LECTURE - 1

FLOODS - GENERAL INTRODUCTION

by

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OBJECTIVE: The main objective of this lecture is to introduce various aspects of flood problem and hydrological anlaysis/design techniques to deal with such problems.

1.1 INTRODUCTION

The flow in a river varies from day-to-day and year to year. The volume of water carried is not the same every year due to complex meteorological factors and varying characteristics of the ground on which the rainfall occurs. The river is stated to be in flood when the flow exceeds the capacity within the banks The magnitude of the floods depends upon the intensity of the rainfall, its duration and also the ground conditions when the heavy spell of rainfall occurs. Arid and semi-arid regions where the rainfall is scanty and infrequent have poor drainage characteristics. Consequently whenever there is a heavy spell of rainfall, such as a case of cloud burst, water accumulation and flooding occurs. Other factors which tend to increase the flooding are erosion and silting which lead to decrease in the capacity of river channels and increased meandering. Earthquakes and land slides, syncronisation of the floods in the main tributary rivers and retardation of flood flow due to tidal effects and cyclones further aggravate the changes caused by floods.

Floods are repeatedly in the headlines of local, national and international media. The problem of floods and their computation is one of the main and most complex problems facing the hydrologists. The optimal development of water resources depends to a considerable extent on flood flow control, design and construction of structural measures and taking proper measures for flood mitigation including non-structural measures like flood plain zoning, flood forecasting and warning, etc. All such hydrologic analysis and design problems require accurate and reliable data for flood estimation using statistical and/or deterministic methods. The estimation of design flood for safety of structures under flood conditions has also to take into consideration cost aspects and to avoid over design.

1.1.1 Definition

Defining a flood is somewhat difficult, partly because floods are complex phenomena and partly because they are viewed differently by different people. A meaningful definition of flood should incorporate the notions of damage and inundation. Some typical definitions are as follows:

(i) A flood is a relatively high flow which over taxes the natural channel provided for the runoff;

(ii) A flood is a body of water which rises to overflow land which is not normally sub-merged;

(iii) A flood is any relatively high streamflow that overtops the natural or artificial banks in any reach of a stream.

The overtopping of the banks results in spreading of water over the flood plains which generally comes under conflict with man and his activities. It is, therefore, necessary to study the characteristics of floods so that they could be controlled. The report of Rashtriya Barh Ayog lists various situations related to floods as follows:

(i) Streams carrying flows in excess of the transporting capacity within their banks, thus overflowing adjoining land;

(ii) Backing up of waters in tributaries at their outfalls into the main river with or without synchronisation of peak floods in them.

(iii) Heavy rainfall synchronising with river spills;

(iv) Ice jams or landslides blocking stream courses resulting in the backwater overflowing river banks;

(v) Synchronisation of upland floods with high tides;

(vi) Heavy local rainfall;

(vii) Typhoons and cyclones; and

(viii) Inadequate drainage to carry away surface water with the desired quickness.

1.1.2 Causes of Flooding

Floods result from a number of basic causes as listed below:

(i) Climatological

(a) Rain, (b) Snowmelt, (c) Icemelt, (c) Combined rain and snowmelt;

(ii) Part climatological

(a) Estuarine interactions between streamflow and tidal conditions; (b) Coastal storm surges;

(iii) Other natural factors

(a) Earthquakes, (b) Landslides, etc.

(iv) Failure of dams and other control works

However, it is to be noted that the identical flood generating mechanisms, particularly those associated with climatological factors may result in very different floods from one catchment to another, or even within a given catchment from time to time. These differences are due to a number of flood intensifying factors/conditions as listed below, which tend to speed up the movement of water within the catchment. Their effect is to reduce the time of concentration (which is defined as the time required for water falling on the most remote part of the catchment to contribute to stream flow at the outlet, either directly as a flow mechanism or indirectly as a push through mechanism of infiltrating water in the higher parts of the basin.

Flood intensifying conditions:

(i) Basin characteristics

(a) Stable - area, shape, slope, aspect, altitude

(b) Variable-interactions between climate, geology, soil type, vegetation cover, wild life, man's activities causing important differences in storage capacity of soil and bed rock, infiltration, and transmissibility of soil and bedrock.

(ii) Network characteristics

(a) Stable - pattern of network

(b) Variable - Surface storage, channel length/contributing or source area, under-drainage

(iii) Channel characteristics

(a) Stable -slope, flood control and river regulation works

(b) Variable - roughness, load, shape, storage.

One of the most important of all flood producing conditions is the total area of interconnected water and water logged surface within the catchment where the effective infiltration capacity is zero and on which, therefore, all falling precipitation contributes directly to streamflow.

1.1.3 Floods in Our Country

The major river systems in the country can be broadly classified into two groups, viz. rivers of the Himalayan region and rivers of peninsular India. The Himalayan rivers are fed by the melting snows and glaciers of the great Himalayan range during spring and summer, and also from rains during monsoon. They are often uncertain and capricious in their behaviour. They carry significant flows during the dry weather due to snowmelt and carry minimum flows, during winter. On the other hand, the peninsular rivers originate at much lower altitudes, flow through more stable areas and are more predictable in their behaviour. Their flow is characterised by heavy discharges during the monsoon followed by very low discharges during the rainless months.

From the point of view of the flood problem, the rivers can also be grouped under the four regions as below:

1. Brahmaputra region;
2. Ganga region;
3. Northwest region;
4. Central India & Deccan region.

The problem of floods varies from basin to basin, so also the magnitude of damages caused by floods. The most flood prone areas are in the Brahmaputra basin and the northern sub-basins in the Ganga basin.The annual flood damages in the Ganga basin states account for about 60 per cent of the total in the country.

Considering total of the protected and unprotected areas floods in any year and failure of protection works, etc. RBA estimated the area liable to floods as 40 million ha. The RBA estimated that during the period 1953-78, on an average about 8.2 million hectares of area was affected by floods every year of which 3.5 million hectares, i.e. 42.7 per cent were cropped area.

The RBA had further observed that the annual average flood affected area for the period 1970-1978 worked out to be 11.9 million hectares of which 5.4 million hectares were cropped area indicating a increasing trend in the flood affected area. Recently it has been assessed, based on the data available during the period 1953-85 that on an average about 7.93 million hectares of area was affected by floods annually which included 3.65 million hectares of cropped area, i.e., 46 per cent of the area affected.

To minimise loss of human lives and cattle as also movable assets, a high priority has been given by the Government for flood forecasting and warning systems on major flood prone rivers operated by the Central Water Commission. The following is the statewise distribution of 145 flood forecasting sites as on 1st Oct. 1985:

1.	Delhi	... 2
2.	Uttar Pradesh	... 31
3.	Bihar	... 36
4.	Assam	... 20
5.	West Bengal	... 15
6.	Orissa	... 10
7.	Gujarat	... 9
8.	Maharashtra	... 7
9.	Dadra-Nagar Haveli	... 2
10.	Madhya Pradesh	... 2
11.	Karnataka	... 2
12.	Andhra Pradesh	... 9

The data is collected from nearly 380 hydrological observation sites and 500 meteorological stations to formulate the forecasts.

The need for flood control and management is being given increasing importance in evolving national water policy. Various measures being suggested include:

(i) Sound watershed management through extensive soil conservation, catchment area treatment, preservation of forests and increasing the forest area and the construction of check dams;

(ii) Adequate flood cushion to be provided in water storage projects;

(iii) Establishment of an extensive forecasting network, alongwith regulation of settlements and economic activity in the flood plain zones.

(iv) Use of structural measures like embankments and dykes as well as non-structural measures like flood forecasting and warning, flood plain zoning, etc. for the minimisation of losses and reduction in expenditure on flood relief.

