subarnarekha are effected by floods and drainage congestion. The small rivers of Kerala when in high floods often cause considerable damage. In addition, there is also the problem of mud-flow from the hills, which results in severe losses.

### **3.0 SPECIAL FLOOD PROBLEMS**

In this section, some special flood problems in India are presented.

#### **a. Problem of Tal Areas**

Natural depressions where water gets deposited during monsoon for longer period are known as Tal areas. Generally, they hamper normal activity affecting the Kharif crop. Mokama group of Tals in Bihar is known for its flood problem. Water gets accumulated in these areas during monsoon and remains stagnant up to September. Similar problems are also seen in Ghaggar detention basin in Rajasthan, depressions available at Ottu, Bhindawas, Kotla lakes in Haryana. Flood problems in such areas are of special nature and needs to be treated separately.

#### **b. River bank/bed erosion**

All natural rivers are with mobile bed flows. Therefore, depending on the flow phenomenon, there may be aggradations and/or degradation in the river banks and beds. A river erodes its banks due to various reasons causing considerable loss of land, deterioration of the river regime and sometimes account for huge losses during floods. Rivers in Brahmaputra-Barak and Ganga basins are prone to severe erosion. The erosion is governed by the discharge in the river, bed slope, sediment flow and composition of bed and bank materials. Deforestation of upper catchment and hills lead to increased sediment load in rivers. Effect of seismic disturbances, and topographical conditions of land also contributes to the erosion problem. River erosion causes a loss to the land resources. The river behaviour causes new riverine landmass to be built up, but these become productive after many years and cannot compensate the land-loss due to erosion. Erosion in the Majuli island, the largest river-island in the world, is the most appropriate example to state the severity of the problem. The Brahmaputra Board has estimated that in the Majuli Island, the annual loss of land due to erosion could be about 3.9 km<sup>2</sup> and an economic loss of about Rs. 31.5 million per annum (IWRS, 2001).

#### **c. Sediment transport by rivers**

One of the problems associated with the floods in India is the transport of sediments by rivers during floods. Himalayan rivers originating from Nepal bring a lot of sediment during floods to the alluvial plains in the valley. Transport of sediments (suspended and bed load) has a major role on river behaviour and river morphology. Thus, the flood problem and its management measures depend a lot on sediment

transport. Several observation-sites for sediment transport in rivers are maintained by the CWC. With the help of the data (on average suspended sediment load), the pattern of increase/decrease of silt load could be examined to assess the morphological changing trend of the river. As recorded by CWC, the total live and gross storage capacity created in India is about 177 and 217 km<sup>3</sup>, respectively. Based on the sedimentation data of 144 reservoirs, the weighted average annual loss in gross storage due to silting computed is 0.44%. Thus, likely annual loss in the total gross storage of 217 km<sup>3</sup> is 0.95 km<sup>3</sup>. Similarly, the annual loss in live storage is 0.31% based on the data of 42 reservoirs. Thus the likely annual loss in the total live storage is 0.55 km<sup>3</sup>. Considering the average density of 1.137 tonnes/m<sup>3</sup>, based on the data of 13 reservoirs, the weight of the total sediment deposits in all the reservoirs in India is 1,080 million ton annually.

#### **d. Dam break flows**

Flooding due to dam break is a mega-disaster as it is associated with huge loss of life and property. An unusual high peak in a short duration and presence of a moving hydraulic shock/bore make it a different problem as compared to other natural floods. In India, historical events (e.g. failure of Machhu dam, Panshet dam, Nanak Saagar dam) for dam break floods are common (Palaniappan, 1997). Sometimes, blockage of water due to deposits caused by landslide takes place. When this natural blockage fails due to increased amount of water at the upstream, huge flooding occurs. The behaviour of this flood is similar to that of dam break floods.

#### **e. Urban drainage**

Flooding of cities in India is a common and annual event. Due to encroachment of the flood plain areas, presence of several structures and absence of proper regulations for maintenance, artificial flood is created. Therefore, proper drainage networking for a city has to be developed.

#### **f. Flash floods**

Flash floods are characterized by sudden rise and recession of flow of small volume and high discharge which causes damages because of suddenness. They generally take place in hilly region where the bed slope is very steep. Typical examples are flash flood of Arunachal Pradesh and flash flood of Satluj in 2000. Large reservoir downstream of flood prone areas can absorb the flood wave. Flash floods are also experienced in arid and semi-arid regions due to the intense and short duration rainfall in the small catchments of the region.

#### **g. Flood due to snowmelt**

Snowmelt is a gradual process. Usually, it does not produce floods. However, sometimes, glaciers hold large quantity of bounded water. When released suddenly, this

causes severe flooding. The rivers originating from the Himalayas in the north are fed by snowmelt from glaciers. In 1929, the outburst of the Chong Khundam glacier (Karakoram) caused a flood peak of over 22,000 m<sup>3</sup>/s at Attock.

#### **h. Flood in Coastal Areas**

Floods in Indian river basins are also caused by cyclones. Coastal areas of Andhra Pradesh, Orissa, Tamilnadu, and West Bengal experience heavy floods regularly. The flood due to the super cyclone combined with heavy rainfall during October 1999 in the coastal region of Orissa is an example. During past 110 years (1891-2000), over 1,000 tropical cyclones and depressions, originating in the Bay of Bengal and Arabian Sea, moved across India. Passage of such storms over a river basin leads to severe floods.

### **4.0 NEED FOR FLOOD FORECASTING**

Warning of the approaching floods provides sufficient time for the authorities:

- i) To evacuate the affected people to the safer places,
- ii) To make an intense patrolling of the flood protection works such as embankments so as to save them from breaches, failures, etc.
- iii) To regulate the floods through the barrages and reservoirs, so that the safety of these structures can be taken care of against the higher return period floods.
- iv) To operate the multi-purpose reservoirs in such a way that an encroachment into the power and water conservation storage can be made to control the incoming flood.
- v) To operate the city drains (out falling into the river) to prevent bank flow and flooding of the areas drained by them.

### **5.0 DEVELOPMENT OF FLOOD FORECASTING IN INDIA**

In 1969, the Government of India created a Central Flood Forecasting Directorate headed by a Superintending Engineer. In 1970, under Member (Floods), six flood forecasting divisions were set up on inter state river basins. These covered the flood prone basin/sub-basins of the Ganga. The Brahmaputra, the Narmada, the Tapti, the Teesta and coastal rivers of Orissa. By the year 1977, the Central Flood Forecasting Organisation comprised of one Chief Engineer's Office, 3 circles and 11 divisions.

Now, in most of the States there are arrangements for the issue of flood warning from the upstream stations to the downstream stations. These warnings include:

- i) Whether the river is rising above a certain specified level, known as danger level or not;
- ii) Whether the river is rising or falling;
- iii) Whether the stage of the river is 'low', 'medium' or 'high'.

The above warnings, issued by telegrams, telephone or wireless systems are of purely qualitative in nature and they give only an indication of the nature of the flood. Such procedures are at present being followed in West Bengal, Andhra Pradesh and Bihar states.

After the completion of certain multi-purpose projects like the Hirakud in Orissa, DVC Projects in Bihar/Bengal, Bhakra in Punjab, forecasting techniques have been evolved using the data of rainfall and stream gauges in the catchment upstream of the dam. Correlation diagrams have been prepared with the previous data to predict the inflow into the reservoir. Based upon this, the reservoir operations are carried out. Such flood forecasting systems have also been set up for Yamuna in Delhi, Koshi in Bihar and Krishna and Godavari in Andhra Pradesh.

Central Water Commission has established a network of more than 147 flood forecasting and warning sites on various inter-state rivers (CWC, 1989).

The data of the river gauges and the rainfall are transmitted to the flood forecasting centres from all the key stations by means of wireless or telegrams. Based on these data and the correlation curves already developed with the previous data, the forecasts are daily issued to the concerned authorities so that they can take the appropriate measures.

## **6.0 DATA REQUIREMENT**

Basically gauge/discharge and or rainfall data are required for flood forecasting purposes. The number of reporting stations depend upon hydrologic need and availability of observers and communications.

