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Flood Plain Zoning - Hydrological Considerations

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Abstract : *Every year floods cause heavy damages of life and property in our country. Inspite of significant achievements in flood control with emphasis on structural measures, increasing pressures of growing population and encroachments into flood plains are resulting in increasing flood damages. The regulation of flood hazard areas; and enactment and enforcement of flood plain zoning could in short term prevent more damage from flooding and in long term significantly reduce such damage. Hydrologic analysis involving use of techniques for flood frequency analysis, water surface profiles, flood routing, flood plain mapping, etc. have a key role in flood plain zoning. These have been described and discussed in this paper.*

1. Introdnction

Every year floods play havoc in our country. The magnitude of the flood depends upon the intensity of the rainfall, its duration and also the ground conditions where the heavy spell of rainfall occurs. Erosion and silting which are increasing due to deforestation lead to reduction in conveyance capacity of river channels, and thus accentuate the flooding. Flood plains are generally heavily populated, since they are very fertile and are easily accessible. In recent years, there have been somewhat indiscriminate development of urban settlements and industries in the flood plains. This has led to considerably more damage due to floods besides the loss to crops and other property in doolf plains. There is need for taking up both short term and long term structural and non-structural measures of flood control and flood plain management.

2. Regulation of Flood Hazard Areas

USWRC (1970) dealt with the specialized and important subject of the regulation of land and water areas by state and local government bodies to minimize flood losses in flood hazard areas. The conclusions based on the studies have general relevance for flood plain management and some of the important conclusions are listed as follows :

(i) Regulation to guide land uses in flood hazard areas can play an important role in reducing flood losses to future construction;

(ii) Uncontrolled development in flood hazard areas results in increased flood heights and recurring flood damages to unprotected uses.

(iii) Flood plain regulations can help assure that benefits of proposed uses at flood-prone sites exceed costs.

(iv) Provisions for and protection of an adequate floodway should be a primary objective in regulating use of riverine flood plain lands.

(v) Designation of minimum flood protection elevations should be a second principal objective in regulation of riverine and coastal low hazard lands.

(vi) A combination of regulatory tools is necessary to control carefully development in floodway areas or coastal high hazard areas and to set minimum protection elevations for low hazard lands.

(vii) Land use regulations must be appropriately combined with other flood plain management techniques to reasonably minimize flood losses.

(viii) Regulations have greatest potential in avoiding flood losses to new uses, not in controlling losses to existing ones.

(ix) Regulations can be effectively combined with flood modifying works, land treatment measures, "flood conscious" governmental policies in extension of public services and public works, flood warning systems, voluntary flood proofing, and flood insurance.

(x) Flood plain regulations must be based upon sound data to meet constitutional requirements.

(xi) Whenever possible, flood plain regulation should be part of comprehensive water and related land use management programs.

(xii) Regulations cannot reduce all losses.

(xiii) Adoption, administration, and enforcement are essential steps for successful flood plain regulation programs.

USWRC (1970) also lists out techniques (both non-regulatory and regulatory) for avoiding losses to potential uses and reducing losses to existing uses, as follows :

1. Avoiding Losses to Potential uses

A. Non-regulatory technique

1. Reducing flood hazards :

(a) Land management activity and protective works such as land treatment practices, dikes, dams, levees, channel straightening, seawalls, and breakwaters to reduce flood hazard;

(b) Voluntary flood proofing.

2. Controlling development :

(a) Private and public fee purchase of flood prone land to restrict lands to open space use;

(b) Private and public aquisition of conservation or flood control easements to prevent on control development;

(c) Tax adjustments to encourage open space uses;

(d) "Flood conscious" governmental policies in extension of public services to flood hazard areas and "flood conscious" governmental policies for public land uses (bridges, ro.ds, libraries, schools, post offices, etc.).