1.1.4 Necessity of Flood Hydrology Studies

There are several situations in which an estimate of future flood conditions is required by many different categories of individual investigation, industry, government agency or other group. Essentially, however, this information is needed for either design or forecasting purposes. In the design situation engineers and planners involved in the design of dams, spillway, river channel improvements, storm sewers bridges and culverts need information on flood magnitude and frequency. In the forecasting situation, local government agencies industrialists, farmers, etc. require more immediate information on flood magnitude and timing so that the appropriate action may be taken. In view of these, a thorough understanding through mathematical modelling of flood formation beginning from sub-basin routing, combining sub-basin floods in the main channel, routing along channel and establishing the flood at the required point is necessary. Therefore, taking up the detailed flood hydrology studies is a must for understanding the runoff process involved in the catchment and stream channel in order to develop general and better methods, for accurate flood forecasts and design flood predictions. Flood studies dealing with flood plain zoning and economic analysis for assessing the actual flood damages are useful for the planners and government agencies involved in flood relief and flood protection activities.

1.2 FLOOD HYDROGRAPH

A continuous trace of discharge or water depth against time during a flood event defines the flood hydrograph. A runoff hydrograph has three main components: (i) rising limb, (ii) crest segment, (iii) recession limb, and it represents total runoff at the gauging site consisting of both direct runoff and baseflow. Generally, the hydrograph peak occurs shortly after the cessation of rainfall, and thereafter the discharge is largely determined by the amount of water held in storage both on the surface and under the surface of the catchment. The rate of exhaustion of storage is reflected in the shape of the recession limb of the hydrograph

- the early part sustained largely by surface detention storage and saturated interflow, while the later stages are sustained by the combination of unsaturated interflow and groundwater flow depending upon catchment conditions.

1.3 FLOOD MEASUREMENT

The most important hydrologic data that is required to be obtained for flood studies is flood discharge and corresponding stage. The selection of a proper site for the discharge measurement on rivers is very important. Several methods exist for the determination of discharges in streams. Some of common methods are as follows:

(a) Area-Velocity Method

(b) Float Method

(c) Area Slope Method

(d) Moving Boat Method

1.3.1 Stage Discharge Relationship (Rating Curve)

Both the stage and the discharge of a stream vary most of the time. In general, it is not practical to measure the discharge continuously and in order to obtain a continuous record of discharge, the stage is recorded and the discharge computed from a correlation of stage and discharge. This correlation or calibration, is known as the stage-discharge relation.

When the measured values of discharges plotted against the corresponding stages give a relationship that represents the integrated effect of a wide range of channel and flow parameters. The combined effect of these parameters is termed as control. If the stage-discharge relationship for a gauging section is constant and does not change with time, the control is said to be permanent. It is called shifting control if it changes with time. Generally, alluvial rivers pose the problems of shifting control. and non-alluvial rivers exhibit permanent control.

For such a case, the relationship between the stage and discharge is expressed in the following form:

$$Q = a\,(H - H_o)^b$$

where, Q = Stream discharge (m^3/sec)
H = Gauge height (stage) (metre)

H_o = A constant which represent the gauge reading corresponding to zero discharge.

a and b = Rating curve constants.

1.4 ESTIMATION OF FLOOD PEAKS

1.4.1 Empirical Methods

Empirical methods for computing flood discharges have been widely used. Over 100 such formulas have been proposed. Most, if not all, of these are inadequate in evaluating the hydrologic factors involved. The increasing accumulation of records of discharge of streams draining small basins has decreased the utility of these empirical formulae and they are being supplemented by more logical methods.

Many such formulae take the general form:

$$Q = C.A.J. \left(\frac{S}{A}\right)^x$$

where, Q = peak discharge;

C = Coefficient depending on climatic and physiographic conditions of the watershed. 'A' is the drainage area, 'J' is the average rainfall intensity, 'S' is the slope of the drainage basin and 'x' if an exponent.

Inspite of the limitations of empirical formulae there are such ungauged regions where no other means of flood estimation are possible. The empirical formulae used for the estimation of the flood peak are essentially the regional formulae based on statistical correlation of the observed peak and important catchment characteristics. The catchments, considered for developing the regional formulae, must be from a hydrologically homogeneous region. Quality control of the peak discharge data is, therefore, a pre-requisite to the analysis. Some of the elements to be considered in the quality analysis are as follows:

(a) All peak discharges should represent virgin flow; (Negligible man made influence)

(b) Peak stage data should be complete and reliable;

(c) Any effect on the peak stage, such as those caused by ice, aquatic vegetation, or reservoir operation downstream, should be noted and taken into consideration when computing the peak discharge;

(d) Methods used to measure or compute peak discharge should be examined for reliability;

(e) The runoff distribution between flood plain and stream channels at the time of peak discharge should be determined.

In order to simplify the form of the regional formulae, only a few of the many parameters affecting the flood peak are used. For example, the catchment area, considered to be an important parameter affecting the flood peak, is used in almost all formulae. However, most of the formulae neglect the flood frequency as a parameter. In view of these, the empirical formulae are applicable only in the region from which they were developed and when applied to other areas they can at the best give approximate values. The empirical formulae are usually based on data obtained for the larger streams because relatively few small streams are gauged in any region. Consequently, the empirical equations are usually applied in computing peak discharges for rivers having large catchment areas, only when streamflow data are inadequate. Any standard text book may be referred for the details of empirical formulae.

1.4.2 Envelope Curves

In regions having similar climatological characteristics, if the available flood data are scanty, the enveloping curve technique can be used to develop a relationship between the maximum flood flow and catchment area. In this method the available flood peak data are collected from a large number of catchments which are similar in hydrometeorological characteristics. The data are then plotted on log-log paper as flood peak vs. catchment area. This would result in a plot in which the data would be scattered. If an enveloping curve that would encompass all the plotted points is drawn, the resulting curve can be used to compute maximum peak discharge for any given area. Envelope curves are very much useful in getting the rough estimate of peak values quickly. An empirical flood formulae of type $Q = f(A)$ can be derived if equations are fitted to these enveloping curves.

The limitation of these curves lies in the fact that they are based on past records available upto the time such curves are drawn. Such curves, should, therefore, be revised from time to time as more and more data becomes available.

1.4.2 Rational Method

If a rainfall of uniform intensity occurs over a basin beyond time equal to time of concentration of the basin, which is defined as the time taken for a drop of water from the farthest point of the catchment to reach at the outlet, then the runoff will be constant at the peak value. The peak value of the runoff is given by the equation:

$$Q_p = C\ I\ A \qquad \text{for } t \geq t_c$$

where, C = Coefficient of runoff;
A = Area of the catchment, and
I = Intensity of rainfall.

This equation is the basic equation of the rational method. Using the commonly used units in metric system, this equation is written for field application as:

$$Q_p = \frac{1}{3.6}\ c\ (I_{tc},\ P)\ A$$

where, Q_p = peak discharge in m^3/s;
C = coefficient of runoff.
I_{tc}, P = the mean intensity of precipitation (nm/hr) for a duration equal to t_c, time of concentration, and an exceedence probability P, and

A = catchment area in sq. km.

The application of the method for peak flood computation requires three parameters, i.e. t_c, (I_{tc}, P) and C.

1.4.4 Frequency Analysis Approach

Frequency analysis approach is generally used in two cases:

(a) Where return period of design flood is small, e.g. design flood for culverts, bridges, barrages, and weirs, etc., and

(b) For very large catchments where unit hydrograph method is not applicable and sufficient long term discharge data are available.

In this approach the sample data is used to fit frequency or probability distribution which, in turn, is used to extrapolate from recorded events to design events either graphically or analytically. Graphical approach requires plotting of data on probability papers and knowledge of plotting positions. In analytical approach the goodness of fit tests are used to test which distribution is fitting to the sample data, the parameters of the distribution are estimated and finally T year flood is computed. There are situations when there is no data available at the site of interest. In that case the regional frequency analysis approach is applied to estimate T year flood. In the recent years many further developments have taken place in this area. It is worth mentioning here that 'there is no procedure or set of procedures that can be adopted which, when rigidly applied to available data, will accurately define the flood potential of any given watershed'.

Flood frequency analysis for a station with long record can be based almost exclusively on the record of that station alone. When only a short record is available at the site of interest, the choice of appropriate probability distribution cannot be based on the sample alone and prior knowledge about the form of distribution has to be used. Such prior knowledge includes:

(i) Any of the distributions of the Gumbel, log Pearson type III, Pearson type III, log normal, etc.

