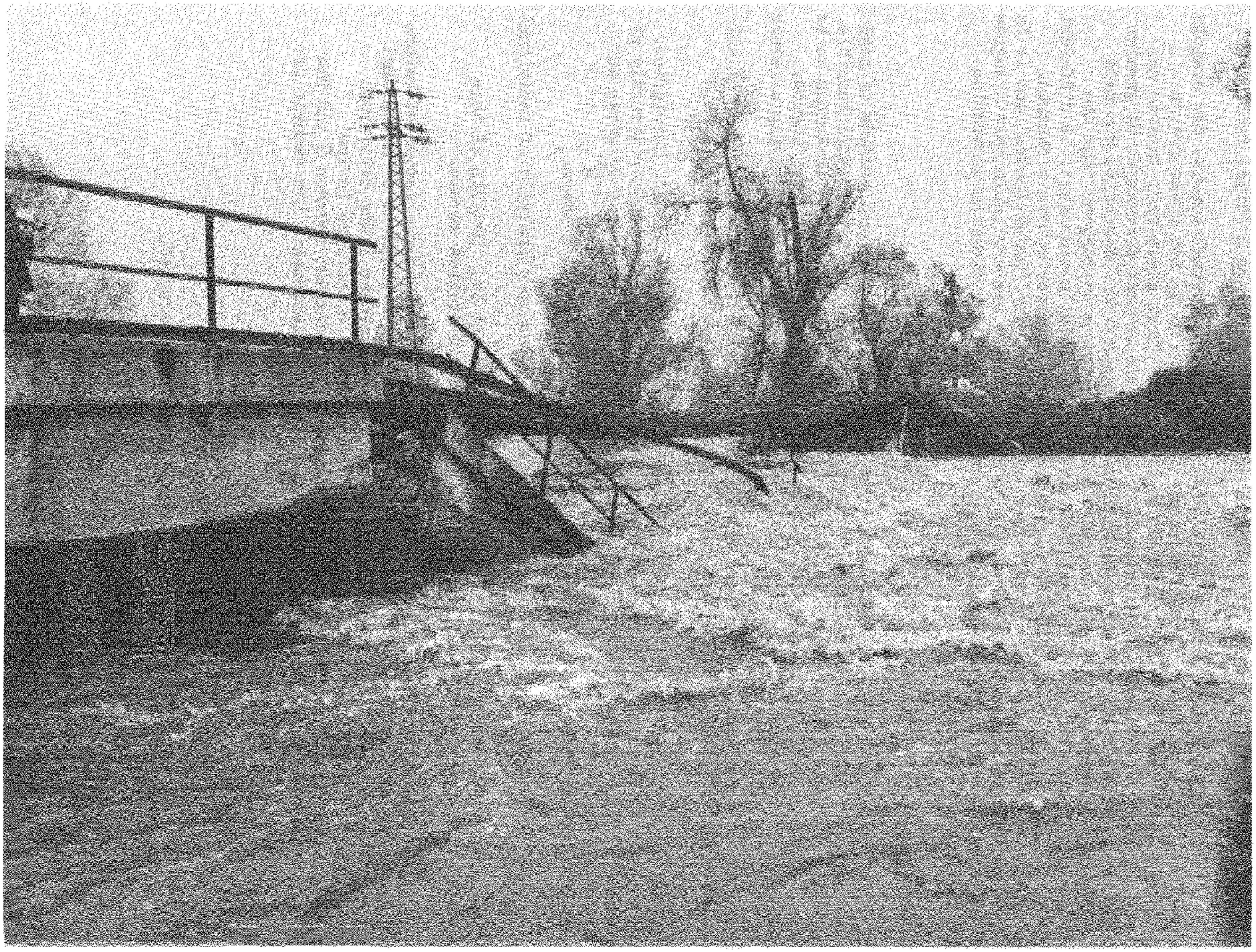

FIG. 2.2 - Damage to Railway Bridge and Communications, Hungary

recorded peak discharge. Thus after analysis, the hydrologist is able to estimate the peak discharge (Q_T) which is equalled or exceed on average 1 (time) in T years.

