succession can reasonably be expected (usually areas affected by tropical cyclones like typhoons or hurricanes). In such cases the period between floods cannot be ignored.

Storage capacity of a reservoir with uncontrolled detention storage is designed by a reservoir-routing method. Knowing the maximum desired flow down-stream Q_k, we route the design flood through the reservoir assuming a certain size and shape of outlets, and compare the peak discharge of the output hydrograph, Q'_{max}, with Q_k. We then keep changing the size and shape of outlets until $Q'_{max} = Q_k$. The required storage capacity is given by the value of S_{max} corresponding to Q'_{max} in in the plot of the routeing curve.

The capacity of controlled detention storage could in theory be found easily by making it equal to the volume of the design flood above the discharge Q_k. This simple procedure has, however, one defect consisting of the fact that the return period of the design flood relates as a rule to its peak flow, not necessarily to its volume. On the other hand, the detention storage capacity depends here exclusively on flood volume, the peak discharge being irrelevant. For this reason, if N-year protection against a certain discharge Q_k is required, the volume of the N-year design flood does not give the correct answer unless the N-year flood has been set up on the basis of volumes rather than peak flows as is usually the case.

One often encountered fact is that the storage needed for a relatively high protection is usually not much larger than storage for comparatively small protection. This is important to design practice where as a result of optimization the optimum degree of protection is often relatively low. Although there is no reason to increase the degree of protection unless it is well justified, the designer should also consider the limited accuracy of economic data on which the optimization is based and weigh it against the cost of additional protection, especially if the computed optimum charge is not well defined.

Flood control by multi-purpose reservoirs and multiple reservoirs

2.2.1.3 In almost every multi-purpose reservoir one of the functions is flood control and detention storage is provided for this purpose. This storage is designed in the same manner as described in the preceding paragraph.

However, a multi-purpose reservoir with a given detention storage capacity can render more efficient flood control than a purely flood-control reservoir of the same detention storage. The increase of efficiency is roughly proportional to the conservation storage of the multi-purpose reservoir whose flood controlling effect is due to the fact that conservation storage is usually not full at the beginning of a flood, and the empty portion of it can be used as an *ad hoc* supplement to detention storage. The availability of this additional storage does not have to be left to chance and usually it is embedded in reservoir operating rules. Its magnitude at any particular time of year depends on seasonal fluctuations of streamflow and is found by statistical analysis thereof.

A quantitative evaluation of the additional effect of conservation storage on flood control can best be done by the Monte Carlo simulation of reservoir operation. In current design practice, however, this effect is often not being evaluated and is regarded as an increased safety margin.

Flood control by a multi-purpose reservoir is far too complex a problem to be described adequately in a short paragraph, the complexities being both of a hydrological and a water-management nature. The principles outlined for simple reservoir design apply also to multiple reservoir control but here also the problem takes on a complex analytical character and operating rules may be correspondingly complex. Advanced procedures exist to evaluate operating rules for such cases. Operational rules developed depend on both experience and the method of flood forecasting employed.

Conveyance Schemes

2.2.2 Construction of dikes and levees is probably the most reactionary engineering method of protecting flood plains. It is certainly one of the most popular and many large continental rivers exhibit a large degree of flood control by this method (Fig. 2.5). It also tends to be cheaper and in many respects more practical than channel enlargement and by-pass channels. All three conveyance methods provide extra capacity for discharge; in the case of levees this may entail an increase of water level whereas by-pass channel systems and channel improvement operate with equal or lower levels of flow.

An adverse effect of conveyance techniques is the negation of natural flood plain storage which before regulation can effect a marked attenuation of peak discharges as a flood wave passes through the reach concerned. Unless carefully planned, therefore, conveyance methods can displace the problems of river flooding to a downstream section (probably not affected previously) by increasing the peak discharge of outflow from the newly protected river reach.

