Flood Control Problems*

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General Considerations

THROUGHOUT the world, alluvial soils are among the most fertile and easiest cultivated. Alluvial valleys are routes for transportation either by water or by road and railroad. Rivers are sources of water, a necessity of life. But these river valleys and alluvial deposits, which have so many desirable characteristics and which have increased so greatly in population, are periodically occupied by the river in performing its task of removing the excess of precipitation from the land area and carrying away the products of erosion.

How a river behaves and how the river flood plain appears depend on the relationships between water and sediment combined with the existing topography. Thus rivers and their alluvial deposits provide an endless variety of forms which are shaped, to a large extent, by the river flow during periods of rapid removal of debris and of excessive rainfall. The mechanics of river formation are such, however, that the highest discharges are not contained within a limited channel. How much water a channel will carry depends upon the frequency of occurrence of a flow. Low flows, which occur very frequently, are not important in channel formation. Neither are the infrequent discharges of very great magnitude which, although powerful, do not occur often enough to shape the channel. Channel characteristics, therefore, are dependent on those discharges of moderate size which combine power with frequency of occurrence to modify the channel from. In the highest discharges of a stream, water rises above the confines of its banks and flows over the flood plain.

It must be considered, therefore, that floods are natural phenomena which are characteristic of all rivers. They perform a vital function in the maintenance of river forms and out of bank flow may be expected with a reasonable degree of regularity.

The demands of the river and man's requirements for land are in opposition to each other. Under light population pressures and low stages of development there is little conflict; but as population pressures increase, more and more of the flood plain is occupied, and greater and greater risks of loss from flooding must be accepted. But sooner or later a flood of unusual magnitude takes place. This is the time when those who have gambled and won for many years must lose, and the relationships between loss and gain is balanced.

There comes a time when the losses, even though they may be economically acceptable, become unacceptable politically and socially. In such cases some level of government undertakes to provide a degree of flood protection to reduce the risk of flood plain occupancy. The greater the magnitude of the problem, the higher the governmental level which undertakes remedial measures. In some areas only a national government can be responsible.

Basically, there are only a few ways in which flood protection may be accomplished. The excess water may be confined between levees or embankments or it may be stored in some place for release at non-damaging rates at a later time. But the most essential factor which must be considered in flood control planning is that only very rarely is it physically possible to provide complete protection against floods; and even more rarely is it economically feasible to provide complete flood protection even if it were physically possible to do so. We know of no case where complete flood protection has been provided against the floods which may be expected from a river basin of appreciable size.

The type of flood control programme selected for a given area is, therefore, one which will conform to local conditions and one which will yield the greatest benefits with respect to its cost and at the same time result in the least harm.

For it must be recognized that there are always some undesirable features which

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result from attempts to regulate rivers. Foremost among these is the fact that floods have their benefits and elimination of floods eliminates benefits. One important benefit is the maintenance of fertility of the overflowed areas. Another is the increased crop yield which may result from the natural inundation of such areas. There are disadvantages to methods of flood control. Confining water between embankments leads to an increase in flood heights by reducing the amount of water held in temporary storage in flood channels. The same process increases flood problems downstream. Confinement of river flow may result in changes in the relationships between width, depth, velocity, slope and sediment load and may result in modification of river sections, in the positions of bends and meanders, and may cause or result in scour or fill. Storage of flood waters requires land which may be valuable. Releases from storage modify the balance between water and sediment and usually cut or widen channels downstream; but deposition of sediment may also take place in some areas.

More importantly the completion of flood protection works results in increased development in the protected area. People farm areas which were flooded frequently in the past. Buildings are constructed and works of all kinds are built on lands which were previously inundated. When, inevitably, a flood takes place which is beyond the protective capacity of the works, much of the damage which takes place is the result of the flood control plan and is far greater than would have occurred had there been no flood protection.