The number of rain gauge stations in the basin should be such that:

- a) The areal rainfall in the catchment can be estimated with the desired accuracy, and
- b) The variation in the areal distribution as well as time distribution can be identified

For network design of river gauges, the following points should be kept in mind:

- a) Wherever the forecast is being issued on the basis of gauge correlation, the base station and forecasting station must be equipped with gauges.
- b) In case more than one tributary are joining the main stream and the forecast is based on multiple coaxial diagram, there should be at least one gauge on each of the tributaries. The location of gauges on the tributaries should be such that the time of the travel from base station to forecasting station in respect of tributaries as well as main stream is constant.
- c) Where the routing model forms the basis of formulation of forecast, the reach has to be divided into various sub-reaches. For each sub-

reach, in addition to the gauge reading discharge observation should also be carried out.

- d) For incorporating the effect of intervening catchment on well designed channel, one gauge has to be installed. If the channel is not well designed, it will be imperative to install adequate number of raingauges to account for the contribution from the intervening catchment.

Apart from gauge/discharge and/or rainfall data interception, evaporation, evapotranspiration, interflow, infiltration, ground water and percolation are used as inputs to several conceptual models which are in operational use mostly in many advanced countries.

## **7.0 METHODOLOGY EMPLOYED FOR ISSUE OF FLOOD FORECASTS**

The various steps involved in the operation before issue of forecasts and warning are as follow:

- i) Observation and collection of hydrological and meteorological data
- ii) Transmission/Communication of data to the forecasting Centres
- iii) Analysis of data and formulation of forecasts
- iv) Dissemination of forecasts and warning to the Administrative and Engineering Authorities of the States.

The above phases are described briefly in the following paragraphs:

### **7.1 Data Collection**

Observation and collection of hydrological data are done by the Hydrological Observation and Flood Forecasting Organisation (HO & FFO), Central Water Commission. Flood Meteorological offices (F.M.O) collects and transmits the meteorological data. The former is responsible for planning of river gauge/discharge network, collection of gauges and discharge data and communication of the data to its Flood Forecasting Centres, while the later is responsible for planning of rain gauge network in consultation with HO & FFO and for collection and transmission of rainfall data to the Flood Forecasting Centres. The F.M.O. provides information regarding general meteorological situation, rainfall amounts of last 24 hours and heavy rainfall warning for the next 24 hours for different regions to the concerned flood forecasting centres of HO & FF Organisation.

At present data of nearly 380 hydrological and 500 hydro-meteorological stations are collected everyday and utilized by flood forecasting centres for formulation of forecasts during monsoon period. Similarly, the meteorological data which includes rainfall amounts, heavy rainfall warning, general synoptic situation and weather forecast are being supplied by F.M.O. to concerned Division and Sub-division/Control Rooms of HO & FFO daily on telephone failing which the informations are being collected by the special messenger of HO & FF Organisation from the F.M.O. office. Now a days, the

data of operational sites are mostly being transmitted to the forecasting centres over wireless network, of HO & FFO, most of which are 15 watt SSB sets.

## **7.2 Data Transmission**

Transmission of data on real time basis from the hydrological and hydrometeorological sites to the Flood Forecasting Control Rooms is a very vital factor in flood forecasting. Transmission of data should be as quick as possible to issue forecast as much in advance as possible in order to enable organization of relief measures to take protective steps. Transmission of the observed data on real time basis is, therefore, extremely necessary for efficient flood forecasting system.

The land-line communication i.e. by telephone/telegram was the earliest and very commonly used mode for data transmission in Flood Forecasting Services till 1970. This system was having the following major drawbacks:

- i) The telegraph offices were not always located very close to the data observation sites and consequently a lot of time was wasted in performing the journey between the site and the telegraph office.
- ii) During heavy rainfall period, when timely requirement of the data becomes extremely essential, the telegraph/telephone system becomes frequently out of order.

The communication system was further improved by installing VHF/HF wireless sets at the data collection sites most of which are 100W/15W HF sets. The wireless stations generally operated by the Wireless Operators for transmission of data to the Control Rooms. Provision of wireless mechanics has also been made for repairs of the sets and their maintenance. Planning, operations, maintenance and improvement of the communication network is looked after by officers and supporting staff. In some of the pilot projects, automatic data transmission system like Telemetry system have been used. However, the maintenance of such automatic instruments in the field is one of the major problems which requires immediate attention.

## **7.3 Data Analysis and Forecast Formulation**

After receipt of the hydrological and hydro-meteorological data at the Control Room, the data are compiled scrutinized and analysed by Engineers/Hydro-Meteorologist engaged in this work. The system of data processing before use in forecast formulation has been introduced to prevent chances of errors. Many forecasting centres have been provided with micro computer facilities for data processing.

The next important step is the formulation of forecast. In fact, the analysis of data and formulation of forecast is the most important stage in the process of forecasting system.

The various flood forecasting centres are using different forecasting models, based on availability of hydrological and hydro-meteorological data, the basin characteristics, computational facilities available at forecasting centres, warning time

required and purpose of forecast. However, some of the common methods being used by various centres are given below:

- i) Simple correlation – based on stage-discharge data.
- ii) Co-axial correlation – based on stage, discharge and rainfall data etc.
- iii) Routing by Muskingum method.
- iv) Successive routing through sub-reaches.

The forecasts obtained from the correlation diagrams or mathematical models etc., are modified as necessary to arrive at a final forecast based on the prevailing conditions in the river. This requires intimate knowledge of the river by the forecaster. Forecasts once issued are further modified and revised forecasts are issued if any additional informations are received after the initial forecasts are made, if necessary.

#### **7.4 Dissemination**

The final forecasts are being communicated to the concerned administrative and engineering authorities of the state and other agencies connected with the flood control and management work on telephone or by special messenger/telegram/wireless depending upon local factors like vulnerability of the area and availability of communication facilities etc.

On receipt of flood forecasts, the above agencies disseminate flood warnings to the officers concerned and people likely to be affected and take necessary measures like strengthening of the flood protection and control works and evacuation of the people to safer places etc. before they are engulfed by floods. Generally, the State Govts. Set up control rooms at States and District Headquarters which receive forecasts and then further disseminate the flood warning to the affected areas and organize relief as well as rescue operation. Flood Forecasts are also passed on to the All India Radio, Doordarshan and the local Newspaper for wider publicity in public interest.

### **8. METHODS FOR FORMULATING THE REAL TIME FLOOD FORECAST**

The methods for formulating the real time flood forecast may be categorized under two groups: (i) statistical methods and (ii) deterministic methods

#### **8.1 Statistical Methods**

Methods base on statistical approach makes use of the statistical techniques to analyse the historical data with an objective to develop methods for the formulation of flood forecasts. The methods thus developed can be presented either in the form of graphical relations or mathematical equations. A large number of data, covering a wide range conditions are analysed to derive the relationships which inter-alia include gauge to gauge relationship with or without additional parameter and rainfall peak stage relationships. These methods are more commonly used in India. Central Water Commission is the central authority for the issue of real time flood forecast in India. Thus

the method presented herein are derived from the 'Manual on Flood Forecasting Central Flood Forecasting Organisation, Patna, (CWC)(1988)'.

### **8.1.1 Correlation between upstream and downstream gauges/discharges**

For developing the correlation between upstream and downstream gauges/discharges the following parameters required to be considered:

- a) Stage and discharge of the base station
- b) Stage and discharge of the forecasting station
- c) Change in stage and discharge of the base station
- d) Travel time at various stages
- e) The rainfall (amount, intensity and duration) in the intercepting catchment
- f) Topography, nature of vegetation, type of soil, land use, density of population, depth of gw table, soil moisture deficiency etc. of the intercepted catchment.
- g) The atmospheric and climatic conditions; and
- h) State and discharge of any important tributary joining the main stream between the base station and the forecasting station.