Another and equally problematical influence of both conveyance and storage schemes is that of peak flow synchronisation. Conveyance methods advance the occurrence of peak flows downstream; storage methods retard the occurrence of peak flows. Again if not carefully investigated beforehand, this can result in a marked increase of river flows downstream of a major tributary due to induced synchronisation of tributarial peak discharges and mainstream peak discharges. An example of this phenomenon occurs in the river Rhine, in West Germany, where a variety of river regulation works have been carried out over a period of many years. Analytical modelling (page 35) shows that flood waves in the river basin have speeded up by a factor of 2 to 3 times. The net result is that if the large flood which occurred in 1882 were to recur, the recorded double peaked hydrograph would coalesce into a much more intense single peaked hydrograph and would cause severe flooding downstream of the river Necker tributary (See Fig. 3.5). The effect is shown qualitatively in Figure 2.6.

Once a design peak discharge has been chosen, design of any one of the three methods is basically a hydraulic problem to determine discharge capacity of proposed schemes and resulting water levels. Conveyance methods tend to be more suitable to the lower reaches of rivers where storage control becomes relatively infeasible.

CONTROL OF LAND USE AND FLOOD PLAIN OCCUPATION

2.3 Identification and evaluation of the flood hazard is a first step in planning control of land use and flood plain occupation. It is, however, a very important step since it gives politicians and planners the necessary information on which to base decisions as to the degree of control required, and the likely consequences that will occur if such control is not effective. Planned development to offset flood disasters extra to emergency measures described in section 3 can take into consideration three major aspects:

1. Urban and rural land use
2. Flood plain occupation control
3. Building specification and water proofing.

Insurance and flood acceptance are two other policies not considered in this description.

Urban and rural land use

2.3.1 Changes in land use can cause marked changes in the hydrological regime and consequently the flood potential of catchments. One of the major concerns in modern hydrology is the ever increasing drainage burden placed upon natural waterways by extensive developments of urban areas and land drainage schemes. Simple deduction suggests that urban areas will increase the flood potential of catchment by virtue of (a) reduction in overall absorption of precipitation at the ground surface giving higher volumes of runoff (b) reduction of time of concentration which greatly accelerates the speed of runoff and (c) reduction of surface retention capacity and initial delay times. Computation of the effect of urban development is feasible and results are often alarming, indicating on occasion increases in comparative peak discharges of several orders of magnitude as urban intensification proceeds. The problem is made more critical by the corresponding increase in potential loss of life and property due to urbanization.