B. Regulations to guide future development :

1. Regulations to prevent obstruction of flood way areas :

(a) Zoning;

(b) Subdivision regulations;

(c) Encroachment regulations as part of State or local regulatory programs;

(d) Regulations for dikes, dams, levees, seawalls, channel modifications and other protective structures or works.

2. Regulations to require minimum protection levels for uses through elevation or other flood proofing :

(a) Zoning;

(b) Building and housing code;

(c) Subdivision regulations;

(d) State-level administrative regulations.

3. Miscellaneous regulations :

(a) Requirements that private sellers and real estate brokers disclose flood hazards in real estate transactions;

(b) Sanitary and health codes;

(c) Official mapping of drain ways and reservoir sites.

II. Reducing Losses to Existing uses

A. Non-regulatory techniques :

1. Land management activity and protective works such as land treatment practices, dikes, dams, levees, channel straightening, seawalls and breakwaters to reduce flood hazards;

2. Private and public fee purchase of existing uses and reallocation of lands to open uses with low damage potential such as areas for conservation, wildlife, nature study, parks and recreation, parking lots, golf courses, etc.

3. Voluntary flood proofing;

4. Urban renewal;

5. Flood warning systems and emergency flood fighting measures;

6. Relocation

B. Regulations to require modifications in existing uses :

1. Regulations to abate artificial flood way obstructions as nuisances if they cause damaging increases in natural flood heights;

2. Regulations which require gradual elimination of unprotected floodway fringe uses through nonconforming use provisions in zoning or other ordinances;

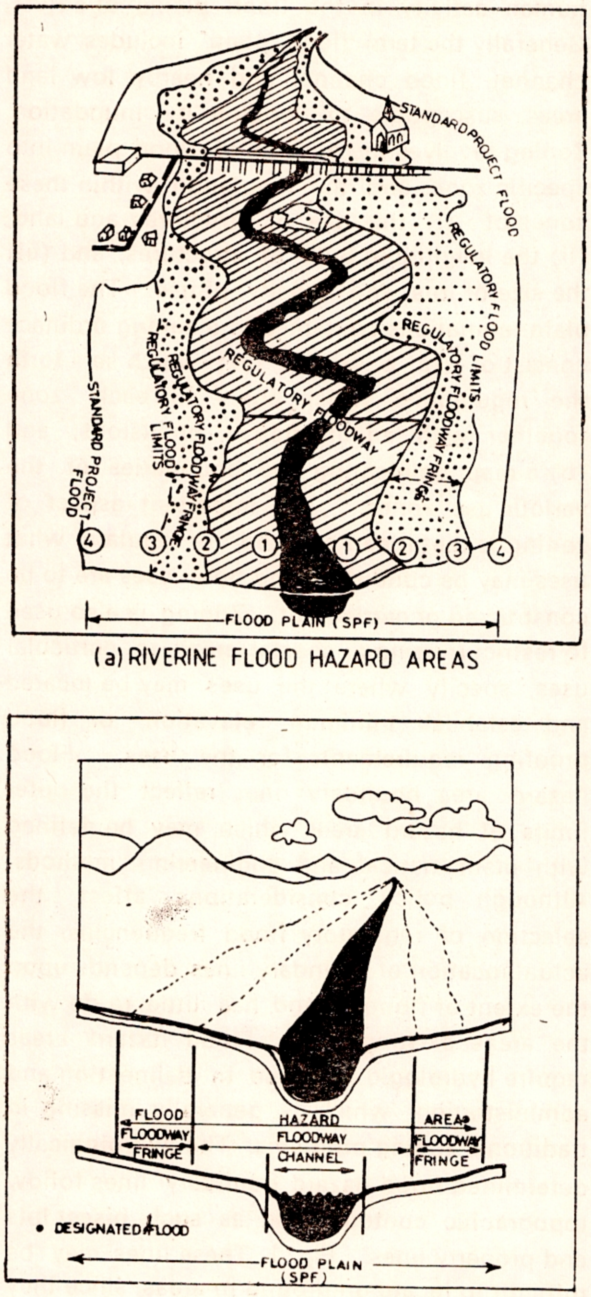
3. Regulations which require immediate or short-term flood proofing or other modifications for existing structures through the use of building and housing codes, and amortization provisions in zoning ordinaces.