(ii) A regional curve consisting of the mean distribution of all recorded floods appropriately scaled by single parameters such as mean flood, and

(iii) When there is no record available at a site, a regional curve together with an estimate of the mean annual flood obtained by appropriate relationship of mean annual flood with catchment characteristics in the hydrometeorologically homogeneous regions.

1.5 ESTIMATION OF FLOOD HYDROGRAPHS

1.5.1 Introduction

The catchment acts upon the rainfall input and converts it to runoff hydrograph. The main processes involved in the runoff generation are the conversion of rainfall to overland flow which is ultimately converted to channel flow, and routing of this flow along the channel. There are a number of ways by which the runoff hydrograph at any point along the channel can be determined depending on the size of the catchment and the approach of converting rainfall to runoff. The important approaches are the conversion of rainfall to runoff by unit hydrograph method for small catchments wherein uniform rainfall is recorded over time and space, and routing of such hydrograph from small catchments along the channel to arrive at the hydrograph along the main channel for large catchments. The mathematical model which combinedly takes care of both these processes and other physical processes prevailing over the catchment in details is known as watershed model.

1.5.2 Rainfall Runoff Process

Runoff is defined as the portion of the precipitation flowing off from a catchment through surface channel or channels as a surface or sub-surface flow.

The runoff actually consists of three portions:

(i) Surface runoff or direct surface runoff;
(ii) Ground water flow or base flow, and
(iii) Direct precipitation over the river stream.

1.5.3 Estimation of Runoff Hydrograph using Unit Hydrograph Approach

Unit hydrograph analysis technique is one of the most commonly used techniques for the estimation of design flood hydrograph. By definition, unit hydrograph is the direct surface runoff hydrograph that would result at the catchment outlet due to unit (1mm/1cm/1inch) rainfall excess distributed uniformly over the catchment in time as well as in space for the specified duration. Thus it can be said that the unit hydrograph deals only with the direct surface runoff and excess rainfall. Therefore, the baseflow must be separated from the streamflow hydrograph and losses must be accounted from the average rainfall hyetograph.

1.5.4 Estimation of Runoff Hydrograph Using Flood Routing Method

Flood routing has long been of vital concern to man as he has sought to understand, construct and improve the transport of water via such waterways as canals, rivers and reservoirs. Flood routing may be necessary for a number of reasons. For example, unit hydrograph and similar procedures for deriving the shape of the flood hydrograph are normally most suited to comparatively small catchments, so that in order to forecast the flood hydrograph at the outlet of a major river catchment, it is necessary to route the individual hydrographs of each of the constituent sub-catchments along the main river. Again flood routing procedures are required when a flood producing storm covers only part of the catchment upstream of the point of interest. Flood routing is also used extensively for design purposes to evaluate the probable effects of channel modification and control structures. Problems involving the surges which result from the manipulation of artificial control or from the sudden breaching of dams and embankments also require the use of flood routing techniques.

1.5.5 Classification of Flood Routing Techniques

The movement of flood wave in a stream channel is a highly complex phenomenon of unsteady flow. Not only does flow vary with time as the wave progresses downstream, but channel properties also vary. The solution is more complicated by the presence of lateral inflow or outflow or both. The theoretical foundation for the one dimensional unsteady flow movement in channels was given by St.Venant in 1871 by two basic equations which are generally known as St. Venant's equations. These equations are the continuity equation expressed as:

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = 0$$

and the momentum equation expressed as:

$$\frac{\partial y}{\partial x} + \frac{u}{g}\frac{\partial u}{\partial x} + \frac{1}{g}\frac{\partial u}{\partial t} = S_o - S_f$$

in which t is time, x is distance along longitudinal axis of the river, A is the cross-sectional area, u is velocity, g is the gravity acceleration constant, y is the depth of flow, S_o is the bed slope and S_f is the friction slope. The above equations do not account for the presence of lateral flow.

Due to the complexities of the St. Venant's equations their solution was not feasible before the advent of computers and, therefore, great many different methods and procedures for solving flood routing problems have been described in engineering literature. In general, those methods that attempt a strict mathematical treatment of many complex factors affecting flood wave movement are not easily adaptable to the practical solution of problem of routing floods as they demand on high computer resources as well as quantity and quality of input data. In order to keep the amount of computation within practical limits and to conform to limits ordinarily imposed by the type and amount of basic data available, it is generally necessary to use approximate flood routing methods that either ignore some of the factors affecting flood wave movement or are based on simplifying assumptions in regard to such factors.

Methods of flood routing are broadly classified as empirical, hydrological, simplified hydraulics and complete hydraulics or dynamic wave methods. The classifications as hydrological or simplified hydraulics or complete hydraulics depend on whether or not the St. Venant's equations are employed in the derivation of the model structure.

(i) *Empirical methods*

These methods were developed generally from intuitive processes rather than from mathematical formulation of the problems. In practice, these methods have been applied to long reaches. Some of the methods found useful in practice are the successive average lag method, progressive lag method and the method based on gauge relations. The method of graphical co-axial diagrams used in our country is based on the gauge relation of upstream and downstream stations. An excellent description of various correlation models used in the form of graphical co-axial diagram form is described in the manual of flood forecasting. Empirical methods are limited in application with sufficient observations of inflow and outflows to calibrate the essential coefficients.

(ii) *Hydrologic routing methods*

Hydrologic methods use continuity equation in lumped form which is expressed for a given routing reach as:

$$I(t) - Q(t) = \frac{dS(t)}{dt}$$

where, I(t) and Q(t) are inflow and outflows respectively, and S(t), the storage in the reach at time t, and a storage equation relating the storage within the reach with inflow or outflow or both. Some of the typical forms of the storage equation are as follows:

$$S(t) = KQ(t)$$
$$S(t) = KQ(t+\tau)$$

Flood routing methods under this category may be termed as semi-empirical as the form of the basic equations are general in nature, but the parameters such as K have to be evaluated with reference to the given reach using observed inflow and outflow data. Therefore, caution is required in using the hydrological methods for routing higher floods which have not been observed in the past or used in evaluating the parameters of the method.

(iii) *Simplified hydraulics methods*

This simplified approach to flood routing is based on the realisation that in a large number of practical cases, the inertial terms of the equations of motion play an exceedingly small role. Without these terms, the St. Venant equations can be combined into one second order partial differential equation describing convection and diffusion processes. Furthermore, if the pressure gradient term of the equation of motion is also neglected, the resulting equation can be combined into a first order partial differential equation describing only convection. The simplified hydraulics models can be reduced to the form of equations of hydrologic model. The main advantages with the simplified models are their simplicity for field use and relationship of the model parameters with the channel and flow characteristics. Therefore, unlike hydrologic models, these models enable for routing floods which were not observed in the past.

(iv) *Hydraulics methods*

If the complete St.Venant's equations are used, the model is known as complete hydraulic model or dynamic wave model. With the advent of digital computers many solutions procedures using these models have been evolved. These models can be categorised accordingly as direct and characteristic methods. In the direct methods, finite difference approximations are substituted directly into St. Venant's equations and solutions are obtained from incremental time (Δt) and incremental distance (Δx) along the waterway. In the method of characteristics the partial differential equations of St. Venant's equations are first transformed into an equivalent set of four ordinary differential equations, which are then approximated with finite differences to obtain solutions. Dynamic models can be classified further as explicit or implicit, depending on the type of finite difference scheme used.

Most of the practical flood routing studies simplified hydraulics and hydrologic methods are sufficient.

1.5.6 Watershed Modelling

The problem of determining river flows from rainfall, evaporation and other factors, occupies a central place in technology of hydrology. The problem can be solved in by the concept of system operation. System is defined as any complex, real or conceptual, which through the application of a law or a set of law relates an input or several inputs to an output or outputs. Clearly the complete description of systems operation is contained in the physical laws and the description of the boundary conditions by which it operates, and the classical analysis would be to discover the laws and describe the system.