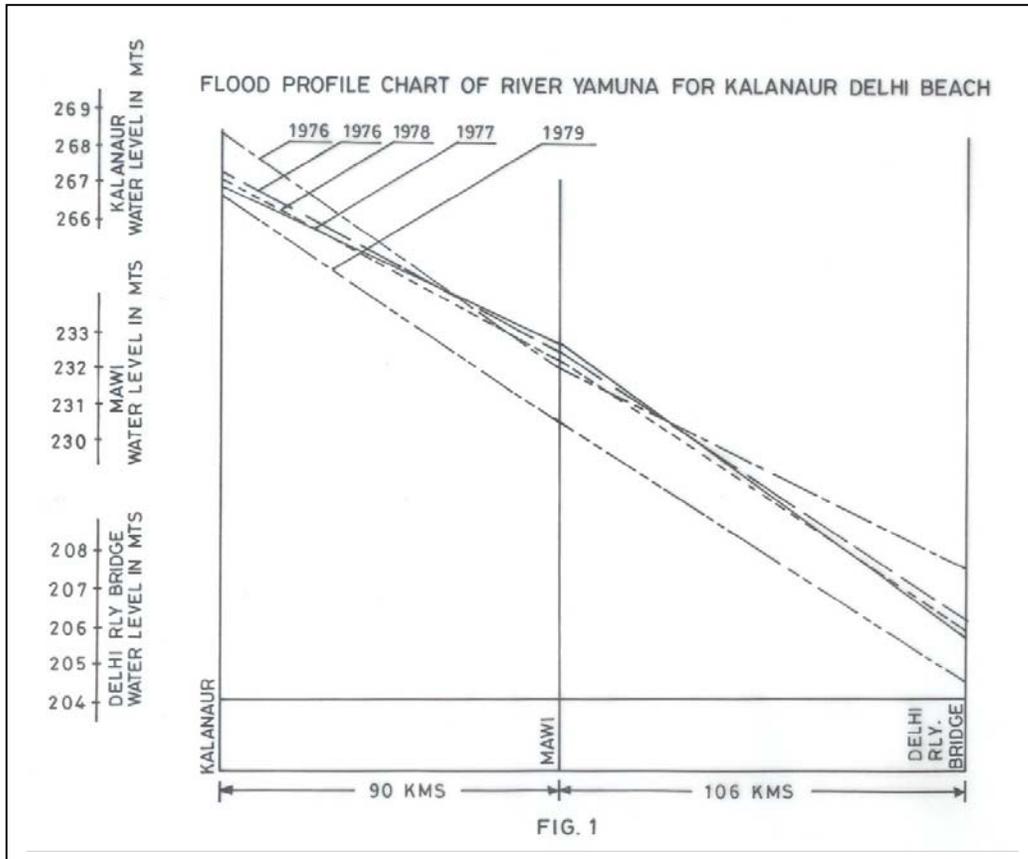
Factor (a) to (d) are basic parameters used in developing the correlation curves. Factors (e) and (f) are taken into account by introducing the rainfall and API. However, factor (g) is not very important for Indian rivers as most of the floods occur during monsoon period only.

One of the most simple and very useful graphical relation is the 'FLOOD PROFILE NOMOGRAM'. This diagram indicate the peak stage at each station along with river for a storm. A number of such lines are drawn for various conditions of storm. The various line should be drawn in different inks and the specific meteorological condition such as heavy concentrated rainfall or other conditions such as breach of embankment etc should be mentioned on such Nomogram for river Yamuna is shown in Fig.1. Although the diagram does not help in accurate forecast formulation, it serves as a very good guide in checking the formulated forecast.

The various type of graphs which are used in forecast formulation can be classified as :

- i) Director correlation between gauges or discharges of U/S and D/S station
- ii) Correlation between gauges or discharge at U/s and D/S stations with additional parameters.

Some of the correlation diagram which are commonly in use are discussed hereunder:



### 8.1.2 Direct correlation between gauge and discharge at u/s and d/s

In such graph basically, only gauge and discharge data forecasting stations and the base stations are utilized in different forms. The following type of correlation are generally used.

- A) **The simplest of all is the correlations between the  $N^{\text{th}}$  hours stage of base station and  $(N+T)^{\text{th}}$  hour stage of forecasting stations; where  $T$  is the travel time of flood wave between the base station and forecasting station. Fig.2 shows one such graph which is used for forecasting the river stage in River Brahmini in Orissa.**

This type of graph can be developed and used for reach the river where there is no major tributary with considerable discharge, catchment between the two station is small so that the effect of rain is negligible and the travel time from base station to the forecasting station is fairly constant for various stages.

However, in most of the cases the travel time is not constant and varies with water level. Apart from this such relations give considerable errors under different conditions.

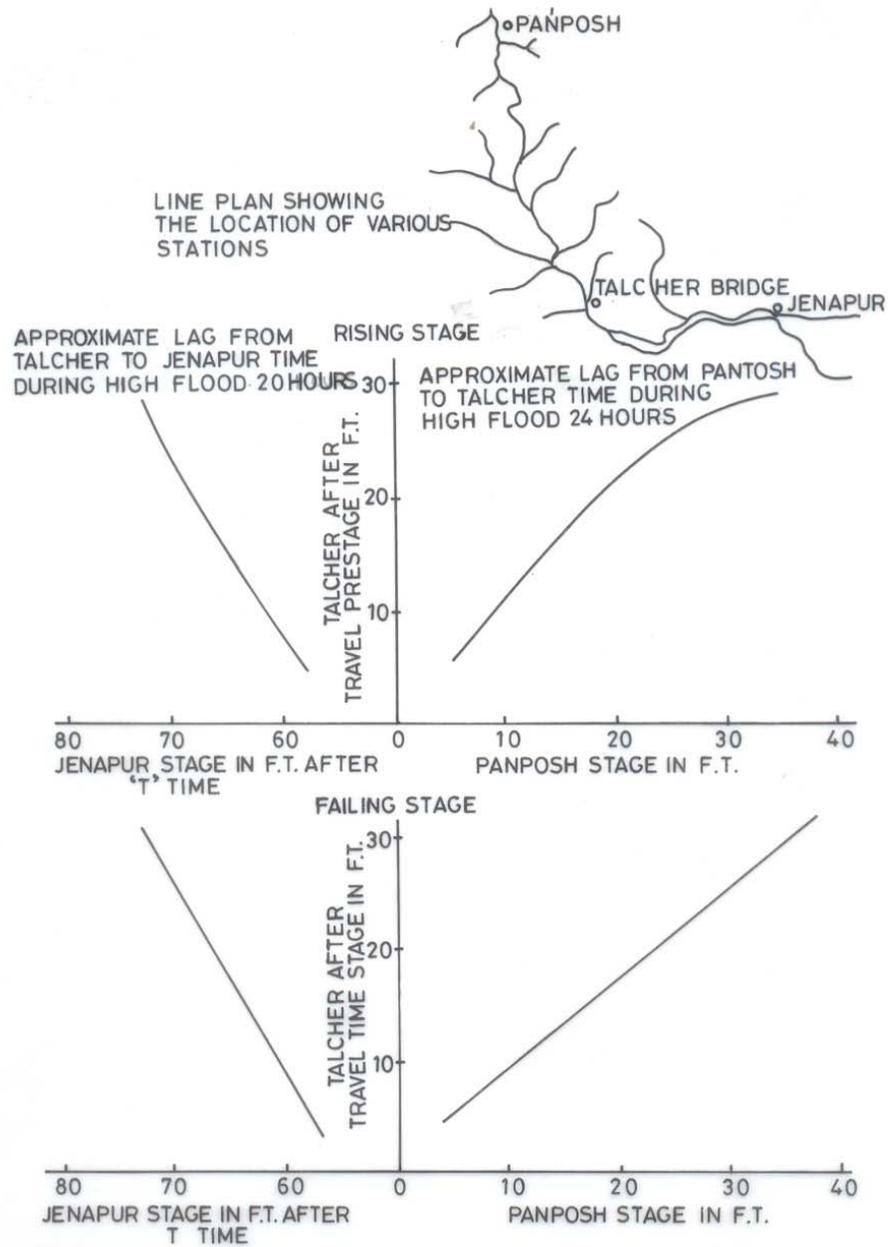


FIG.2 CORRELATION DIAGRAM OF RIVER BRAHMANI BETWEEN GAUGE AT PANPOSH TALCHER AND JENAPUR

These relations can be considerably improved if the following aspects are taken into account.