Flood disasters are usually associated with very infrequent events, for example when T is of the order of 50 to 100 years. Estimation of Q_T for these return periods is generally subject to uncertainty. In the first place many data do not cover a period of 50 years or more so that estimation of peak discharges of greater infrequency necessitates indecisive graphical extrapolation. Secondly, the data being analysed represent only a sample. There is nothing to suggest that the following 50 years or so will reveal the same hydrological environment. A different frequency distribution may therefore be apposite and disaster criteria changed. Estimates therefore are nothing more than estimates or even 'guesstimates' and it is important to appreciate even when many hydrological data are available that a degree of uncertainty exists and subsequent planning decisions for disaster prevention should be made accordingly.

Regional frequency analysis

2.1.1.2 When fewer years of data exist for a given river, but when records of peak discharges are available for several rivers within the region, it is still possible to estimate flood frequencies making use of all available data. The technique to be used is based on the principle that within a hydrologically homogeneous region, ratios of $\frac{Q_T}{\bar{Q}}$ are constant for major rivers (Q_T is the peak discharge having a return period of T years and $\bar{Q}$ is the mean annual peak discharge). Thus an average of all estimates of the same ratio $\frac{Q_T}{\bar{Q}}$ derived from various gauged catchments within a region is considered to give a better estimate of the regional value. Thereafter, for a river with very few data, but for which $\bar{Q}$ can be estimated either directly or indirectly, the product of its $\bar{Q}$ with the appropriate required ratio $\frac{Q_T}{\bar{Q}}$ gives an estimate of the rivers peak discharge Q_T for the return period T years.

Development of regional $\frac{Q_T}{\bar{Q}}$ values necessitates frequency analysis of individual river data no matter how short in record length these may be. Details of this aspect and techniques of pooling ratio values are not described herein.

For a regional river with no data but for which $\bar{Q}$ needs to be estimated before Q_T can be determined, a useful technique is the initial development of a regional relationship between $\bar{Q}$ and physiographic catchment parameters using data from gauged catchments. Meteorological parameters may also be included in the relationship which normally reduces to statistical correlation between $\bar{Q}$ and the independent parameters. A simple and very efficient relationship for example is:

$$\bar{Q} = a A^{b}$$

where A is the catchment area

and a and b are coefficients to be evaluated.

This and more elaborate relationships have been in effective use for more than 50 years and provide an essential link between catchment characteristics and flood flows during flood estimation when data are scarce. An example of parametric correlation for East-African streams is shown in Fig. 2.3.

Flood maxima - "The regional Flood"

2.1.1.3 Extreme or maximum possible peak discharges for use in special design situations are usually determined by constructing envelope lines on a graph of observed extreme peak values plotted against the catchment area when such data exist for a sufficient number of catchments in a region. Alternative techniques involving maximization of precipitation storms also exist but are difficult to apply and in many cases are too indecisive and unrealistic. When data are scarce, empirical envelope relationships can be used such as the Myer-Jarvis equation:

$$Q\ max = \frac{100p}{\sqrt{A}}$$

in which p is an appropriate regional parameter which can be chosen from experience and recommended values.

By far the most effective way of determining extreme flood levels (and discharges thereafter) is through exhaustive survey of river side conditions and questioning of local inhabitants. Older inhabitants can very often recall catastrophic conditions especially if they occurred during their earlier years of life. Judicious enquiry can lead a hydrologist to definite conclusions of the past severity of floods, and this can thus lead to a most effective intuitive estimation of probable maximum or at least a very rare event. Morphological and vegetal environment in and around the flood plain can be a most useful guide to this intuitive reasoning. Old river courses can be identified and the age and type of vegetation together with the nature and grading of soil and sand or gravel deposits, can be useful in considering when, where and how often inundation takes place.