3. Flood Plain Zoning

Flood plain zoning means restricting any human activity in the flood plains of a river. Generally the term 'flood plain' includes water channel, flood channel and nearby low land areas susceptible to flooding by inundation. Zoning involves the division of flood plain into specific zones and the regulation within these zones of : (i) the use of structures and land; (ii) the height and bulk of structures, and (iii) the size of lots and density of use. The flood plain regulations contained in a zoning ordinace consist of : (a) a written text which sets forth the regulations which apply to each zone together with administrative provisions, and (b) a map delineating the boundaries of the various use zones. The important aspect of zoning is that it can be used to regulate what uses may be conducted and how uses are to be constructed or carried out. Zoning is also used to restrict riverine or coastal areas to particular uses, specify where the uses may be located and establish minimum elevation or flood proofing requirements for the uses. Flood hazard area boundary lines reflect the outer limits of hazard areas which may be defined with mathematical and engineering methods. Although policy considerations affect the selection of regulatory flood frequencies, the actual location of boundary lines depends upon the extent of flooding and has little to do with the areas existing uses. Flood hazard areas require hydrologic expertise in delineation and administration, which is generally missing in traditional zoning programs. The hydrologically determined flood hazard boundary lines follow topographic contours and as such bisect lots and property lines. Fig. 1 These lines may be difficult to locate on ground in areas, since they do not follow property lines, roads or other man made features (USWRC, 1970).

A model bill for flood plain zoning was circulated by the then Ministry of Agriculture and Irrigation (Deptt. of Irrigation), Government of India, to the State Governments in July 1975. It included the following aspects :

(i) Flood zoning authority and its power;



(a) RIVERINE FLOOD HAZARD AREAS

(b) VALLEY CROSS SECTION

Fig. 1. Typical Sketch (Adapted from USWRC 1970)

(ii) Surveys and delineation of flood plain areas;

(iii) Notification of limits of flood plains;

(iv) Prohibition or restriction on the use of the flood plains;

(v) Compensation;

(vi) Power to remove prohibited constructions.

The approach to the management of floods in general falls under three strategies : (i) modifying the hazard by using structural control to alter the course or flow or water, (ii) moderating the impacts of flooding on individuals and communities through insurance, disaster relief and tax adjustments, and (iii) reducing the risks of flood damage envisages use of land management techniques such as restricted occupany through zoning codes, regulations, etc. alongwith traditional strategies and tools, such as civil works. The exposure to flood hazards is very much affected by the growth in population and evolving patterns of flood plain use for not only agriculture but also for housing commerce and industry. The National Flood Insurance Program in USA (USDC, 1980) attempted to map the flood plains of each community so that regulations can be adopted and enforced locally. It was realised that a perfect flood plain map is almost impossible to achieve since error is bound to accumulate in the process of analysing flood flow characteristics from stream gauge data. A number of different approximate methods to suit the conditions of different areas, depending on the type of information available and the hydrologic and land use conditions were considered. These included use of fixed setback from the stream centre or bank, area inundated by the largest flood of record, generalised relationships between regulatory flood depth and readily measurable stream and/or drainage basin characteristics, soil maps, etc.

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 plain zones. This includes delineation of the areas which are subject to flooding including classification of land with reference to relative risk of flood plains use intended to safeguard the health, safety and property of the general public.