- (i) The variation in travel time
- (ii) Varying conditions during rising and falling stages of the flood (Fig.2).
- (iii) Antecedent Moisture conditions of the stream (This can be roughly taken into account by drawing two different sets of curve, one for the few initial flood waves and the other for remaining flood waves).
- (iv) Downstream Boundary Conditions ( The data of the stages for high tides or larger rivers may be used to consider back water effects)

**B) Direct correlation between the peaks, at forecasting station and base station:**

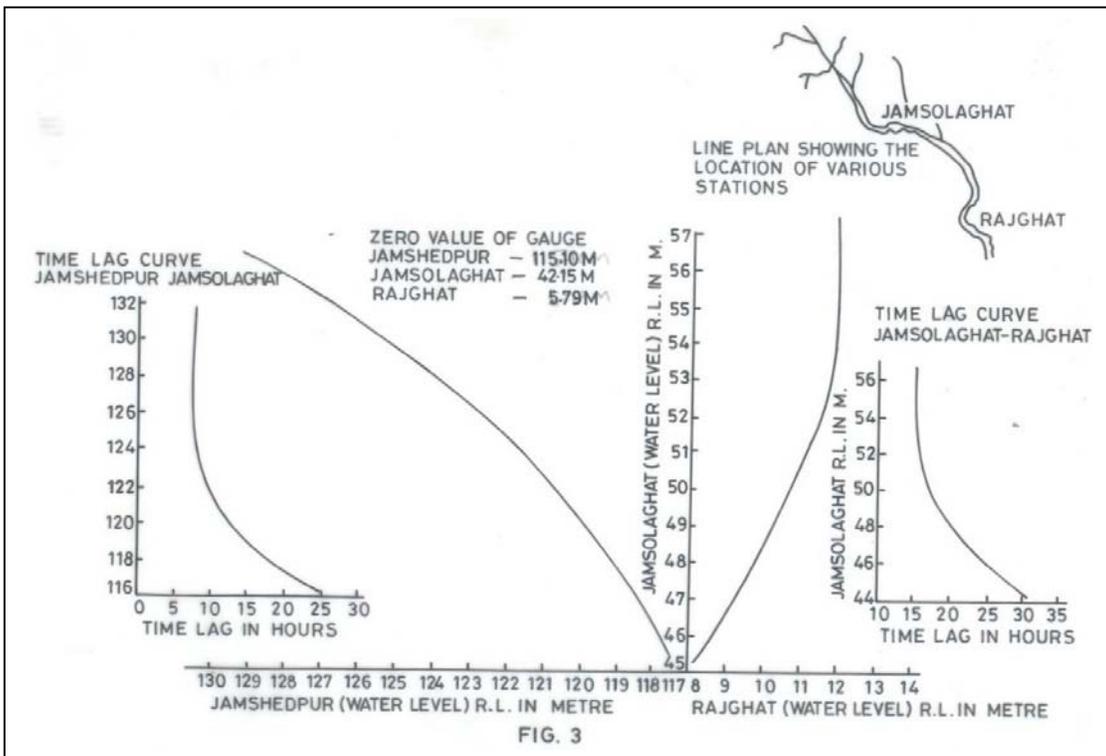
The gauge (peak) at the base station and the gage (peak) at the forecasting station for the various intensities of flood are plotted. The travel time at various intensities of flood is also plotted corresponding to peak. Such graphs have been successfully used for river Subernarekha in Orissa. The graph is shown in Fig.3 warning time available is about 24-30 hrs.

**C) Correlation between the change in stage of the base station and change in the stage of forecasting stations during T hours (T = time of travel of flood wave between the base station and forecasting site)**

Such a method obviates errors, to some extent, due to aggradation or degradation in the river section, depending upon flows. This correlation has been found more suited to large rivers with more uniform change in levels and discharges between the base stations and the forecasting stations. Such graphs developed for river Ganga between Dighaghat and Dandhighat is shown in Fig.4. Separate graphs have been developed for Rising stage and Falling stages.

**D) Correlation between the N<sup>th</sup> hour and (N+T)<sup>th</sup> hour stages of the forecasting station with change in stages at the base station during past 'T' hours as variable.**

Different sets of graphs are drawn for rising and falling conditions of the river. Such graphs are used for forecasting river stages at a number of site. One such correlation used for forecasting Dalmau stage on river Ganga (under Lucknow Division is shown at Fig.5). If there is larger fluctuation in the stages of the base stations, the parameter of average gauge within past 'T' hrs at the base station is introduced in the 1<sup>st</sup> quadrant instead of change in stage of the base station. In the 2<sup>nd</sup> quadrant N<sup>th</sup> hour stage of the base station is also leveled to account for the intensity of flood. This has been found suitable



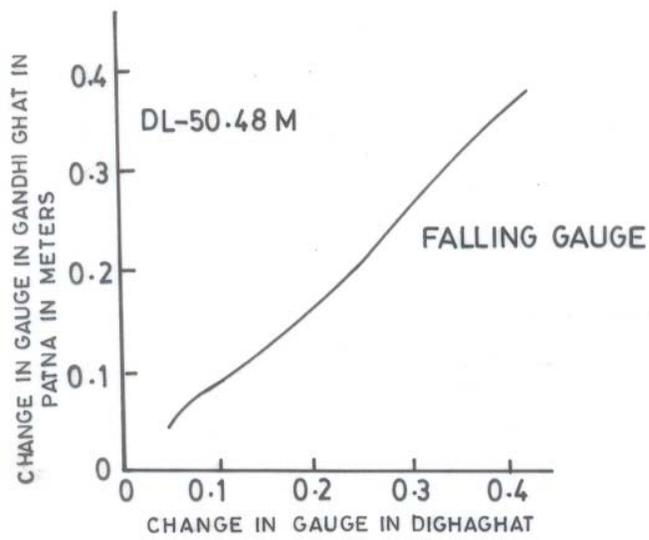


FIG.4-CORRELATION GRAPH FOR DIGGHAT PATNA

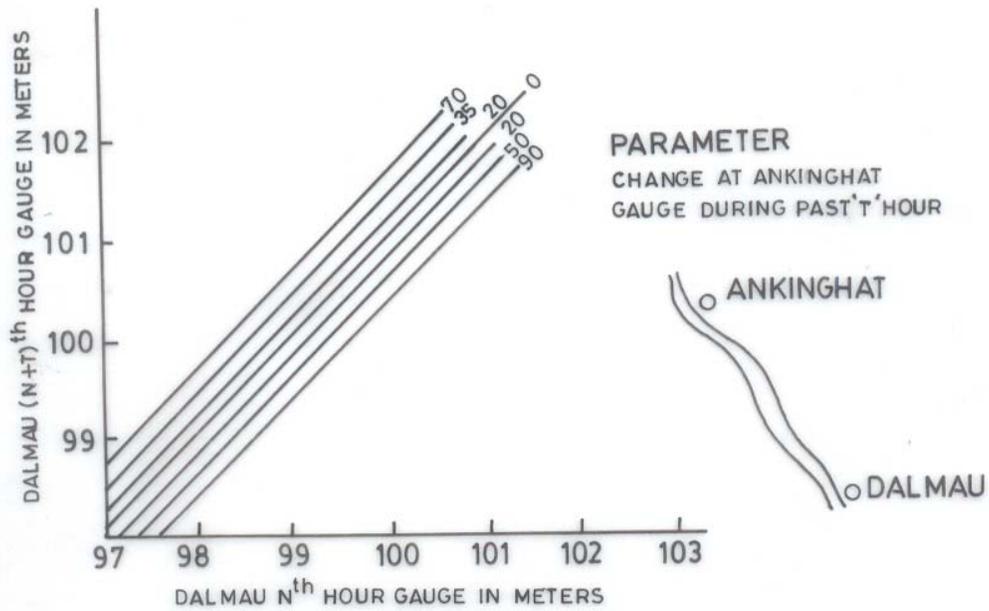


FIG.5-CORRELATION GRAPH FOR DALMAU SITE ON RIVER GANGA

when the base station is D/S of a control structure on the river, through which the flows are released with wide fluctuations. Such correlation is shown in Fig.6.

**E) In rivers having wide fluctuation in U/S stages and relatively much less reduced fluctuations in lower reaches due to large scale inundation/valley storage in between the two points, tendency effect is considered. This is done by correlating  $N^{\text{th}}$  and  $(N+T)^{\text{th}}$  hour stage of the forecasting site in Past 'T' hours as variable in the 1<sup>st</sup> quadrant. Then in the 2<sup>nd</sup> quadrant, the average gauge of the base station is considered as a variable. This type of graph have proved quite useful in Bagmati and Adhwara group of rivers of Bihar in Ganga Basin. One such graph developed for Kamtaul site of River Adhwara is shown in Fig.7.**

**F) Gauge to Gauge correlation in Coastal Rivers :**

The coastal rivers pose special problems is regards to formulation of forecast because of the tidal effect. The simple gauge to gauge relation will not yield satisfactory result. Before developing a G-G correlation charts, it is considered imperative to analyse the various cases, arising in coastal rivers, separately and develop different set of curves, for the formulation of forecasts. The various cases encountered in the coastal rivers, are discussed below in brief :-

- i) The river in in high stage and there is no tidal effect.
- ii) The river is in low stage and there is a tidal effect. As a result of which there will be backwater effects in the lower reaches of the river. The backwater effect has to be incorporated in the formulation of forecast.
- iii) The river is in high stage and there is a tidal effect. The river will not be able to drain freely and there will be looking effect which will affect the forecast significantly. This aspect has to be considered, while developing the charts etc for the formulations of forecast.