Hydrologic models are mathematical formulations to simulate natural hydrologic phenomena which are considered as processes or as systems. Any phenomena which undergoes continuous changes particularly with respect to time may be called a process. As practically all hydrologic phenomena change with time, they have hydrologic processes. The hydrologic processes and their models can be divided into two broad classes:

(i) *Deterministic process*

(ii) *Stochastic or probabilistic process*

The hydrologic behaviour of watershed is a very complicated phenomenon which is controlled by an unknown large number of climatic and physiographic factors that vary with both time and space. The catchment behaviour is distributed, nonlinear, time variant and stochastic in nature.

Generally, a model which, having its parameters determined by physical measurement in the field is known as a physically based watershed model and a model which, having had its parameters determined by optimization is known as a conceptual watershed model. In either case, however, it is desirable that the model should reflect the physical reality as closely as possible.

Physically based models, which provide a distributed and physically sound description of the hydrologic process in a catchment have significant advantage. Most of the governing parameters in a physically based model have a direct physical interpretation and their ranges can be established reasonably well on the basis of field and laboratory investigations. This has some important implications for the applicability of physically based models, Human activities in a watershed, as for example, deforestation schemes or irrigation development projects, can be related directly to changes in physical catchment characteristics at certain location and information can be utilised in the physically based models to predict the hydrologic effects of such changes. Further, by being able to establish reasonable ranges for most of parameters on the basis of short term intensive field investigations physically based model can be used to make at least approximate hydrologic prediction without the benefit of long simultaneous records of rainfall and streamflow for model calibration over a typical catchment. In fact, practically any hydrologic information which can be obtained on the basis of investigations in the catchment can be utilized directly in the system.

Thus, physically, based models have a wide range of applications in the analysis of hydrologic consequences of water utilisation and control projects for which a deterministic and distributed hydrologic description is required. Further, the system is well suited to interact with mathematical hydraulic models which are generally deterministic and distributed as well. One such models is Systems Hydrologique European (SHE) jointly developed by the Institute of Hydrology, Wallingford (U.K.), SOGREAH, (France) and Danish Hydraulic Institute (Denmark). The use of physically based models such as SHE model in particular is generally demanding in terms of computer time and data requirement, which in turn means intensive and sophisticated instrumentation in the watershed. In a number of situations simple conceptual models can provide hydrologic forecasts of satisfactory accuracy at less expense. A number of conceptual models for total catchment response have been developed for various purposes and for different situations. Following are some of the well known models which are either used for daily runoff hydrograph simulation or for flood hydrograph simulation:

(i) Sacremento Model;
(ii) Tank Model (Daily Analysis & Flood Analysis);
(iii) SSARR Model;
(iv) HEC-1 Generalised Flood Hydrograph Package.

1.6 DAM BREAK FLOOD

Dam failures are often caused by over topping of the dam due to inadequate spillway capacity during large inflow to the reservoir from heavy precipitation runoff. Dam failures may also be caused by seepage or piping through the dam or along internal conduits, slope embankment slides, earthquake damage and liquefaction of earthen dams from earthquakes and land slide generated waves in the reservoir. Usually the response time available for warning is much shorter than for precipitation-runoff-floods. The protection of the public from the consequences of dam failures has taken an increasing importance as population have concentrated in areas vulnerable to dam break disasters.

One of the preventive measure in avoiding dam disaster is by issuing flood warning to the public of downstream where there is a dam failure. However, it is quite difficult to conduct analysis and determine the warning time regarding dam break flood at the time of disaster.The method used for such analysis gains more credibility and one can simulate the past dam break failure scenario using that method with reference to failure mode and flood wave movement downstream of the dam. National Institute of Hydrology has carried out dam break studies using DAMBRK Model for Machhu Dam-II in Gujarat.

The DAMBRK model developed by Fread attempts to represent the current state-of-art in understanding of dam failures and the utilization of hydrodynamic theory to predict the dam break wave formation and downstream progression. The model has wide applicability; it can function with various levels of input data ranging from rough estimates to complete data specification, the required data is readily accessible and it is economically feasible to use, i.e. it requires a minimal computation effort on large computing facilities.

The model consists of three functional parts, namely: (i) description of the dam failure mode, i.e. the temporal and geometrical description of the breach; (ii) computation of the time history (hydrograph) of the outflow through the breach of affected by the breach description, reservoir inflow, reservoir storage characteristics, spillway outflows, and downstream tail water elevations, and (iii) routing of the outflow hydrograph through the downstream valley in order to determine the changes in the hydrograph due to valley storage, frictional resistance, downstream bridges or dams, and to determine the resulting water surface elevations (stages) and flood wave travel time.

1.7 METHOD OF COMPUTING THE DESIGN FLOOD

The following methods are generally used for the computation of the design flood:

(i) Empirical Method;
(ii) Rational Method;
(iii) Flood Frequency Method;
(iv) Unit Hydrograph Technique, and
(v) Watershed Models.

The empirical method, rational method and flood frequency method are generally used for estimating the magnitude of design flood peak. However, the unit hydrograph technique and watershed models can be used to estimate the design flood hydrograph in addition to the magnitude of the design flood peak. The use of a particular method depends upon:

(i) The desired objective;
(ii) The available data, and
(iii) The importance of the project.

The empirical formulae are essentially the regional formulae based on statistical correlation of the observed peak and important catchment properties. These formulae are only applicable in the region from which they were developed within the range of flood peaks used. If these formulae are applied to other areas they can at best give approximate values. The rational formula is only applicable to small size less than 50 sq. km. catchments. The frequency analysis approach is the statistical methods to predict the flood peaks of a specified return period with limitations due to the various assumptions involved. The unit hydrograph method is basically a rainfall-runoff relationship normally applicable to moderate size catchments with area less than 5000 sq. km. Event based watershed models, such as HEC-1, are also used in the estimation of design flood for moderate as well as large catchments. With the advent of high speed digital computers multiparametric physical watershed models have been developed, taking the physical behaviour of the catchments into consideration. However, the scope of such models are somewhat limited as far as design flood estimation is concerned specially in the inadequate data situation. The reason for the inapplicability of the physical models is that the uncertainty involved in the estimation of model parameters for extreme event situation which may lead to erroneous design flood estimates.

Regarding the methods involved for design flood estimation of major structures, the following definitions are useful:

(i) *Design flood*

Flood adopted for the design of a structure

(ii) *Spillway design flood*

Design flood used for the specific purpose of the designing the spillway of a storage structure. This term is frequently used to denote the maximum discharge that can be passed through the hydraulic structure without any damage or serious threat to the stability of the structure.

(iii) *Probable Maximum Flood (PMF)*

It is the flood discharge that may be expected from the most severe combination of critical meteorological and hydrological conditions that are reasonably possible in the region. The probable maximum flood is used in the design of major hydraulic structures, for example, dams for which virtually complete security from potential floods is sought.

(iv) *Standard project flood (SPF)*

It is the flood discharge that may be expected from the most severe combination of meteorological and hydrological conditions that is considered reasonably characteristic of the geographic area in which the study drainage basin is located. Extremely rare combinations of those conditions are not considered. The peak discharge for a standard project flood is generally about 40 to 60 per cent of that for the probable maximum flood for the same drainage basin. The standard project flood is often used where failure of the structure would have somewhat less disastrous effect. For example, it is used in the design of flood control facilities whose overtaxing or failure might be disastrous.

The method based on unit hydrograph approach is applicable for small to moderate catchments (less than 5000 km^2). For the catchments which are larger than 5000 sq. km. in size and even also for the smaller basins where different parts of the basin have widely different runoff characteristics, single unit hydrograph for the catchment should not be used for estimating the design flood in the project basin. It is, therefore, necessary to divide the total drainage area of the basin in to sub-basins and derive separate unit hydrographs for each sub-basins analysing the data of different storm events of respective sub-basins. A flood hydrograph is then determined for each sub-area. The calibrated unit hydrographs for each sub-basin must be tested by reproducing some of the independent events not considered in calibration for the respective sub-basins before using in the design flood estimation procedure. The sub-area flood hydrographs are routed down the stream channel to the project site using streamflow routing methods described. Before this, the flood routing parameters for different reaches of the stream channel have to be calibrated analysing the available inflow and outflow hydrographs of past recorded events for respective channel reaches. The calibrated flood routing parameters for each reach must be tested by reproducing the outflow hydrographs of some of the independent events not used in calibration.