The hydrological computations in general would include ;

(a) Consideration of a specific reach of river having gauge and discharge measurement sites at upstream and downstream ends;

(b) Establishment of rating curves for both sites;

(c) Division of reach into sub-reaches with consistent parallel water surface profiles for the range of discharges;

(d) Establishment of rating curves for sub-reaches (in cases where stage computations are not made as a part of flood routing or backwater computations);

(e) Selecting and calibrating appropriate flood routing technique;

(f) Carrying out flood frequency analysis to estimate flood peaks for different return periods and corresponding risk levels;

(g) Determining corresponding flood hydrographs for different return period floods;

(h) Routing of flood hydrograph through the river reach and computing flood levels for different return periods for each subreach;

(I) Marking the corresponding flood limits for each flood on the counter map of the basin area covered by the river reach;

(j) Taking into consideration existing land use within these limits, compute v/s damage functions;

(k) Decide about limits of flood plains for restricting different types of land uses for future activities.

4. Hydraulic and Hydrologic Analysis

The basic concept of flood plain zoning involves regulating the land use in flood plains with a view to restrict the damage caused during floods. It aims at determining the specific locations, the extent of areas likely to be affected by floods of different magnitudes and frequencies, the likely depths of submersion and to ensure the development of these areas in such a fashion that the flood damage could be kept to the minimum. It is, therefore, necessary that the flood plain areas are surveyed on a sufficiently large scale and zones are demarcated corresponding to different flood frequencies both in maps and on the ground. It is possible to fairly accurately forecast the likely flood events in many large flood prone river basins. However, in order to enable the people and the local administration to take full advantage of such information, it is essential to link up the forecast flood levels and the likely specific areas that would get submerged at those flood levels. This has to be first done on maps with suitable contours and then also to be transferred on ground.

The flood plain mapping and zoning exercise is also useful in the determination of flood damage by development of damage frequency curve using discharge-frequency, stage-discharge and stage-damage relationships for a river reach. The discharge-frequency and stage-discharge relationships are obtained by hydraulic and hydrologic techniques. While for developing stage-damage relationship steady state water surface profile is assumed for the given reach and for every magnitude of flood elevation or stage, the damage to the properties located in flood plain upto corresponding depth of submergence is estimated from economic analysis including field surveys and inventories of structures and land use practices in the flood plain. Hoggan (1989) has suggested the following guidelines for flood plain hydraulic and hydrologic analysis to develop discharge frequency curves and stage discharge curves at key locations throughout a river basin.

1. On a map of the basin, locate watershed boundaries, existing and planned project sites, index points where discharge-

frequency curves are required, and locations of gauges. The location of project sites and index points should be based on consultations with planners and economists who are part of the study team.

2. Delineate subbasin boundaries consistent with step 1, taking into account physiographic and climate variability in the basin.

3. Obtain streamflow records for gauge within the basin and for gauge, in close proximity, outside of the basin. Develop discharge-frequency curves in accordance with appropriote criteria for all sites which have 10 or more years of recorded data. For relatively short records, say those covering less than 25 years, it may be desirable to calibrate a rainfall-runoff model to the frequency curve. They generate a more reliable curve for rare events using design storm data. See steps 9 and 10.

4. Obtain rainfall data for stations in and near the basin for five or major storm events of record within the range of storm frequencies being analyzed, if possible.

5. Estimate unit hydrograph parameters and loss-rate parameters for any gauged sub basins.

6. Employ regional analysis to determine parameter estimates for ungauged subbasins.

7. Develop estimates of routing parameters for stream reaches.

8. Develop a multisubbasin model and adjust parameters using parameter estimation procedures and data from 'observed' events.

9. Develop hydrographs for design storms with selected exceedance frequencies.

10. Estimate rainfall loss function parameters for the design storms to produce peak discharges consistent with discharge-frequency estimates developed from gauged data.

11. Compute a discharge hydrograph at each index location for each design event.

12. If regional frequency criteria are available for the basin, develop discharge-frequency curves at index locations using the regional frequency information.

13. Plot the regional frequency curves developed with precipitation runoff analysis on the same graph.

14. On the basis of the results of the preceding step and any other pertinent information available, adopt consistent frequency curves for the index locations.