Thus, it is seen that the three cases, mentioned in the preceding sections, call for development of different sets of charts to be utilized for the formulation of forecast.

Realising the necessity of considering the tidal effect in the formulation of forecast for the area below Akhupada in Baitarni river basin a tidal gauge has been recently installed at Chandbali. The data from the tidal gauge in conjunction with the annual tidal table (published yearly by the Survey of India) forecast will be quite useful in determining the tidal influence and backwater effects on the lower reaches of the river. This will be of particular importance when tides are enhanced by storm surges accompanying the movement of tropical cyclone on shore. The data, obtained from the tidal gauges will come quite handy in development of charts for forecast formulation, considering tidal effect.

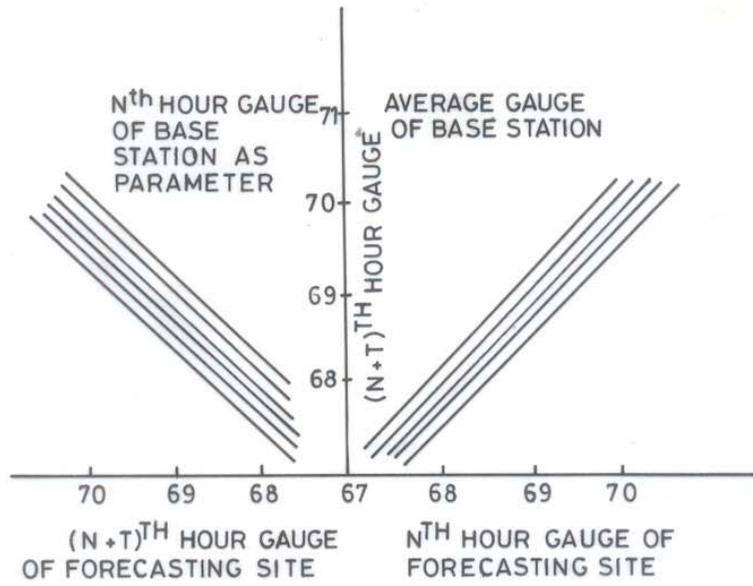


FIG. 6

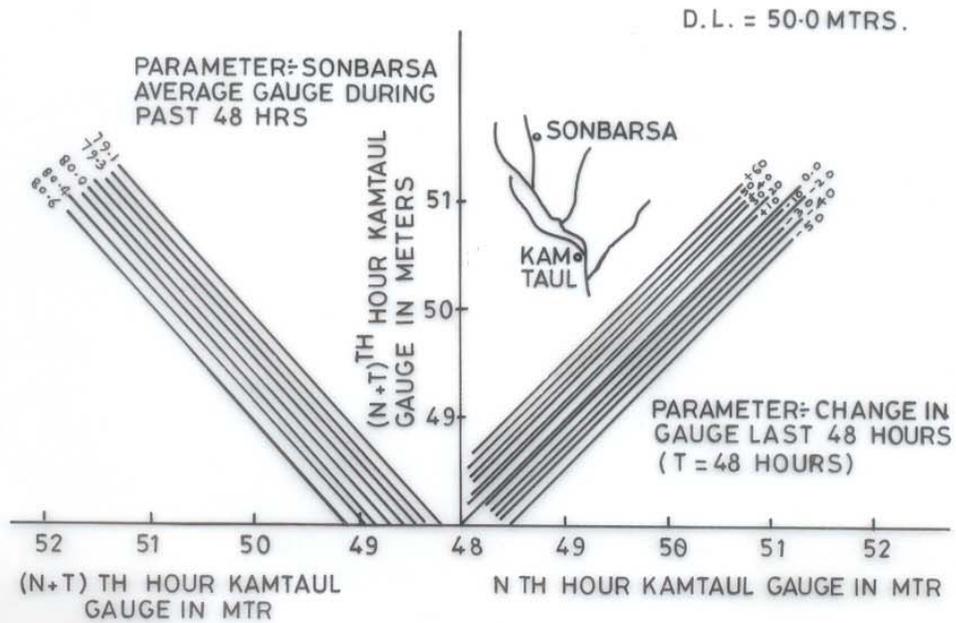


FIG. 7- CORRELATION GRAPH FOR THE SITE KAMTAUL RIVER ADHWARA

Some of the correlation diagrams which have been developed using the U/S and D/S gauges have been discussed above. Besides these the discharges at U/S and D/S stations are also used for formulation of the forecast and some mathematical equations have been developed and are in use. A few of them are discussed below:

**(G) Poanta – Tajewala Model (For River Yamuna)**

The travel time from Poanta to Tajewala being 2 hours, Poanta gauge in ft. at  $t$  hours,  $G_p(t)$  is correlated to Tajewala discharge in cusecs,  $Q_T(t+2)$  for rising limb

$$Q_T(t+2) = 7.4045 \times 10^5 G_p(t)^{4.333} \quad (1)$$

Another relation has been developed for falling limb when the travel time of 3 hours is found to be more appropriate and the relationship is:

$$Q_T(t+3) = 1.819 \times 10^{-6} \times G_p(t)^{5.555} \quad (2)$$

The graphical representation is shown in Fig. 8.

**(H) Gauge-Rise Models for various reaches of Yamuna.**

The height of the flood wave at D/S section is related to its height at the U/S section:

$$(G_{DP}-G_{DO}) = a(G_{UP}-G_{UO}) + b \quad (3)$$

Where  $G_{DP}$  and  $G_{UP}$  are the peak gauge at the D/S and U/S sections.

$G_{DO}$  and  $G_{UO}$  are the estimated gauges at the time of recorded peak, had the recession prior to the start of the flood wave continued.

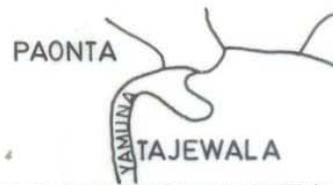
$a$  &  $b$  are constant, to be evaluated on the basis of past flood data. One such equation developed for Kalanur and Delhi reach of the Yamuna is shown in the Fig. 9.

**(I) Discharge-Rise Models**

The discharge rise due to a flood wave at a D/S section is related to that on an U/S section, if the effect of the intermediate catchment contribution is not significant

$$(Q_{DP} - Q_{DO}) = m(Q_{UP}-Q_{UO}) + n \quad (4)$$

Where  $Q_{DP}$  and  $Q_{UP}$  are the discharges at the D/S and U/S sections  $Q_{DO}$  and  $Q_{UO}$  are the estimated discharges at the time of recorded peak, had the recession prior to the start of flood wave continued and  $m$  and  $n$  are constant to be evaluated on the basis of past flood data. On such relation developed for Kalanaur – Mawi reach of Yamuna is shown in Fig. 10.