If reservoirs exist in the drainage area above the project site, it is necessary to route the flood through such reservoirs. Using the calibrated unit hydrographs for different sub-basins and calibrated flood routing parameters for different reaches, the design flood hydrograph from the most critical positioning of the design storm can be determined at the project site.

The simplest procedure in the estimation of design flood by frequency approach is to select a return period and use either graphical techniques or analytical approach to derive the corresponding event magnitude. The return period of recurrence interval of a flood represents the exceedence interval during which the flood will be equalled or exceeded on an average once, e.g. T-year flood will be equalled or exceeded on an average once in T-years.

The return period for which a structure should be designed depends on the acceptable level of rick which is the probability of occurrence of a flood at least once during successive years of design life of the structure. Risk acceptable depends upon economic and policy considerations. The general formula for calculation of risk is expressed as:

$$R = 1 - (1 - \frac{1}{T})^n$$

where, R is the risk, T is the return period in years for which the structure should be designed, and n is the design life of the structure (in years).

1.8 FLOOD PLAIN MANAGEMENT

It is generally seen in our country like in many countries that the flood affected area and flood damages are on increase despite massive investments made on flood control measures. Further, human activities in the catchments such as urbanisation, construction of dams for utilization of water resources, flood control levees, etc. have increased the nature of flood hazard. In view of this fact there have been major attempts to improve knowledge of the flood hazard and of the possible responses to it. As a result it is being realised that total elimination of flood hazard is not possible and alternative approaches to reduce the flood hazard are necessary. The viability and appropriateness of alternate measures must be worked out in relation to the nature of hazards.

Flood plain management includes all planning and actions needed to determine, implement and revise plans for the best use of flood plains and their water resources for the welfare of the country. Its goal is to strike a balance between the values obtainable from the use of flood plains and the potential losses to individuals and society arising from such use. The three general strategies for reducing flood losses are:

(i) *By modifying the flood*

Under this category the following measures have been adopted in our country:

a) Reservoirs, b) Flood embankments, c) Diversions,
d) Channel improvements, and e) River training works.

(ii) *By reducing the susceptibility to damage, and*

Under this strategy, the following measures have been adopted in our country:

a) Flood forecasting and warning, and b) Raising of Villages

(iii) *By reducing the impact of flooding.*

This strategy is achieved in our country through the following measures:

a) Flood fighting, and b) Redistribution of losses through disaster relief and tax remission.

Modifying the flood in order to keep flood water away from development and populated areas may be achieved through flood protection and flood abatement measures. Flood protection can be achieved through construction of flood levees, flood walls, channel improvements, diversion schemes, reservoirs, etc. These measures are also known as structural measures of flood control. Abatement of floods involves modifying the characteristics of the factors affecting runoff of the catchment in such a manner that runoff is delayed. As such it involves actions to be taken on the catchment. These actions may comprise of afforestation, modifying the land use, regulating flow from urban areas, etc. These actions may be combinedly known as watershed management. While this strategy may be suitable for controlling runoff responses from small catchments, its effectiveness for large catchments seems to be small because the watershed management practices are not very much reflected in the much downstream area of large catchments.

Reduction in the susceptibility to damages can be achieved by keeping people and development away from flood hazard area. The important measures involved in this strategy are flood plain regulations, development and re-development, flood forecasting and warning with an evacuation plan, and flood proofing.

The strategy of reducing the impact of flooding is meant to reduce the distress of the individuals and communities at the time of flooding or after the experience of flood problem, through emergency measures such as evacuation, flood fighting, public health measures, flood insurance and provision of relief and recovery.

All these three strategies briefly mentioned herein are adopted in our country with more emphasis for the strategies of modifying the flood and reducing the impact of flooding. The strategy of reducing the susceptibility to damages is not very popular although it deserves more attention in the near future.

For developing appropriate flood management measures a proper understanding of factors affecting hydrological aspects of floods with regard to intensity and duration of flood is necessary. In addition to the natural factors, increasing human activities over the catchment such as deforestation, flood protection works, dams, urbanisation, etc. have profound influence on the hydrology of floods of the catchments.

The natural factors which increase the magnitude and duration of floods assuming physiographic conditions remain unchanged are the intensity of rainfall, the antecedent factors over the catchment, which include the conditions over ground and lakes, stream channel conditions such as vegetation of reservoir flowing full or empty, etc. and flow at damage centre. The human induced factors which increase the magnitude and duration of floods are the deforestation, antecedent condition over reservoirs, flood control works upstream of the damage centre which include embankments, reservoirs, channelization, etc. and urbanisation.

Intense rainfall of short duration over upstream of catchments is sufficient to produce flash floods near the foot hills. For large catchments intense rainfall of prolonged duration results in floods of larger magnitude. When the catchment is saturated due to antecedent rainfall and when the infiltration capacity is reduced to minimum infiltration rate, the possibility of flood formation is increased.

Similarly, when the lake is full due to antecedent rainfall, the flood moderation capability of lake is reduced leading to less or no alteration of flood peak passing through it. Also, when channel is full or depleting its storage, due to antecedent rainfall, the addition of further runoff aggravates the flood situation. Such situation arise due to formation of multi peak floods caused by rainfall in successive short durations.

When reservoir is full due to antecedent flood a further oncoming flood worsens the flooding situation in the downstream of reservoir due to uncontrolled release of water from the reservoir leading to increased flow in the channel, sometimes beyond its safe capacity. The flood situation is further worsen when there is dam failure or when there is a heavy rainfall in the intervening catchment between reservoir and the damage centre. Development of flood control works such as embankments, flood wall, etc. in the upper reaches prohibits the natural catchment storage available for the flood water and the channelised water finds new location downstream of these works. When the floods exceed the design flood capacity of these control works, they cause devastation to the extent which otherwise would not have been caused when these works were not existing. Urbanisation increase the formation of quick runoff by preventing infiltration and restricting natural storage available for the flood water. Thus the factors responsible for inducing magnitude and duration of floods should be identified before taking appropriate flood management measures.

1.9 FLOOD PLAIN ZONING

Flood plain zoning means restricting any human activity in the flood plains of a river where the plains are created by overflow of water from the channels of rivers and streams. Generally the term 'flood plain' includes water channel, flood channel and area of nearby low land susceptible to flooding by inundation. The activity of flood plain zoning has the short term objective of preventing more damage from flooding and in the long term to reduce and even eliminate such damage. A model bill for flood plain zoning circulated by the then Ministry of Agriculture and Irrigation (Department of Irrigation), Govt. of India, to the State Government in July 1975, included the following aspects:

- (a) Flood zoning authority and its power;
- (b) Surveys and delineation of flood plain area;
- (c) Notification of limits of flood plains;
- (d) Prohibition of restriction on the use of the flood plains;
- (e) Compensation;
- (f) Power to remove constructions after prohibition.

The application of remote sensing and hydrological analysis is mainly involved in delineation of flood plain area and deciding about limits of flood plains. Surveys have to be carried out for determining the nature and extent of flood plains of rivers. Such surveys form the basis of establishing flood plain zones. This includes delineation of the areas which are subject to flooding including classification of land with reference to relative risk of flood plain use intended to safeguard the health, safety and property of the general public.

1.10 FLOOD FORECASTING

Flood forecasting is a process of estimating future stages of flows and their time sequence at selected places along a river during floods. The estimates or predictions required generally are:

- (i) Maximum discharge and its time of occurrence
  (the crest of a flood hydrograph)
- (ii) The levels expected at various points of time during rising and falling stages of flood in a river above a specified water level or the warning level
  (shape of discharge hydrograph above a discharge level)

Utility of forecast is very much dependent on its timeliness and accuracy. If the forecast is not available sufficiently before the event occurs, its value is nil. The entire forecasting service has to be planned around a time factor. This time factor should be large enough so that efficient dissemination of the forecast is possible and adequate time to organise alleviation measures is available.