15. Develop steady-flow water surface profiles to enable the development of stage-discharge rating curves for the index locations, it may be necessary to develop water surface profiles prior to step 7 to determine storage-outflow data if a storage routing method is being used. In this case, the final stage-discharge rating curves are determined from a second computation of water surface profiles, made after the routed hydrograph is computed.

16. For future land use and future project conditions, modify the calibrated precipitation-runoff model to reflect the projected future conditions. For example, unit hydrograph and loss-rate parameters might be modified to reflect urbanization; routing parameters might be modified to reflect channel modifications; and reservoir routing parameters might be added to evaluate a proposed reservoir. If channel modifications are being simulated, it may be necessary to compute a new set of water surface profiles to reflect the modified channel hydraulics.

17. Run the modified model with the design storm in step 9 to develop future-condition frequency curves. An assumption frequently made in this situation is that the

frequency of runoff for a given design storm for both existing conditions and modified conditions.

The author mentions some of the well known computer programmes developed by the U.S. Army Corps of Engineers, Hydrologic Engineering Centre (HEC) for flood plain analysis viz. HEC1 Flood Hydrograph Package, HEC-2 Water Surface Profiles Program, MLRP-Multiple Linear Regression Program, HECWRC-Flood Flow Frequency Analysis Program, and STATS - Statistical Analysis of Time Series Data; which are available in personal computer (PC) versions, MS DOS compatible.

5.1 Probability and Risk

In any flood plain mapping and zoning study, it is necessary to decide the magnitude of floods of different return periods or probability of occurrence. In conventional flood frequency analysis, the return period is so determined that the associated risk is often ignored or not mentioned, and consequently, the result often leads to misleading conclusions or decisions. Besides, the basic simple calculated risk, there are risks and uncertainties due to limited record of data, transformation of rainfall data to runoff information, from using a point record to represent an area information, from considering the hydrologic system. as a deterministic or stochastic system, time invariant system, mathematical techniques used, measurement errors, etc, and also neglecting effects of human interference.

The flood frequency analysis procedure and results for a particular case, depend to a great extent on available information/data satisfying general probability concepts which from the basis of the approach. Floods being natural phenomena, it is not possible to exactly identify the population set of all possible outcomes. It can only be inferred from examination of a large number of occurrences. In addition to identifying the possible events in the parent population, one also requires some idea about the frequency of occurrence of each event comprising the population. A complete description of the frequency of occurrence of each event in a parent population is termed as 'frequency distribution'. Knowing the parent population and its distribution, it is possible to determine the probability of occurrence of any specified event in the future (HEC, 1975). However, in order for probability theory to be strictly applicable in making probability estimate for future events, the parent population must satisfy the critaria for :

i) Homogeneity : There must be at least one unifying property or characteristic which can be used as a basis for specifying not only elements that are included in the population, but also elements that are excluded from the population.

ii) Independence : The occurrence or non-occurrence of any event must not depend on or be related in any way to the occurrence or non-occurrence of any other event in the population.

iii) Randomness : Whether a particular event occurs or does not occur at a given time must be completely a matter of chance.

iv) Stationarity or Time Invariance : The events comprising a population and their associated probabilities of occurrence should not change with time. In other words, the physical processes that underline the frequency of occurrence of the outcomes cannot change with time.

If any of these four properties are not an attribute of a population, the use of probability theory in making probabilistic estimates of future events may result in erroneous inferences. However, it may be possible to obtain useful probabilistic estimates, even when the population and its distribution, do not conform strictly to the limitations imposed by these properties. This would require sound judgement with proper reasoning in carrying out the analysis and inferring the results.