LINE PLAN SHOWING THE LOCATION OF VARIOUS STATIONS

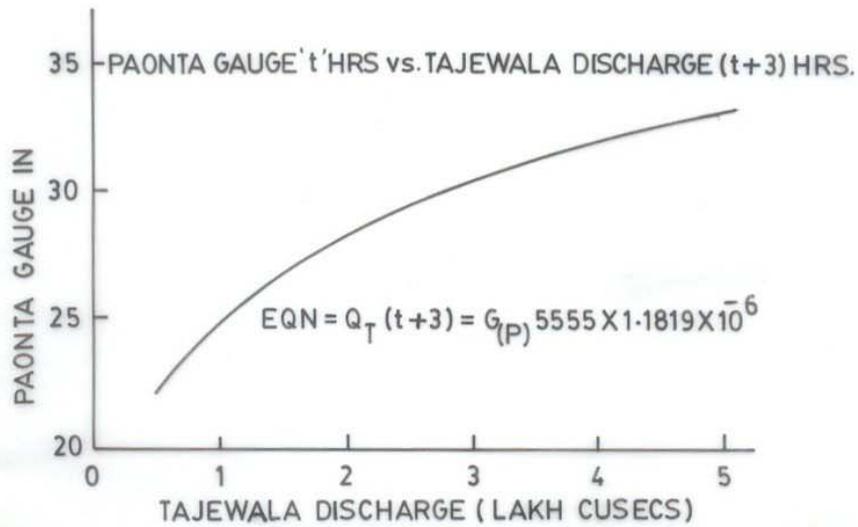
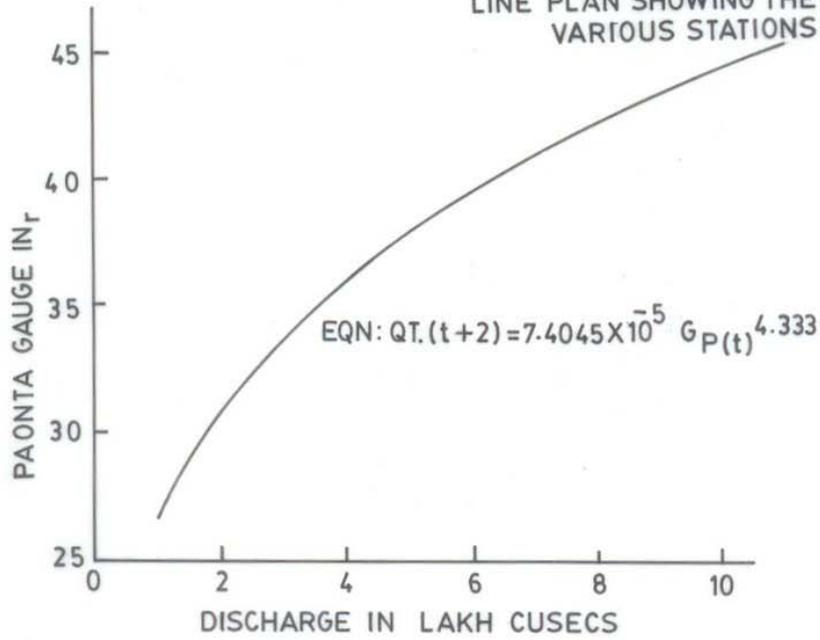
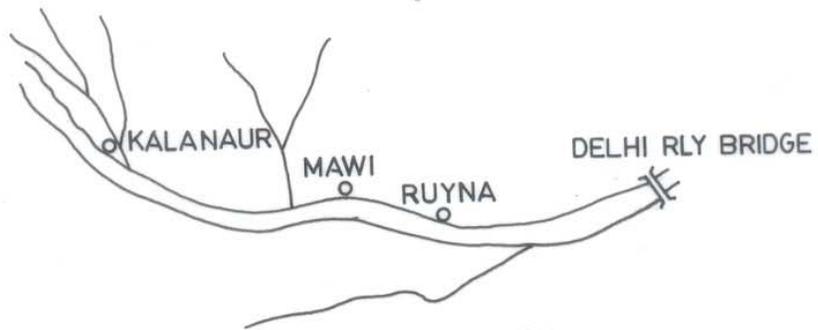


FIG. 8- PAONTA GAUGE Vs. TAJEWALA DISCHARGE (WITH 2 HRS. LAG) RISING LIMB



LINE PLAN SHOWING THE LOCATION OF VARIOUS STATION

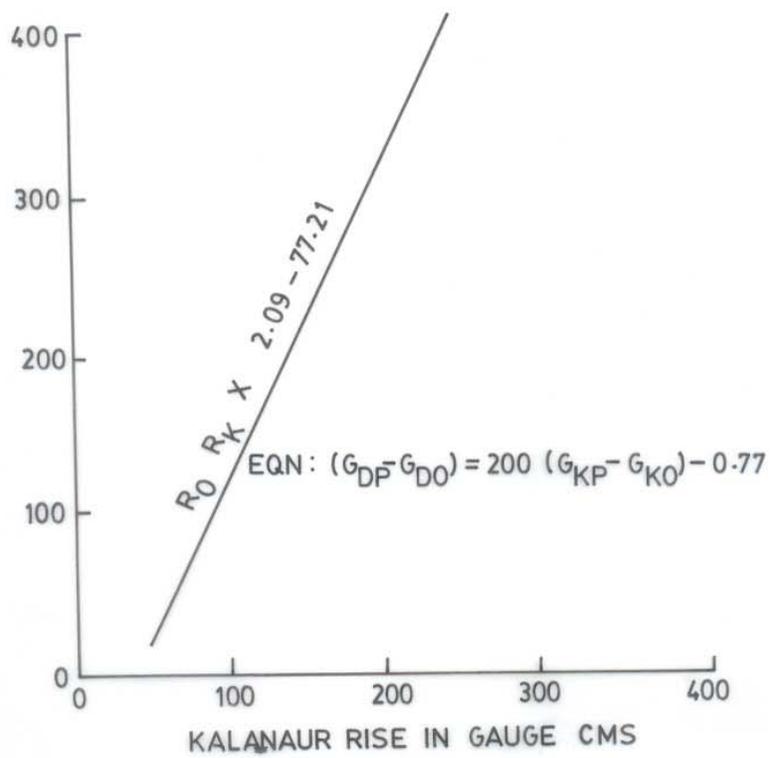


FIG. 9

LINE PLAN SHOWING THE  
LOCATION OF VARIOUS  
STATIONS

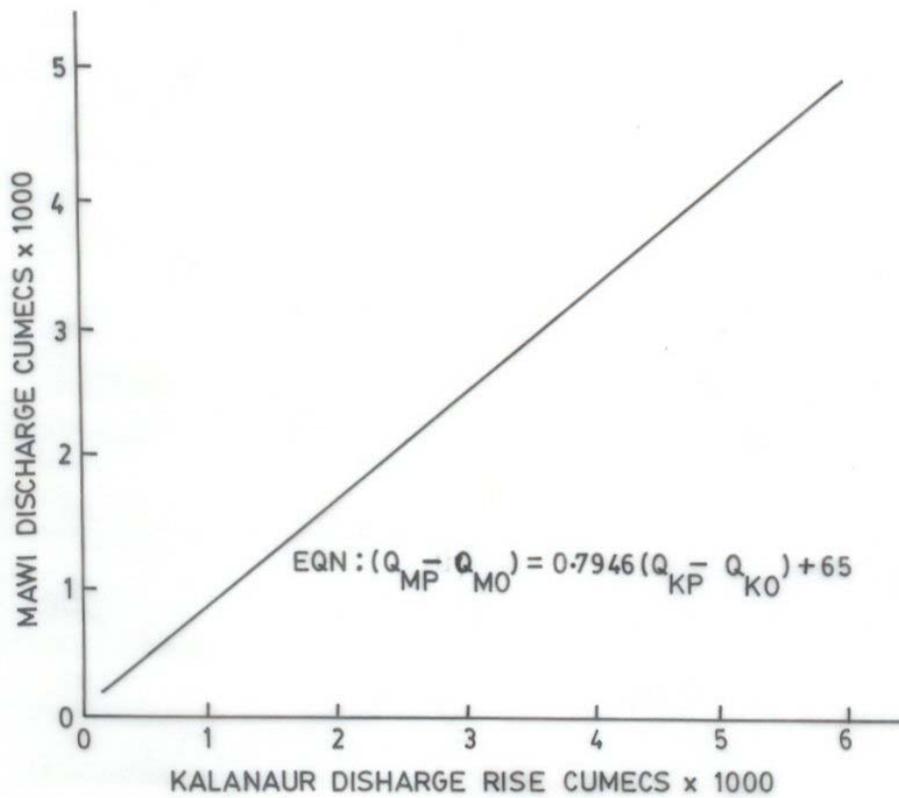
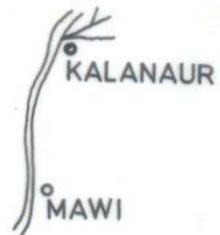


FIG.10-CORRELATION BETWEEN RISE IN DISCHARGE  
AT KALANAUR AND MAWI

### 8.1.3 Correlation between gauges at u/s and d/s with additional parameters.

When the direct gauge to gauge correlation are not successful because of appreciable contribution due to rainfall in the reach catchment, intermediate tributaries or the varying soil moisture condition etc., then the introduction of additional parameters of discharge of the tributary, average rainfall over the intercepting catchment, API etc. become necessary and it gives better results.

With the availability of more and more data and introduction of better data transmission facilities, the correlation diagrams are being developed with more and more additional parameters. The various parameters are introduced in different quadrants.