Meteorological data

2.1.1.4 Frequency of flood peak discharges, probable maximum peak flows, and associated hydrographs, are estimated sometimes by using meteorological data. In doing so it is necessary to recognize the cause of flooding which is generally assumed to be either storm rainfall, or snowmelt, or occasionally a combination of the two. Methods used depend upon the existence of relationships between meteorological phenomena and resulting river flood discharges. These are outlined later in a discussion of Flood Forecasting Methodology (page 38). The only difference between the use of these relationships for flood estimation and their use for flood forecasting is the character of meteorological data input. For flood forecasting, it is necessary, of course, to use currently observed information. In the case of flood estimation meteorological data are of a probabilistic nature. For rainfall induced floods, for instance, assumptions are necessary concerning the frequency of occurrence of rainfall intensity, its duration, its areal distribution and the initial wetness of catchment which influences the volume of runoff. Snowmelt flood estimation (without streamflow data) involves assumptions concerning amount of snow lying on the catchment, atmospheric temperature and again the initial wetness of catchment or whether or not the upper soil horizons will be in a frozen state.

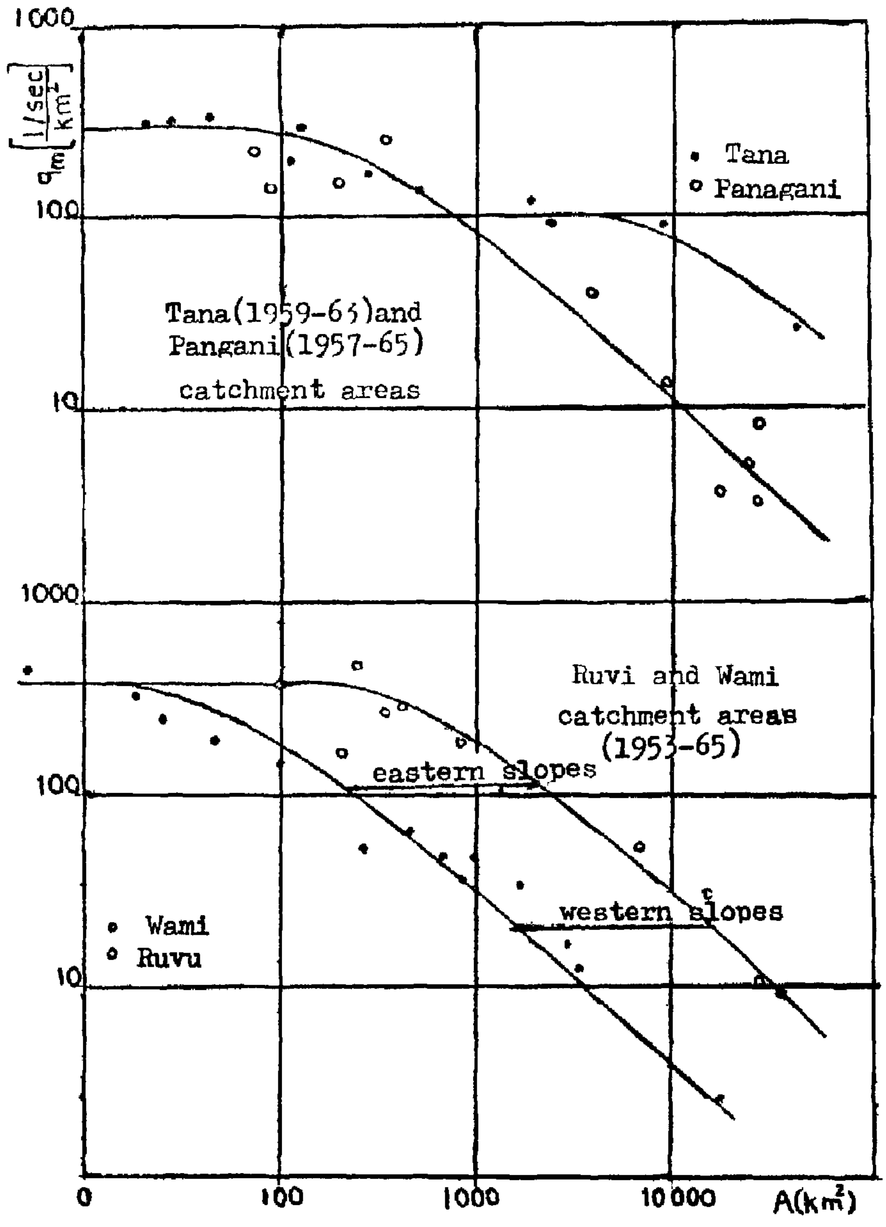

FIG. 2.3 - The relation of the design specific discharge to the catchment areas in the case of East-African streams.