While dealing with natural phenomena like floods, it is almost always impossible to identify specifically each possible outcome in a population and to calculate on a theoretical basis, its relative frequency of occurrence, that is, the true distribution of the parent population is unknown. For such situations, a general description can be deducted and instead of describing the frequency distribution a priori, it is obtained through analysis of samples. The reliability of the population characteristics inferred from analysis of a sample is directly dependent upon the extent to which the sample is representative of the population which is, in turn, dependent to a large extent on the size of the sample. For example, historical record of annual peak floods of 100 years is a relatively small sample in comparison to size of population (which includes all annual peak floods that have even occurred or that will occur at that location in future). But from knowledge of meteorology. hydrology and other related sciences. it could be assumed that population inferences from 100 year sample would be relatively reliable. Even where short records are available, hydrologic engineering evaluation and decisions cannot be delayed to obtain larger record. It is frequently necessary for such cases to augment the available data through consideraion of data obtained at other locations in the same region.

In hydrologic engineering problems such as flood frequency analysis for design flood estimation, the sample of flood series used to draw inferences about the relative frequency of various events within a population, would have to be very large before one could expect infrequent extreme events to be represented within the sample. There has to be some way of inferring, from the sample information, enough about the population from which the sample was drawn to permit one to estimate the probability of occurrence of events more extreme than those in the sample. This is achieved through identification of and testing with satistical distributions to select a distribution whose characteristics are consistent with known characteristics of natural phenomena under study (Seth, 1984-85).

The distribution generally used for modelling the peak flood flows are :

i) Two parameter log normal
ii) Three parameter log normal
iii) Extreme value such as Gumbel EV1
iv) Exponential
v) Gamma
vi) Pearson type III
vii) Log Pearson type III

Recently, the use of the Wakeby distribution with five parameters has also been recommended. This is becoming popular among researchers because of its capabiiities to model both the tail ends of the flood series separately.

The distribution like gamma, exponential and Pearson type III have been used generally on the basis of empirical considerations of goodness of fit and not based on a prior assumption such as for Gumbel EV-1, log normal, etc. Some attempts have also been made to use mixture of two distributions.

For estimation of parameters of statistical distributions, following four techniques are generally ; used :

i) Graphical
ii) Least squares
iii) Method of moments
iv) Method of maximum likelihood

Kite (1978) mentions the fact that the calculation of risk is based on the assumption that the underlying event distribution is known. Uncertainty occurs because the basic data available contain random measurement and computation errors, non-homogeneity in time, loss of information in changing from a continuous record to a discrete data set and so on. These imperfect data are then used to estimate the parameters of the assumed population distribution. Uncertainty generally increases as the variance of the sample data increases and decreases as the sample length increases. The author also points out the fact that the sample data occupies the central portion of a fitted probability distribution, while the event magnitudes which it is required to compute will be in the extremes, so that the best fit/distribution may not necessarily be the best to use. If for a time invariant hydrologic system the probability of occurrence of an event, X greater than the design event Xo during a period of n years is P and if it has a return period of T years, then the probability that X will occur at least once in the n years is given as :

$$P_{1x} = 1 - (1 - 1/T)^n \qquad \ldots(1)$$

This gives the risk of failure and is based on the assumption of independencc of annual events.

5.2 Flood Routing Analysis

Flood routing has long been of vital concern to man as he has sought to understand, construct and improve transport of water via such waterways as canals, rivers and reservoirs. One of the purposes of flood routing is to translate data on stage or discharge from one location to another. Routing is also used to predict streamflow at downstream locations resulting from the application of design storms and considering unit hydrograph approach for small subbasins to arrive at flood hydrograph at the outlet of a large river basin. Flood routing is also used extensively for design purposes to evaluate the probable effects of channel modifications and control structures. There are two general types of routing techniques, (i) hydraulic, and (ii) hydrologic. Hydraulic routing involves solution of the differential equations of unsteady flow in open channels. Hydrologic routing, a simpler approach, generally employs the equation of continuity and the relationship between storage and discharge. There are also a few hydrologic methods which are based on lagging of averaged hydrograph ordinates rather than storage discharge relationships (Ponce, 1989).