Often the time available is constrained because time is needed for data from the upstream catchment to reach the place of anlaysis. Analysis involves checking inconsistent - incomplete data and its validation before it is used for computing an accurate forecast. The need is for the data to be processed fast and inconsistencies rectified, and with such data input complete prediction calculations are carried out as rapidly as possible. It is only thereafter that a reliable estimate for forecast gets ready.

In all computations, if forecasts are to be for the next 24 or 48 hours, some meteorological information for that time has to be included. It is, in this context, earlier reliance on statistical methods is giving way to information from satellite imagery and our understanding of moving air systems causing precipitation.

As flood forecasting starts with a warning level and further rises in stages, monitoring of the associated rainfall 'event(s)', monitoring of the flows along the various paths merging to an output discharge hydrograph is resorted to. Estimates of such output discharge hydrographs are thus based on the event and response simulation.

In small catchments of less than 1200 sq. km. with the time of occurrence of peak less than six hours, meteorological conditions predominate and a forecast has to be completely based on precipitation rates, and their spatial distribution over the catchment. The larger catchments can be tackled with accent on distributed models, i.e. where the catchment is first divided into a number of smaller catchments and river reaches. Discharge hydrographs, emanating from each of the smaller catchments or tributaries are compounded,and routed through river stretches, sequentially till the flow reaches the point where the forecast needed is reached.

In the Indian context, waters are impounded behind dams at great cost and are a precious resource which no operating engineer can let of without expecting filling immediately. Further, as live storages in all the reservoirs compare less favourably with average annual inflows, the practice is to use all the storage for conservation purposes only. Often incidental flood moderation is planned. Such constraints create a situation when flood moderation storage separately is unavailable, as a flood wave impinges.

Perhaps, ungated spillways, or provision of uncontrolled surcharge storage could have moderated each and every flood if that is available to some degree. But with such a design, the spillway can become costly or impractical as long length of spillways are not easily accommodated in the available channel widths.

The above situation leads to gated spillways, having considerable discharge capacity at the Full Reservoir Level (FRL). This capacity may range over 200 years return period flood to the PMF depending on storage available between FRL and maximum water level in the reservoir.

This places gates with high discharge capacity in the hands of operating personnel. Such a tool in the hands of operators either due to human error or misadjustment can cause intense flooding downstream. This fact makes it incumbent that both policies of operation for the reservoir staff, as also advance information on incoming flood discharge and volumes be made available for judicious operation of release gates. That is, a viable system for operators to fall back upon before decisions needs to be built up to reduce risk.

1.10.1 Real Time Forecasting Systems

As mentioned earlier, forecasting needs meteorological data from the catchment, river flow data in reaches or stretches of river at the analysis points at the earliest. A network of hydrometeorological stations to obtain such data at sufficiently fast sampling rates and on real time basis has to be organised to make it available for suitable computations. The data collection and transmission network and computational procedure have to meet the following:

i) Such a system of stations will need suitable sensing instruments that can cope with highest and lowest observed variable or rates of variables with accuracy at sampling rates envisaged;

(ii) Measurements which make such data have to be transmitted to the analysis centre with the least possible delay, i.e. system needs good telecommunication linkage;

(iii) Processing of such collected data to spot absurd values, errors in measurement and check continuity and consistency between meteorological and hydrological variables by using high speed computers through suitable software;

(iv) Computer (Hardware) facility to carry out speedy and accurate computations. Software options by way of mathematical packages can be used after duly adopting them to each situation;

(v) Software packages (models) calibrated at one point of time are related to experience gained up to that time. They need improvement by way of updating as further data becomes available. For this work, a R & D wing is needed continuously to update and improve the procedures.

Summing up, a forecasting system should have a data network, an efficient transmission system, computational facilities and an analysis wing.

1.10.2 Forecasting in India

In our country the systematic forecasting programme started in 1959 by Central Water Commission on the river Yamuna. Slowly this programme was extended to all major rivers and their tributaries. Now forecasts for 145 centres in the country are issued covering various river basins. An UNDP assisted project for 'Improvement of River and Flood Forecasting System in India' was taken up on the river Yamuna as a pilot scheme in 1980. This project was completed and the system put to test during 1985 monsoon season. Under the proposal, the data is being collected automatically at different sites and transmitted to Central Station at Delhi through VHF links. The data is further processes by HP 1000 F series computer installed at CWC, Delhi and the forecast issued by application of hydrological models such as SSARR, HEC-1F, NAM and Non-linear Cascade Model.

At present, in most of the river systems, the forecasts are formulated with the help of multiple correlation diagrams in which the actual river stages at the base and the forecasting stations, the rainfall in the intervening catchment with appropriate antecedent precipitation index and the stages of the tributaries joining the river between base and the forecast stations are the parameters.

In the last two decades, significant progress in flood forecasting in India has been made. All major inter-state rivers in the country have been covered by a flood forecasting programme. At present, data from nearly 340 hydrological sites and the 500 meteorological stations are included in the programme for collecting data for forecasting. Data is mostly transmitted to analysis centres over radio-telephones by a network of 450 wireless sets most of which are 15 watts, single side band radio sets. Land line communication including telex and teleprinter circuits provide support where ever they are available.

As of now, data transmission via High Frequency Radio (HF) sets and manual operators, errors in vocal transmission are possible. Reliance is placed on correlation techniques and forecasts are, however, scrutinized carefully by experienced officers, before release.

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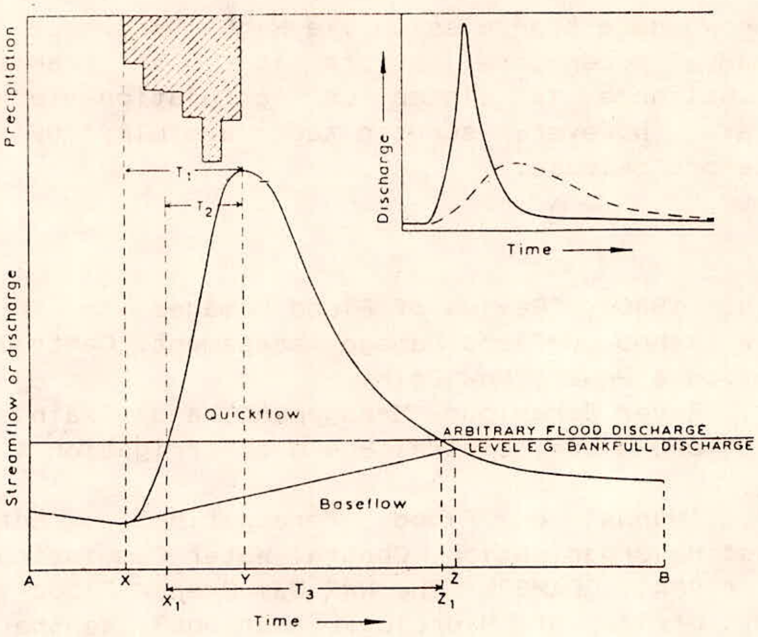


Figure 1. River flood hydrograph: *Inset* Hydrographs on flashy and sluggish streams
Source: Hoyt and Langbein (1955) p. 42.