The use of meteorological-flood estimation techniques is subject to more uncertainty of answer than streamflow data methods. Nevertheless, it finds particular application in smaller river basins and especially in urban catchments where land use changes may in time modify the hydrological regimen. Meteorologically based methods provide a useful background to estimating maximum possible flood levels or discharges. In tidal rivers, for instance, where wind induced set up superimposed on Spring Tide conditions can be the most serious possibility, maximization of wind set up by analysis of observed wind velocities can provide very useful information on maximum probable water levels in an estuary.

River Morphology

2.1.1.5 On occasions, particularly when no hydrometeorological data are available, the concept of alluvial regime (the self-forming characteristics of alluvial river channels) can be a useful aid to flood estimation. There exists the concept that severity and frequency of flood discharge must in some significant way influence the shape and size of a river channel, particularly of course when flowing full. Bankfull discharge has been shown, in certain regions, to approximate to a peak discharge having a frequency of between 1 in 1 year and 1 in 5 years. Hydraulic estimation of bankfull discharge or a directly gauged value can therefore be used in some circumstances and in conjunction with an objectively estimated or intuitively derived ratio of $\frac{Q_T}{\bar{Q}}$ for any return period of T years, it can be used to estimate values of Q_T for a river reach. Conversion of this discharge into the equivalent depth of flow is carried out using hydraulic methods. The technique is very approximate and much research still needs to be carried out to improve it; in the hands of an experienced hydrologist and one especially conversant with hydraulic and morphological characteristics of alluvial rivers, it can nevertheless provide a most useful guide to the extent and severity of river flooding.

The hydrologist may be able to give information on the seasonality of flooding but this will depend very much on the hydrological regime of the catchment in question. Climate and size of catchment are very important in this respect. Large rivers, for instance, draining basins situated in regions with strong seasonality of precipitation or snowmelt give predictably long duration flood flows with fairly predictable time of occurrence of peak discharges. This is not true of small catchments, although even in these the occurrence of flood events may be seasonal but their occurrence in the season may be randomly distributed; other equally random flood events may also be possible outside the "flood" season. The presence of hydrological data and a good local knowledge are key factors in understanding the seasonality criteria.

Hazard assessment

2.1.2 Hazard assessment is strictly the evaluation of potential damage and loss of life due to river flooding. Total hazard assessment demands a variety of expertise and is possible only when all previously specified hazard criteria have been identified and estimated. In many developed regions assessment is frequently based on a cost analysis of potential damage. In developing regions, however, financial cost of damage is seldom an appropriate criterion to use.

Assessment very often reduces to the estimation of hazard criteria only, and in its simplest form flood hazard is depicted in plan by lines which represent the areal extent of water surface. Longitudinal profiles of water surface are also shown. These water surface profiles are determined both for floods of specified frequency of occurrence and for historically recorded or estimated events of catastrophic magnitude. When provided with sufficient and relevant annotation, flood hazard plans serve to indicate to planners the potential severity of inundation.

Water surface profiles frequently derive from flood estimation and are determined by surveys of rack marks and questionnaires. Areal photography (and now satellite photography) is also an efficient method of determining the limits of river flooding. When little or no survey information is available it is necessary to resort to a detailed hydraulic analysis to determine probably water surface profiles. For this a thorough understanding of fluvial hydraulics is essential.

As an alternative, it may be possible to build a physical hydraulic model of the entire river reach and flood plain, complete with representation of structural and other development, and to use this model to study the hydraulic behaviour of the region when subjected to various flood peak discharges. Problems in using such models are their validation and the extrapolation of scale effect, but to a large extent these problems may be overcome and the model used to evaluate surface water profiles and velocity distribution. Hydraulic modelling of flood problems need not be carried out in the region concerned. This may be done, and is currently being done, in one of several excellent international hydraulic laboratories having a reputation for solving complex hydraulic problems.