The basic hydraulic equations that describe one dimensional unsteady flow of open channels, the Saint Venant equations are expressed as :

(i) Continuity equation :

$$A \frac{\partial v}{\partial x} + v B \frac{\partial y}{\partial x} \; B \frac{\partial y}{\partial t} = q \qquad \ldots(2)$$

(ii) Momentum equation :

$$\frac{\partial y}{\partial x} + \frac{v}{g} \frac{\partial v}{\partial x} + \frac{1}{g} \frac{\partial v}{\partial t} = S_o - S_f \ldots(3)$$

where, S_f = Friction slope, S_o = Bed slope, y = Depth of water, v = Average velocity of water, x = Distance in direction of flow (one dimensional), A = cross sectional area, B = top width of flow, q = local inflow.

Solution of these equations, called the dynamic wave equations completely defines the flood wave with respect to distance along the channel and time. However, the data and computation time requirements are quite large. As such various simplifying assumptions viz. kinematic wave and diffusion wave have been proposed.

Hydrologic methods of flood routing, because of their computational simplicity are more commonly used in simulation studies.

However, they do require the estimation of empirical coefficients that are difficult to evaluate in the absence of observed flow data. These methods use continuity equation in lumped form which is expressed for a given routing reach as :

$$I(t) - Q(t) = \frac{dS(t)}{dt} \qquad \ldots(4)$$

where, I (t) and Q (t) are inflow and outflows respectively and S(t) the storage in the reach at time t. A storage equation is used to relate the storage within the reach with inflow or outflow or both. Some of the common hydrologic methods are Muskingum, Muskingum

Cunge, Kalinin-Milyukov, Lag and Route Modified Puls, etc.

5.3 Water Surface Profile Analysis

Water surface profiles associated with peak discharges in a stream are needed for a variety of reasons. They are used to delineate areas of inundation and depths of flow associated with potential floods of various sizes. They are an important factor in determining the suitability of development proposals for parcels of land located in the flood plain. They also reflect the effect of existing bridges on water levels and may affect the design of new bridges. They are also used for determining heights of flood levees and embankments and demarcation of flood zones. For this purposes water surface profile computations are performed at the beginning of study with a range of flows to obtain storage-discharge data for use with hydrologic routing techniques such as Modified Puls method. Such computations are however not required with hydraulic routing techniques, which provide the depth of water directly.

6.0 TYPICAL STUDY FOR MACHHU DAM II

A typical study for flood plain zoning of downstream area of Machhu Dam II in Gujarat State was carried out by Santoshi and Seth (1988-89), which involved hydrologic analysis and computations discussed above. A typical study for flood plain zoning of downstream area of Machhu Dam II in Gujarat State was used the National Weather Services DAMBRK Model developed by Fread (1984) to compute the maximum flood elevation due to dam break flood of Machhu Dam-II downstream of the dam. The routing option of DAMBRK model using dynamic wave theory was used to compute the maximum flood elevations due to floods with different peaks, which includes 100, 200, 500, and 1000 years return period floods, 1979 flood, design flood and dam break flood from Machhu Dam-II and floods with peak 8765.3, 9734.9, 10956.3 and 11879.7 cumecs, representing earlier estimates of 100, 200, 500, and 1000 year floods. The maximum flood elevations due to floods as mentioned above were computed at about half km interval along the reach of 39.65 kms downstream of the dam and the same have been marked on contour map on both the sides of river reach at corresponding locations. These maximum flood elevation marks at different downstream location were joined by straight lines indicating flood The inundated areas within these limits were also been measured to assess the total inundated area due to the corresponding flood downstream of the dam (Fig. 2). It was seen that dam break flood affects the maximum area (160.40 sq. km.) along the reach and 100 years unrevised flood affects the minimum area (37.287 sq. km.) along the reach. The quantitative results are however dependent upon accuracy of available information regarding river cross-sections and contours in the flood plain, and assumptions made for routing of flood wave.