The basis for decisions on the type of flood control scheme, wherein the advantages and disadvantages of various methods of control and their combinations are weighed, is the collection and analysis of basic data, first for the purpose of understanding the forces and processes involved and second for the purpose of interpolation or extrapolation from known conditions to unknown conditions. In the flood control field the adequacy of disciplines varies widely. Unfortunately the least adequate is probably the most important, the one dealing with stream morphology. This is a very broad subject, since it must consider the hydrologic characteristics, including runoff and sediment movement and their variations with time, and those characteristics associated with the hydraulics of the stream having to do with width, depth, velocity and slope.

Thus we find there is general agreement on some of the methods to be used to establish certain criteria for flood control. Methods are well standardized for determining the size of a flood to be used for various purposes in project design. Procedures for routing flood flows are generally uniform. But the methods of analysing the flow of sediment-laden discharges in alluvial channels have not been agreed upon.

The applicability in a specific instance of standardized procedures is limited by the availability of basic data. Lack of basic hydraulic data for ever plagues the planning engineer, because basic data increase in value with the length of record. Thus projects which are being planned today should have records of precipitation, runoff, and sediment load which were collected at least 25 years ago. In dealing with basic data we have to utilize inadequate data to the best advantage in our current planning and at the same time assure ourselves that 10 or 15 years hence understanding of specific problems and problem areas will be much greater than it is now.

Data Collection in India

The writers are appalled at the magnitude of the flood problems in the Ganga Basin. Essentially these problems result from the filling of the basin with the debris from the Himalaya mountains and their foot hills. This process is complicated by (1) very high rainfall which is seasonal, leading to great variation in stream discharge (2) great difference in elevation which combined with large exposures of geologically young rocks in great topographic relief results in high sediment loads, and (3) frequent seismic disturbances of great magnitude.

We know of no way in which data can be collected to analyse the potential of seismic disturbance, but with respect to the knowledge of rainfall and runoff and the characteristics of sediment load, we find that, as usual in undertaking water resources development, a longer and more diverse record would be desirable. It appears, for example, that rainfall records from locations on the Gangetic Plain are adequate to meet all needs which have so far developed. Records available from hill and mountain areas leave much to be desired, but this is the usual situation. Too few people live in such areas to permit the establishment of an adequate hydrologic network. Constant pressure is required to expand the network to its practical limits and methods must be developed to extrapolate existing records to areas of no data. Our discussions with the staff indicate that these problems are recognized and efforts are being made to solve them. The results of the effort to expand the network in the upper Kosi river drainage has been outstanding.

Stream flow records do not appear to be as adequate as rainfall records. Many records are simply gage heights. These are of value but not as valuable as records of the quantity of water flowing in the river from day to day. There are essentially only three locations where discharges are measured in North Bihar, and these are associated with collection of data for specific projects. The useful data collected at gaging stations is not confined to records of discharge. Information on stream width, depth, velocity and slope is of great value in many types of studies and these data should be sent to central locations to supplement runoff data.

We suggest that consideration be given to the centralization of complete records of gaging station operations. The advantage to be gained from such a procedure are: (1) A central record body is built up which provides ready access to records of streams having dissimilar characteristics. (2) Ready access permits easy study of records for any purpose which may be desired. (3) Procedures for the collection and analysis of data may be reviewed and the worth of the record evaluated. (4) Responsibility for uniformity and adequacy of technical performance can be placed in a single responsible officer.

The collection of sediment data is in its infancy in India as it is in other countries. Indian methods of data collection were designed for the purpose or estimating rates of sediment accumulation in reservoirs. Procedures are very satisfactory for this purpose, but if the uses of sediment data are to be expanded, it will be desirable for a modification to be made in current procedures. As a case in point, the collection of sediment samples at 0·6 depth results in the over-estimation of fine material and the under-estimation of the coarse material. Many sizes of sediment load which are of greatest importance in determining channel characteristics do not even appear in a 0·6 depth sample.