Some of such diagrams which are at present under use are discussed below in brief.

- a) Correlation between the  $N^{\text{th}}$  hour, and  $(N+T)^{\text{th}}$  hour gauge of forecasting station with change in the level of a tributary during past  $T_1$  hours and change in level of the base station during past  $T$  hour.
- b) Correlation between  $n^{\text{th}}$  hour and  $(N+T)^{\text{th}}$  hour gauge of forecasting station with following parameters:
  - i) Rise/Fall at U/S base station
  - ii) Rainfall observed at the U/S base station.

When a number of tributaries affect the water level at the forecasting station, then the change in the base station on the main river as well as base stations on the tributary can be considered as additional parameters.

#### A. Multi tributary model

A discrete, linear, time-invariant model has been developed for operational flood forecast of river Brahmaputra at Dibrugarh. This model is based on the difference of the gauge reading at the forecasting station and the upstream base station in the tributary. The use of differences of gauge readings as input in the model takes care of the aggradation or degradation of the river bed of the tributary and the main river. The model in general is expressed as:

$$g_{(i+T),i} = A_{1,i} g_{i,(i-T)} + \sum_{j=1}^m A_{2,j} h_{(i-T+T_j),(i+T)_j} + \sum_{j=1}^m A_{3,j} h_{(i-T_j),(i-T_j-T)} \quad (5)$$

Where  $m$  = Number of tributary (=3 in this case)

$T$  = Forecasting time

$T_j$  = Lag time between the forecasting station ( $T \leq T_j$ )

$h_{(i-T_j+T),(i-T_j)}$  = Difference in gauges at the U/S station on the tributary between  $(i-T_j+T)$  and  $(i-T_j)$  th instant.

$h_{(i-T_j),(i-T_j-T)}$  = Difference in gauges at the U/S station on the tributary between (i-T<sub>j</sub>) and (i-T<sub>j</sub>-T)th instant.

$g_{i,(i-T)}$  = Difference in gauge at ith and (i-T) the instant of time at the forecasting station.

$g_{(i-T),i}$  = Difference in gauge at (i-T)th and ith instant of time at the forecasting station i.e. the forecast value.

$A_{1,j}, A_{2,j}, A_{3,j}$  are the parameters which are to be found out.

The parameters  $A_{1,j}, A_{2,j},$  and  $A_{3,j}$  can be estimated by the method of least square technique. In this case the forecast of Dibrugarh is formulated with the help of observed gauge data on three major upstream tributaries namely Dihang, Debang and Lohit.

### B. Rainfall-stage method

The relationship for estimating the peak discharge or the peak stage with the help of rainfall data is of great operational significance in the sense that it enables one to find the expected peak discharge or stage which is one of the important requirements in flood warning. In its simplest form it is the relation between the average rainfall over the catchment and the peak stage. This relation may be either a graphical or mathematical and can be very easily established by using the statistical technique. The results can be further improved by incorporating other parameters such as API etc. These relations are used on many places with quite good result but the deficiency in this method is that the time of occurrence of the peak or the full shape of hydrograph can not be forecast.

One such relation has been developed for Anandpur site on river Baitarni where the peak discharge is estimated by using the relation.

$$Q_{max} = 1.451 - 0.1678x + 0.0129x^2 \quad \dots\dots (6)$$

Where  $Q_{max}$  = peak discharge at Anandpur in lakhs of cusec.

$$x = x_1 + x_2$$

$x_1$  = Weighted storm rainfall over the catchment in cms.

$x_2$  = Effective Antecedent rainfall in Cms.

The weighted storm rainfall over the catchment is estimated by assigning certain weights to the various stations, depending upon the area and geographical condition.

$$X = 1.0A + 0.2B + 0.7C + 0.6D \quad (7)$$

Where A, B, C and D represent the rainfall at various stations in Cms.

The effective antecedent rainfall is taken as certain percentage of the antecedent rains.

The following table has been assumed and used in all calculation.

Weighted antecedent Rainfall in mm	Percentage of antecedent rainfall to be taken as effective
0 - 15 - -	- - Nil
15 - 20 - -	- - 20%
20 - 30 - -	- - 25%
40 - 60 - -	- - 30%
60 - 80 - -	- - 35%
80 - 100 - -	- - 40%
100 - 120 - -	- - 45%
120 - 140 - -	- - 50%
140 - 160 - -	- - 60%
160 - 180 - -	- - 70%
180 - 200 - -	- - 80%
More than 200 - -	- - 90%

The relation has been developed by analyzing data of previous 23 storm and the results are quite satisfactory.

## 8.2 Deterministic methods:

One of the important areas in hydrology pertains to the study of the transformation of the time distribution of rainfall on the catchment to the time distribution of runoff. This transformation is studied by first relating the volume of rainfall to the volume of direct surface runoff, thus determining the time distribution of rainfall excess (the component responsible for direct surface runoff on the catchment) and then transforming it to the time distribution of direct runoff through a discrete or continuous mathematical model. The first step decides the volume of the input to the catchment and therefore any error in its determination is directly transmitted through the second step to the time distribution of direct runoff. A number of watershed conceptual models find this component for each time step through a number of stores representing various processes on the catchment. The parameters of these models including those in the functional relationship are determined from the historical record and their performance is tested by simulating some of the rainfall-runoff events which have not been used in the parameter estimating process. The models need to be run continuously so that the status of various stores is available at all times. One of the operational uses of these models is in the area of real time flood forecasting required for real time operation of the reservoir. In such a situation these models are run by inputting the rainfall and forecasts are issued assuming no rainfall beyond the time of forecast value of the rainfall in the future.

The infiltration part of these models and their context decide the volume of input. At the time of calculation the catchment is also performing the transformation operation to produce the direct runoff at the gauging station. Since the model is simulating the

action of the catchment it would be appropriate to make use of this information in finding out the contribution which the rainfall is going to make to the direct runoff on the catchment. However, the complexity of these models does not lend itself to this exercise during the event. SSARR (Stream flow Synthesis and Reservoir Regulation) model, Sacramento model and NAM-System 11 FF model are some of the watershed conceptual models for formulating the real time flood forecast. In India, the real time flood forecast have been formulated in some pilot projects using these models. However, these conceptual models are not being utilized because of inadequacy of data and problems associated with the proper calibration of the models.

Of late methods based on unit hydrograph approach have been formulated for real time forecasting which overcome the difficulties associated with complex hydrological models. The unit hydrograph method has long been recognized as a useful tool for converting excess rainfall to direct surface runoff by linear transformation. The assumptions underlying this method and their limitations with regard to areal size, linearity and uniform spatial and temporal distribution of rainfall have been discussed in most of the text books and research papers. In India, the applications of unit hydrograph technique are restricted to the catchments of sizes less than 5000 Sq. Km. However, for the catchments of sizes more than 5000 Sq. Km., a network model is developed. In this model the catchment is divided into sub-catchments and the main river is divided into sub-reaches, considering the two consecutive nodes. The nodes are the points where the tributary of the sub-catchments join the main river. The principle of unit hydrograph is applied for converting the excess rainfall to direct surface runoff for each sub-catchments considered as lateral flow to the river and the flood routing technique is used for routing the direct surface runoff at the upstream node through the river sub-reaches up to the downstream node. The computations are performed for the network model structure to estimate the direct surface runoff at the outlet of the catchment. HEC-1 model has an option of the network model simulation using these concepts.

The Hydrologic Engineering Centre (HEC) of the US Army Corps of Engineers, USA has developed a computer model HEC-1F, a modification of model HEC-1, for the purpose of real time forecasting. HEC-1F model uses the unit hydrograph technique with constant loss rate to forecast the runoff. Forecasting by HEC-1F model is accomplished by re-estimating the unit hydrograph parameters and the loss rate parameters as additional rainfall runoff data are reported and using these updated parameters the future flows are estimated for forecasting. The Snyder's synthetic unit hydrograph described by two parameters is used as unit hydrograph model. For the estimation of the unit hydrograph and constant loss rate parameters, the model uses univariate search technique of optimisation. HEC(1984) provides the complete details of the model. In India, HEC-1 F model is applied for formulating the flood forecasts of a pilot basin.