The water velocity hazard deserves special attention since data for its evaluation are rarely produced during the process of flood estimation, and its presence is very often difficult to anticipate. In times of flood, velocity of flow is often (but not always) high and its distribution across river and flood plain irregular to such an extent that reverse flows can sometimes occur. Points of attack of highly erosive velocities, excessive hydrodynamic forces on bridge piers and buildings, and afflux of water levels due to permanent or temporary obstruction in the flood way are all potentially serious effects of water velocity. Disasters occur as a direct result of these alone.

It is almost impossible to foresee all disasters associated with river flooding. Experience indicates that unforeseeable hazards exist. A good designer and planner endeavours to allow for this and adopts margins of safety which give designs capacities in excess of those flood limits estimated. The margin of safety provided is usually nominal, but it can be associated with possible hazards such as the effect of flood surge caused by flood bank failure or the effect of afflux in water level due to blockage at a bridge opening or the formation of an ice jam.

ENGINEERING CONTROLS

2.2 Engineering methods obviate flooding either by attenuating peak discharges through the use of storage (methods (a) and (c) page 5), or by constraining flood water within natural or man made waterways - conveyance methods (methods (b), (d) and (e) page 5). Their design is usually based on their theoretical performance when subjected to a "design flood". Design of storage schemes requires the design flood to be specified as a complete flood hydrograph whereas for conveyance methods, only the peak discharge is usually required. In both types, the peak discharge is chosen in respect of a given frequency of occurrence and values are derived by one or more methods of flood estimation.

The chosen frequency depends on the consequences of failure. Schemes which protect on a cost-benefit basis and where failure does not have disastrous consequences are usually designed against peak discharges having frequencies ranging between 1 in 10 years to 1 in 50 years. Major schemes, such as dams, where failure to protect might have catastrophic consequences and possibly cause loss of life, are frequently designed to protect against extreme peak discharge or some high percentage of it. Dam spillways for instance are sometimes designed against probable maximum inflows to the reservoir. Actual choice of return period is based on experience and intuition. In developed regions, however, attempts are made to carry out rudimentary cost-benefit analyses of flood protection schemes but such analyses may not be applicable to developing regions. In these, cost-effectiveness would seem more generally appropriate.

In many large river systems efficient flood control for a country is very often practically possible only when developed in an adjacent country (i.e. upstream control of flood waters to mitigate flooding in a downstream reach). This frequently demands international agreements and cooperation and more especially so if upstream control works also serve to supplement the water resources of the region upstream generally not influenced to any significant extent by the river flood problem.

Reservoirs

2.2.1 Design of storage schemes and particularly of reservoirs depends on whether or not storage is to be controlled or uncontrolled.

Controlled and uncontrolled reservoir storage

2.2.1.1 The current understanding is that controlled and uncontrolled storage is identical with gated and ungated storage, respectively. This, however, is grossly misleading and could lead to dangerous consequences in reservoir flood-control.

It is true that a fully controlled storage must have a gated outlet but a gated outlet does not automatically guarantee full control over the storage. In order that the storage be fully controlled the outlet capacity corresponding to zero storage must be equal to or greater than the maximum possible rate of inflow. If this condition is not met the filling of storage at high inflows cannot be prevented and control over the rate of the filling is limited once the inflow exceeds outlet capacity. Thus the degree of storage controllability depends on the capacity of outlets which, of course, must be gated.

On the other hand, in most dams the storage above the spillway crest is not entirely uncontrolled even if the spillway has no gates. The reason for this is the fact that, as a rule, the dam has a gated bottom outlet and that by operating its gates the filling of storage above the spillway crest can be partly controlled. The degree of controllability again depends on the capacity of the gated bottom outlet. However, here the control can never be complete because even with the outlet closed the emptying of the storage above an ungated spillway crest cannot be prevented.

Controlled detention (flood-control) storage is the most efficient means of reducing flood peaks for in this case the reduction to certain flow Q_k (a non-damaging flow) requires the minimum storage capacity which is equal to the volume of the flood above the discharge Q_k. In Figure 2.4 this volume is denoted by A and the corresponding ideal output hydrograph is Q'_A. In this case the detention storage can be emptied (and prepared for the next flood) within a time t_A after inflow has dropped below Q_k which again represents the shortest time possible (the actual emptying time is slightly longer since the reduction of outflow from Q'_A to Q is never instantaneous).