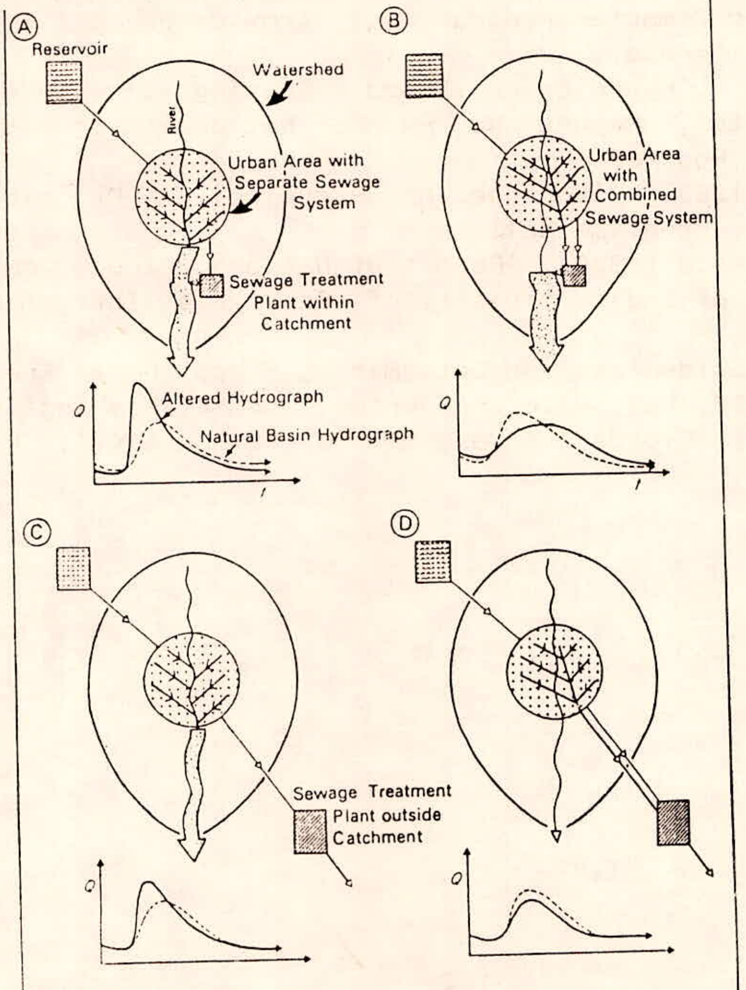
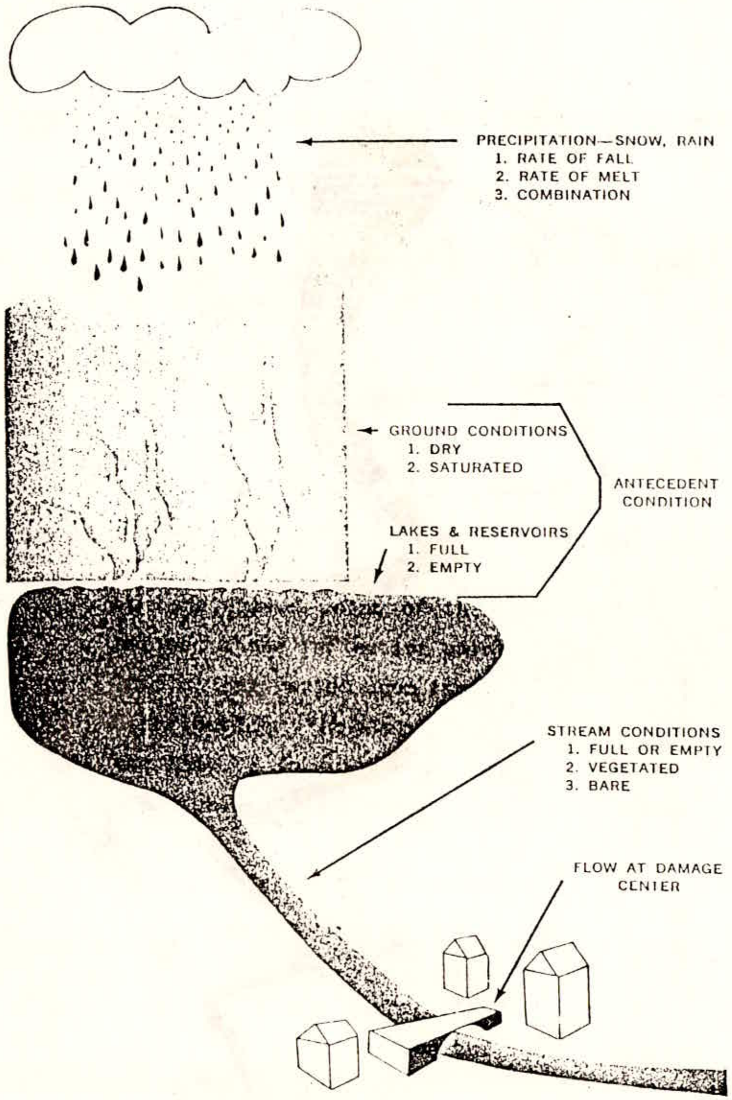


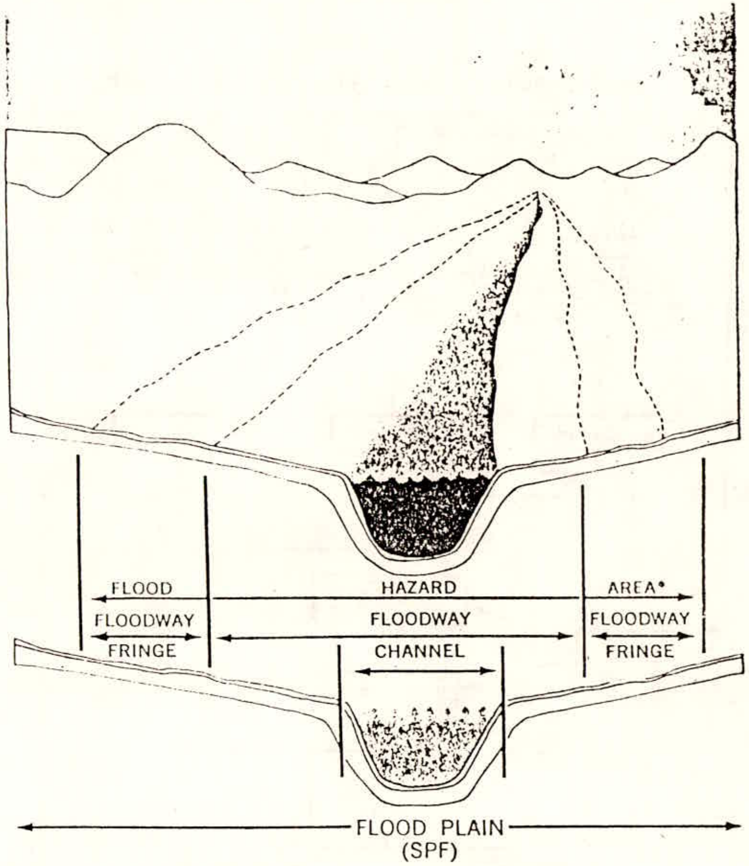
Figure 2 Variability of urban hydrological systems in Britain, and the implications for changes in flood hydrographs.