## **9. FLOOD FORECASTING STATUS IN ARID AND SEMI-ARID REGIONS OF INDIA**

The arid and semi-arid regions of India receive less rainfall as compared to the other regions. The occurrence of floods in this region are not so frequent. However, in the

past, flash floods have been occasionally experienced in the region due to high intensity rainfall for short duration causing loss of human lives and properties. As such there is no system of forecasting flash flood because of lead period being very short. There is a need for developing the real time rainfall forecasting system and its linkages with the flood forecasting technique in order to provide the flash flood forecast well in advance for taking the emergency actions for evacuating the people so that their lives may be saved and the losses of the properties may be minimized. In this regard, the provisions may be made for the radars and other automatic instruments to measure and forecast the rainfall together with the advance communication and dissemination system in this region.

## **10. MODERNISATION OF FLOOD FORECASTING SERVICES**

The flood forecasting services provided by the Govt. of India through Central Water Commission, which has over 25 years of experience in the field and commendable performance to its credit, is presently poised for big leap forward by application of modern technology in the field of communication and introduction of high speed computers for forecast formulation.

In order to improve the warning time and the accuracy of the forecast, it was considered necessary to adopt latest technology for real time collection and transmission of hydrological and hydro-meteorological data and application of the high speed computer using hydrological and mathematical models.

In order to achieve these objectives, a pilot project to establish fully automatic operational river and flood forecasting system in the country with the assistance of World Meteorological Organisation (W.M.O)/United Nations Development Programme (U.N.D.P) has been implemented in the Yamuna basin upto Delhi. The experience gained from this project is being applied to modernize other forecasting centres in the country.

Another scheme called C.W.C. – DHI (Central Water Commission & Danish Hydraulic Institute, Denmark) collaboration project, with the Damodar river basin as focus project, has also been implemented and computerized mathematical models developed in the DHI is being used for inflow forecasting for formulation of flood control scheme. A scheme on similar line has been taken up for Godavari Basin.

Availability of hydrological & meteorological time series data as well as spatial data is somewhat limited. Because of this, it is difficult to calibrate and validate the multi parameter hydrological models for formulating the real time flood forecast in the field. Recently, a World Bank Aided hydrology project phase –I has been completed for the nine states of India viz. Andhra Pradesh, Maharashtra, Gujarat, Kerala, Tamilnadu, Karnataka, Madhya Pradesh, Chattish Garh and Orissa. Under this project, the observation networks for monitoring the hydro-metereological variables have been strengthened for different river basins located in these states. A Hydrological Information System (HIS) has been developed for the processing, storing and retrieving the data collected from the field. State Data Centres are linked with the National Data Centres and a system has been evolved for providing the data to the user agencies through internet. It has improved the data availability for these states. Another World Bank Assisted Project Phase-II is likely to start soon wherein the hydrological analysis would be carried out using the processed data available for HIS. Under this project, the development of a

Decision Support System (DSS) for real time flood forecasting of Bhakhara – Beas reservoir system has been envisaged.

The computing techniques like Stochastic models, Artificial Neural Network (ANN) and Fuzzy Logic are being applied for real time flood forecasting. However, such applications are mostly limited to research and development at academic and research institutions of the country. However, operational uses of such techniques are yet to be established and encouraged.

## **11. STOCHASTIC MODELS FOR REAL TIME FLOOD FORECASTING**

Several stochastic/time series models have been proposed for modelling hydrological time series and generating synthetic stream flows. These include Box-Jenkins class of models (Box and Jenkins, 1970; Salas et.al., 1980). The time series models are considered to be most suited for real time forecasting as on-line updating of model forecasts and parameters can be achieved using various updating algorithm. It has been observed that the dynamic stochastic time series models are most suitable for on-line forecasting of floods (Kalman, 1960; Sage and Husa, 1969; Eykhoff, 1974; Kashyap and Rao, 1975; Kumar, 1980; O'Connell, 1980; Chander et al., 1980, 81, 84). These models also provide a means for the quantification of the forecast error, which may be used to calculate the risks involved in the decisions based upon these forecasts. Further, these models can be operated even with interrupted sequences of data and easy to implement on computer and other computing devices.

## **12. ARTIFICIAL NEURAL NETWORK MODELS FOR REAL TIME FLOOD FORECASTING**

The formulation of real time flood forecasting using statistical & stochastic models is based upon the assumption of linearity whereas the quantity of runoff resulting from a given rainfall event depends upon a number of factors and is dominantly non-linear. Recently, another class of black box models in the form of Artificial Neural Network (ANN) has been introduced in modelling real time problems wherein the non-linear relationship between the rainfall and runoff process is modelled. The ANN model has wide applicability in Civil Engineering applications and many research papers have been published on its application. The use of ANN in real time flood forecasting is of very recent origin and is still in the evolution stage. Recently Xiong and O'Connor (2002) studied four updating models for real time flood forecasting, in which the authors have shown that the use of ANN model as forecast error update model has in fact not improved the real time flow forecasting efficiencies over that of the standard AR model.

## **13. FUZZY LOGIC TECHNIQUES FOR REAL TIME FLOOD FORECASTING**

The emergence of a flood and thus its forecast depend elementarily on the discharge process in the natural catchment area of the river. This process is rather complex and its mapping into a suitable process model for an automated flood forecast is accordingly difficult. Hydrologic models are useful only to the degree that they represent

processes in the world. Mathematical models have been developed based either on physical considerations or on a statistical analysis to estimate floods from small as well as large size catchments. Existing flood forecasting models are highly data specific and complex. Unlike mathematical models that require precise knowledge of all the contributing variables, fuzzy logic, on the other hand, offers a more flexible, less assumption dependent and self-adaptive approach to modelling flood processes, which by their nature are inherently complex, non-linear and dynamic. Fuzzy Logic based model can be used to model process behaviour even with incomplete information. Fuzzy logic is widely regarded as a potentially effective approach for effectively handling non-linearity inherently present in the hydrological processes (Zadeh, 1965). Moreover, this technique can be used for modelling systems on a real-time basis (Lohani et al. 2005). Other advantages include: the potential for improved performance, faster model development and execution times and therefore reduced costs, the capability to plug fuzzy logic directly into conventional models and the ability to provide a measure of prediction certainty. Fuzzy Logic based procedures may be used, when conventional procedures are getting rather complex and expensive or vague and imprecise information flows directly into the modeling process. With Fuzzy Logic it is possible to describe available knowledge directly in linguistic terms and according rules. Quantitative and qualitative features can be combined directly in a fuzzy model. This leads to a modeling process which is often simpler, more easily manageable and closer to the human way of thinking compared with conventional approaches.

The use of fuzzy logic in the field of hydrological forecasting is a relatively new area of research, and the potential to enhance flood forecasting by incorporating other soft computing technologies into a hybrid solution still remains to be exploited. Recently use of fuzzy set theory has been introduced to interrelate variables in hydrologic process calculations and modelling the aggregate behavior. Further, the concept of fuzzy decision making (Bellman and Zadeh, 1970) and fuzzy mathematical programming have great potential of application in flood management models to provide meaningful decisions in the face of conflicting objectives.

#### **14. CONCLUDING REMARKS**

In India, most of the techniques for formulating the real time flood forecast are based on statistical approach. For some pilot projects, network model and multi-parameter hydrological models are used. Conventional systems of communication are normally used for transmitting the data in real time. The automatic systems of data communication like Telemetry system are used in pilot projects on limited scale. In the areas of arid and semi-arid, flash floods are usually experienced. As such there is no system for formulating the flash flood forecast in the region. It results in heavy losses of lives and properties.

There is a need for significant improvement of the real time flood forecasting systems in India. Efficient automatic communication systems are required to be established for transmitting the data in real time. The forecasting techniques such as deterministic models, stochastic models, ANN and Fuzzy Logic techniques etc are required to be studied and a suitable method may be recommended for field applications based on the performance evaluation criteria and considering the data availability and

purpose of the forecast. The information about the flood have to be disseminated well in advance to the people likely to be affected so that an emergency evacuation plan may be prepared and properly implemented. The hydrological information system is required to be developed for all the river basins of India. The techniques based on deterministic approach have to be developed and applied for the real time flood forecasting. The pilot project proposed under World Bank Aided Hydrology Project Phase-II for the development of Decision Support System (DSS) for Bhakhra-Beas Reservoir System would provide useful information to decision makers in real time for taking necessary flood management measures in the downstream of the reservoir. Further more, the technology to be acquired under the project would be very much useful for developing such systems in other flood prone river basins. Flash flood forecasting is another important area which require immediate attention.

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