If the same reduction of flood peak were to be achieved by an uncontrolled storage the required storage would be A + B (Figure 2.4). The portion B is hydrologically ineffective since it is wasted on reduction of flows that do not have to be reduced, period $\overline{t_o t_k}$, and on unnecessarily high reduction of flows, period $\overline{t_k t_h}$. Naturally, the time needed for emptying the storage, t_{A+B}, is much longer than t_A.

The first necessary condition for the effectiveness of a controlled storage is, of course, a sufficient capacity of gated outlets which must be at least Q_k. If it were lower, say Q_o, the whole detention storage could be filled even before input reached the damaging flow Q_k (time t_1 in Figure 2.4), and there would be no detention storage left. In practice the reservoir would keep on filling until the water level reached the dam crest at some time t_2; the whole dam crest would function as an ungated spillway (see hydrograph $Q'_{(A)}$ in Figure 2.4) and overtopping could cause destruction of the dam.

The second condition is that the gates be operated in such a way as to prevent any filling of detention storage before the input reaches Q_k. To meet this condition requires high responsibility and physical endurance from operating personnel (permanent duty during flood danger), as well as highly reliable gate mechanisms and power supply.

Generally speaking the higher efficiency of controlled storage as compared to uncontrolled storage is always reached at the expense of the over-all safety. The usual arrangement on dams is therefore such that (1) at least an "emergency" ungated spillway is provided with its crest not higher than the elevation of the normal maximum flood level in the controlled detention storage, (2) the freeboard (vertical distance between the normal maximum flood level and the dam crest) is at least one metre more than necessary for passing the total design flood over the emergency spillway.

Design of a flood-control reservoir

2.2.1.2 The main conceptual difference between the design of a reservoir for low-flow regulation and for flood-control resides in the fact that in the former case one takes into account the periods between successive water shortage and uses as a basis the whole time series of streamflows, while in the latter case the periods between successive floods are considered long enough to release the stored water and storage capacity is determined on the basis of one single flood.

The reason for not taking into account the periods between floods is the assumption that the time needed for emptying the detention storage is always much shorter than the shortest expected period between two floods of the magnitude comparable to the design flood. Although this is usually the case, there are certain climatic conditions where the occurrence of two major storms in close

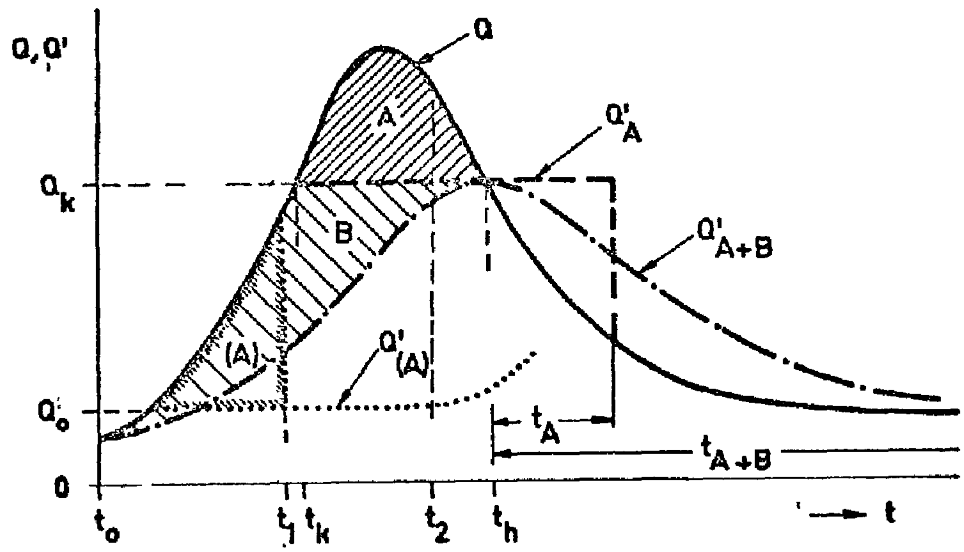

Figure 2.4 - Comparative effectiveness of controlled and uncontrolled detention storage shown in hydrograph form.