It is suggested that sampling procedures used in the United States be adapted to meet Indian requirements. We suggest, in particular, the use of equipment equivalent to the type of samplers developed by the United States Federal Agencies which will provide samples of water and sediment moving near the stream bed. For this purpose it is suggested that an adequate number of samplers varying in size from depth-integrating hand samplers for shallow streams and reconnaisance investigations to the heaviest depth-integrating samplers for use on larger streams be obtained from the United States. It is not suggested that the large pointintegrating samplers be secured until the sediment sampling programme is well developed.

There is a series of publications, which should be made available with the sediment sampling equipment, reporting the results of inter-agency studies in the sediment field by the United States Government. These deal with an analysis of various types of samplers, the development of the recommended sampler, methods of securing samples in the field, methods of determining size of sediment particles, reports of field tests of sediment samplers and studies of volume-weight relationships of sediment. We suggest that the conclusions found in these studies be given consideration in developing the Indian sediment sampling programme.

The present method of determination of sediment size appears to be satisfactory. We would recommend, however, that sediment be reported on a weight rather than on volume basis. This suggestion is made because of the great variations in sediment weight which are observed under natural conditions particularly in the finer sizes. At reasonably frequent intervals complete mechanical analysis of the suspended sediment should be made, taking care to secure analyses of sediment carried by a range of discharges.

It seems to us that while the Indian engineer faces great problems, he also faces great opportunities. Nowhere on earth is it possible to study the alluviation of streams with such a wide range of discharges, slopes and sizes of suspended load. Hence from the standpoint of developing the science of river engineering there should be a well rounded and continuing investigational programme which would cover the Himalayan front. We are firmly convinced that the returns from such a study in the form of more precise planning, lower construction costs, freedom from operation problems, and lower maintenances costs will be many times the expenditures necessary to finance such studies. These studies are not research in the abstract sense. They are highly practical and have the definite objective of aiding in the sound development of water resources.

Such a programme would correlate field surveys to determine stream slopes, size of bed material, river cross-section (which should include rivers of such magnitude that supersonic depth-finding equipment must be used in their measurement) with hydraulic studies. The latter should deal with stream width, depth, velocity and roughness, and with measurements of suspended load and its size, together with the flow of the streams, and the frequency of various discharges. Enough work has already been done in India to indicate that such a programme would be effective. What are now required are funds to defray costs, manpower to undertake the work and energy to drive to a successful conclusion.

Principles and Observations Relative to River Morphology

The authors have been personally concerned with research in the mechanics of rivers, the inter-relation of discharge, sediment load, and the shapes and patterns of river channels. Though our experience in India has been insufficient to analyse the operation of these factors in the rivers of India, we believe that an outline of some observations made on American rivers might provide some analogies applicable to Indian conditions.

A river builds its flood plain and carves its channel in response to the discharge and sediment load provided by the drainage basin. The amount and distribution of water and the quantity and size characteristics of the sediment debris are functions of the precipitation, geology, topography and physiography of the drainage basin. These qualities of the watershed determine the discharge, sediment concentration and size of the sediment particles. These can be considered independent factors with respect to the channel. The dependent factors are then the channel width, depth, velocity and slope. Rugosity is a semi-independent factor, for it is governed both by the depth-particle size ratio and by sediment concentration. Under certain conditions the channel may inherit a slope and temporarily be forced to accommodate to it, but in geologic time slope finally tends to be adjusted to a mutual interdependency with other dependent factors.

Furthermore, the forces of erosion and deposition tend to adjust and readjust in response to local variations, and these checks or balances tend to create and maintain a quasi-equilibrium which characterizes nearly all channels. Though regime in natural channels is seldom completely fulfilled, it is closely approached. Even when a natural channel is aggrading or degrading, braiding or meandering, the hydraulic factors still tend to be nearly balanced, and divergence from regime is reflected in only small deviations from values of hydraulic factors which characterize regime conditions. As a result of these interactions, channels are similar and change in a similar manner if they have similar discharge and loads. A corollary to this is that one may judge the general character of discharge and load by inspection of the channel characteristics.