7.0 REMARKS

The flood plain zoning has the short term objective of preventing more damage from flooding and in long term to reduce and even eliminate such damage. This may be considered as alternative to structural measures and more attention should be paid for use of such measures in future practices. For balanced flood control program, a combination of structural measures wherever necessary to contain flood water, with non-structural measure such as flood plain zoning for limiting flood plain development and flood control is necessary. The quantitative results of hydrologic analysis are however dependent upon accuracy of available information regarding river cross sections and contours in the flood plain, and assumptions made for routing of flood wave.

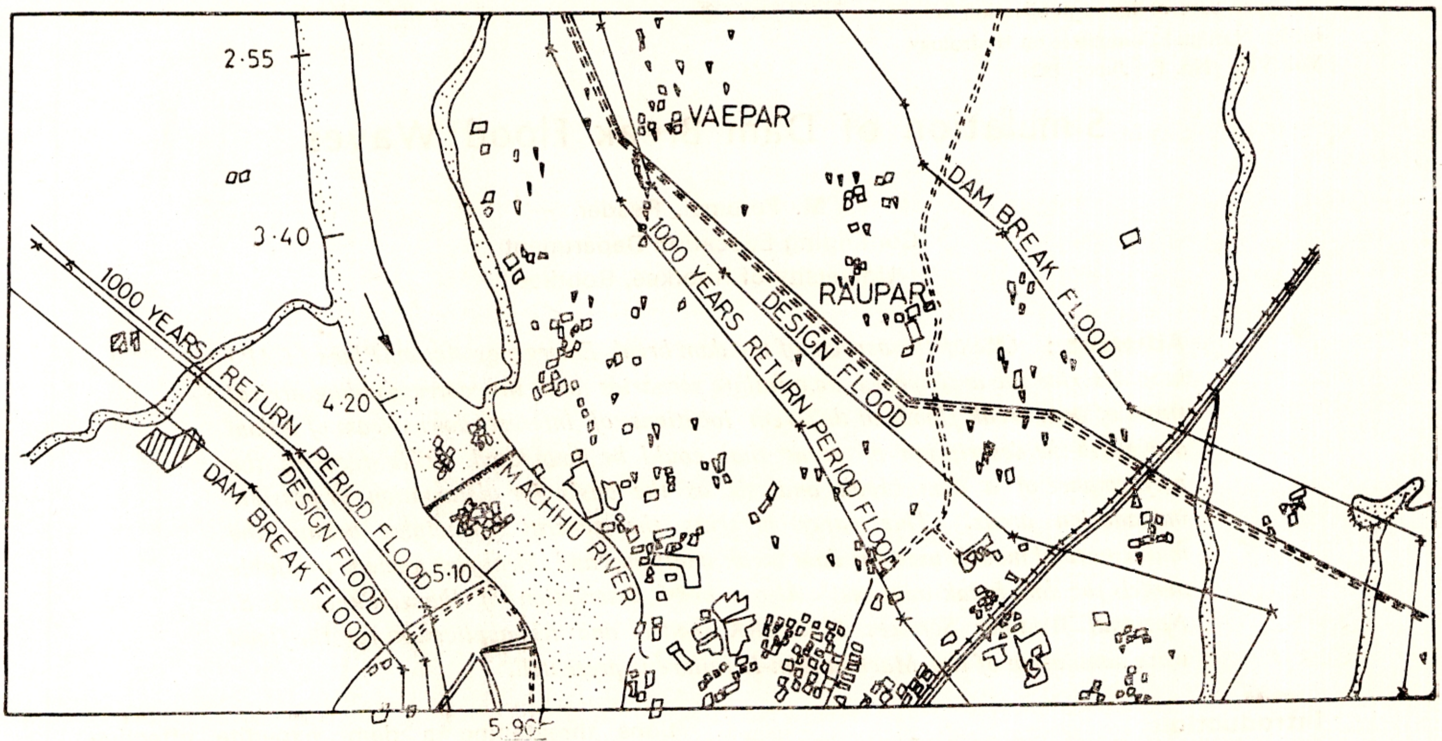


Fig. 2—Area Inundated for River Reach 2.30—5.90 km. of Machhu River D/S of Machhu II Dam

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