FLOOD FLOW FACTORS

FIG. 3

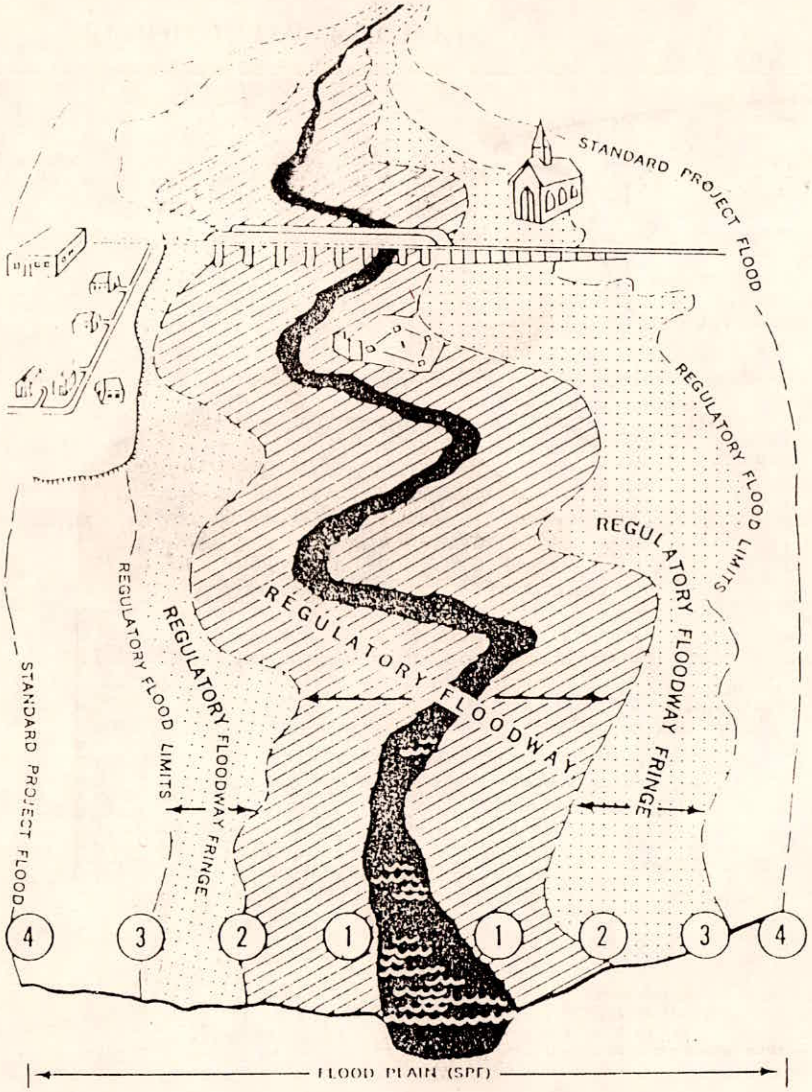
VALLEY CROSS SECTION



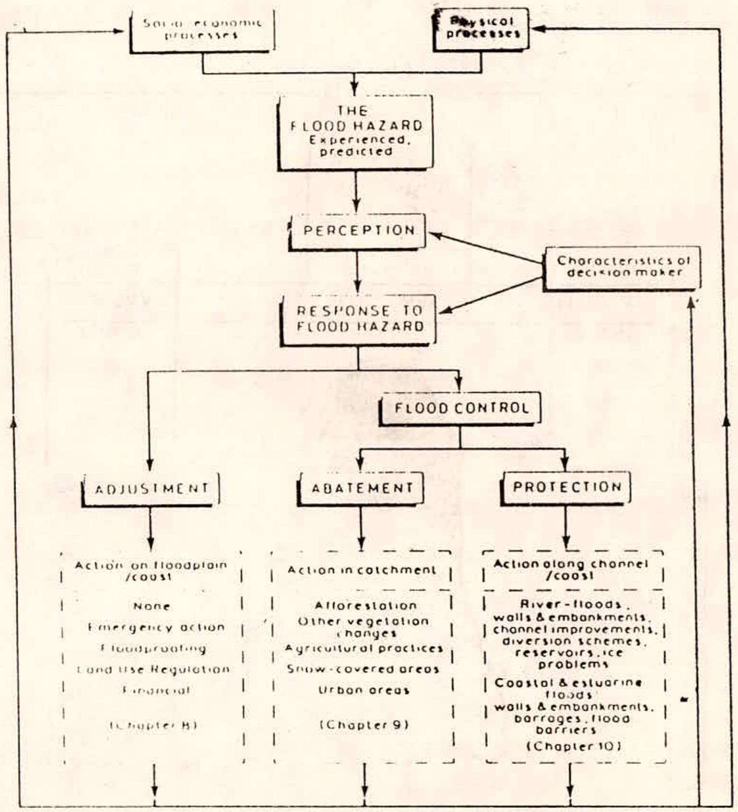
* Designated flood.

FIG. 4

RIVERINE FLOOD HAZARD AREAS



1. REGULATORY FLOODWAY- Kept open to carry floodwater—no building or fill.
2. REGULATORY FLOODWAY FRINGE Use permitted if protected by fill, flood proofed or otherwise protected.
3. REGULATORY FLOOD LIMIT Based on technical study—outer limit of the floodway fringe.
4. STANDARD PROJECT FLOOD (SPF) LIMIT Area subject to possible flooding by very large floods.



ure The main elements of man's response to the flood hazard

Fig. 6

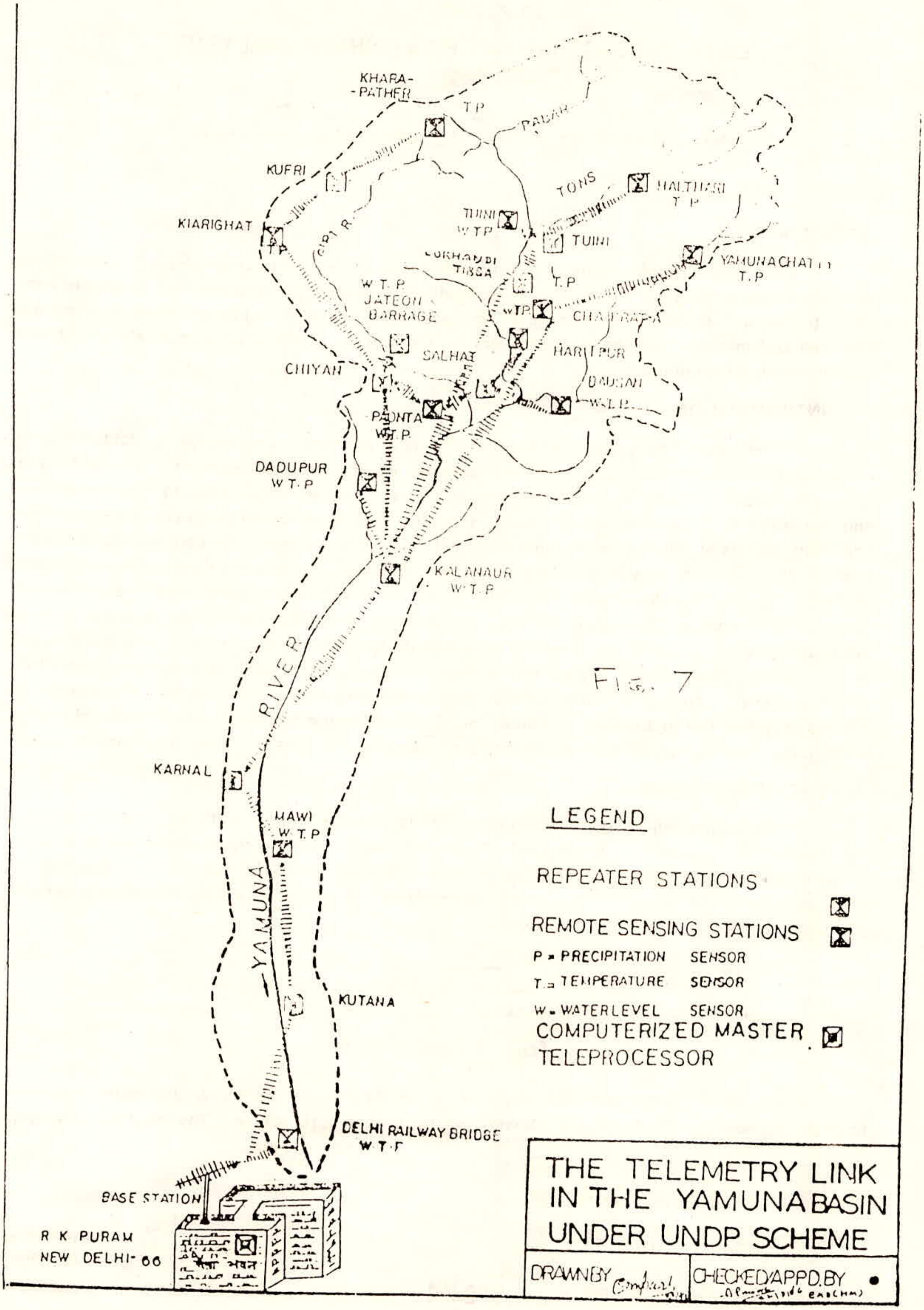


Fig. 7

THE TELEMETRY LINK IN THE YAMUNA BASIN UNDER UNDP SCHEME