River pattern is defined as the plan view of the channel as seen from the air. There are three general types of patterns. The first is meandering, which is characterized by a relatively small value of width-depth ratio, as compared with other patterns of rivers having equal bankful discharge. The second is the braided pattern distinguished by many anastomozing channels separated by bars or islands. This pattern is typified by relatively large total width of water surface relative to mean depth as compared to other patterns at equal bankful discharge. Channels which are not divided by islands and do not meander may be called the " normal " pattern.

Comparing rivers of equal bankful discharge, braided patterns only occur when the channel gradient exceeds a given value, and meandering patterns when the slope is less than that same value. " Normal " patterns, however, can occur in either range of channel gradient.

Our own observations on natural rivers and experiments in the laboratory have led us to conclude that the primary cause of river braiding is selective deposition. When the load introduced into the reach is relatively small in quantity, bed particles tend to move in a band over the centre of the channel, the width of the band increasing with increasing quantity of sediment introduced. When the load includes particles slightly too coarse to be kept in motion, these come to rest near the middle of the channel and in doing so trap or hide some of the finer particles.

By this process a central bar is gradually built up, which on the average is somewhat coarser than the mean of the introduced load. Despite the decrease of depth immediately over the central bar, velocity actually remains the same or increases somewhat at that place as a result of decreasing roughness over the bar, and the particles continue to move over the bar instead of in the deeper portions of the channel which flank the central bar. The building of the bar is also accompanied by increasing water surface slope. As the bar builds closer to the water surface, the velocity then decreases, bed sediment over the bar ceases, at which time the band of moving sediment is diverted into one of the deeper segments flanking the bar. At such a time essentially two channels exist separated by a bar which becomes an island when the water surface is lowered.

These central bars force the flanking channel to erode the channel boundaries with the result that discrete channels separated by islands are formed. The central bars grow by addition at their downstream ends and are often cut across by new channels as the process of channel shifting continues. The shifts often make separate channels rejoin, so the net result is a limited number of channels, continually dividing and rejoining.

That the slope of such a braided stream should be steeper than that for a single channel carrying the same total water and the same size of particles follows from the general consideration that channel slope tends to vary inversely as a power function of discharge.

Thus a channel becomes braided because of progressive deposition of the coarse portion of the debris load, and the slope of the braided channel generally is determined by the load and the flow pattern rather than vice versa.

Meandering on the other hand represents a condition in which there appears to be little segregation of particle size in the process of deposition, and there is less tendency for material to move in the centre of the channel. Central bars do not form. Deposition is primarily on the point bars on the convex bank of a channel in a bend.

Meanders tend to move downstream and the whole river wanders from one part of the flood plain to another. Because deposition is nearly equal to erosion, general aggradation occurs more slowly than in braided channels and the movements of the channel are, therefore, slower. In this sense the meandering pattern is more stable in that it can more easily be restricted within a given meander belt.

Meanders are formed by processes which occur in all channels, for the wave length of meanders is directly proportional to river width, and this proportionality also holds true for pools and alternate riffles which occur in all natural channels.

It is believed that meanders become developed only under certain combinations of width and velocity-depth ratios. If one considers the change in velocity, depth, and width downstream in most rivers at bankful stage, it will be noted that width increases as the square root of discharge as found by Lacey, depth increases as the 0·4 power of discharge and velocity increases as about the 0·1 power of discharge. The slope, however, tends to decrease as about the 0·4 power of discharge causing in general decrease in size of debris downstream. Thus decreasing slope and decreasing size of material downstream with a concomitant slight increase in velocity demonstrate that in general the load and discharge tend to govern the width, depth, velocity and slope rather than the velocity governing the load. The decrease of particle size downstream in a large river is the result of sorting of coarse particles from fine as well as breakage and abrasion. The depth increases downstream faster than velocity and this is one factor which tends to make a meandering pattern in downstream recahes of a river system.