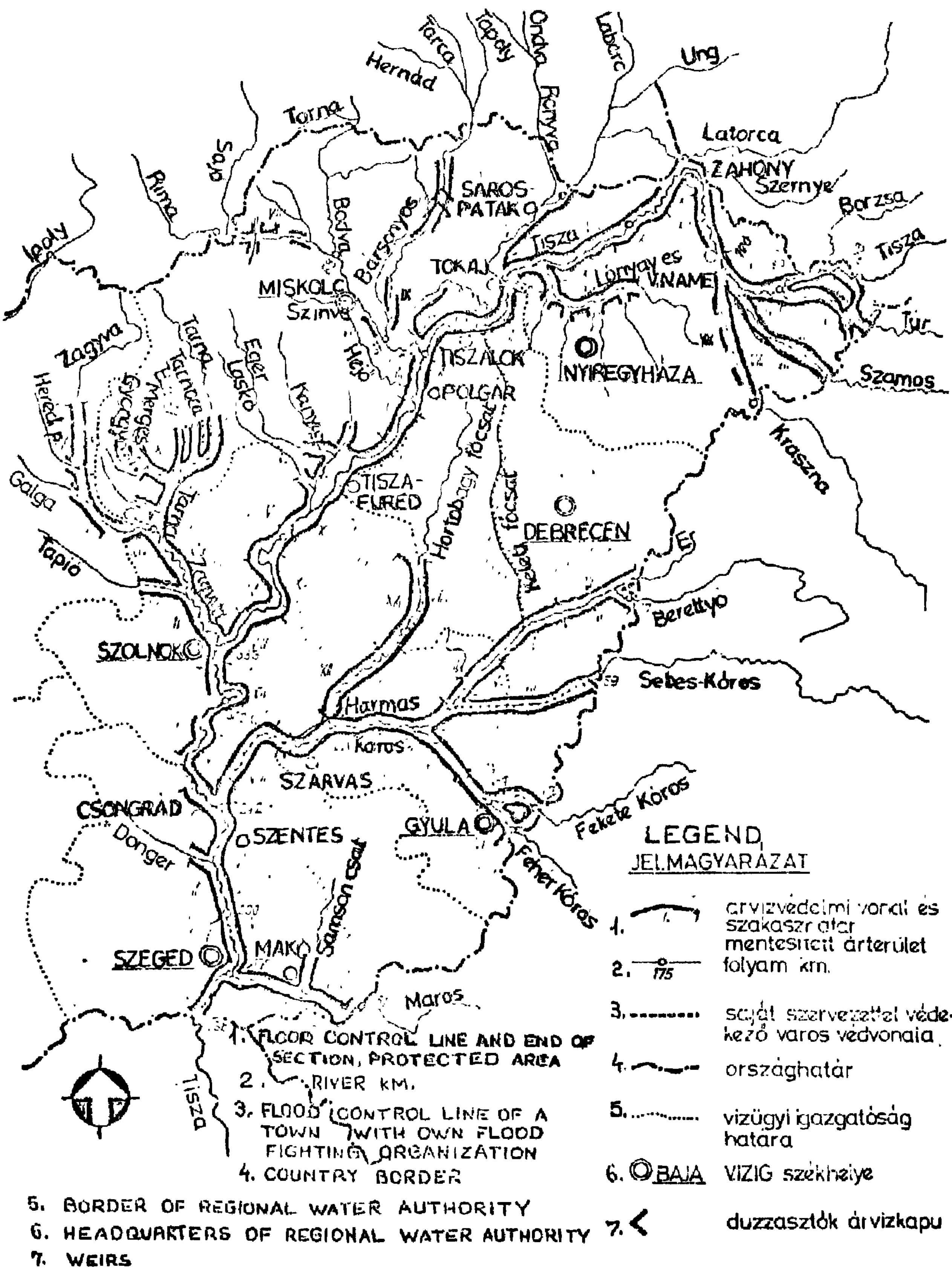
In addition to increased discharge intensity another tragic effect of these changes, unless remedial measures are taken, is the destruction of the drainage channel itself. Differential scour and accretion to accomodate higher discharges causes river bank instability as well as potential undermining of riverside developments, and when this happens excess material in the river may give rise to shoaling or blockage and consequent temporary but damaging afflux of the water surface. Anticipation of these problems with urban development is therefore essential.

A good illustration of the effect is shown in Fig. 2.7. This shows for different degrees of urban development, classified A to D, that unit peak discharge can increase by as much as six times that of an unurbanized catchment. This marked effect is however limited to small catchment areas. On large areas the effect is not so marked and urban influence may not be evident to any large extent. It is also not as important during the occurrence of extreme events.

Changes in rural land use have similar impact; increase in land drainage schemes increases peak discharges and change in vegetal cover promotes variability of catchment flood response. Documentary evidence of these effects is not as emphatic as it is in the case of urban development. Afforestation or deforestation seems to be the major rural land use investigated. In the U.S.A., for example, it has been demonstrated that for an increase of afforestation on a small watershed equivalent peak discharges are gradually reduced over a period of approximately 25 years by an average value of about 60 per cent. In the U.S.S.R a similar reduction has been demonstrated and it has been shown that in a snowmelt environment

Fig.2.5-MAIN FLOOD CONTROL IN THE TISZA VALLEY

TISZAVÖLGYI ÁRVIZVEDELMI FŐVEDVONALAK



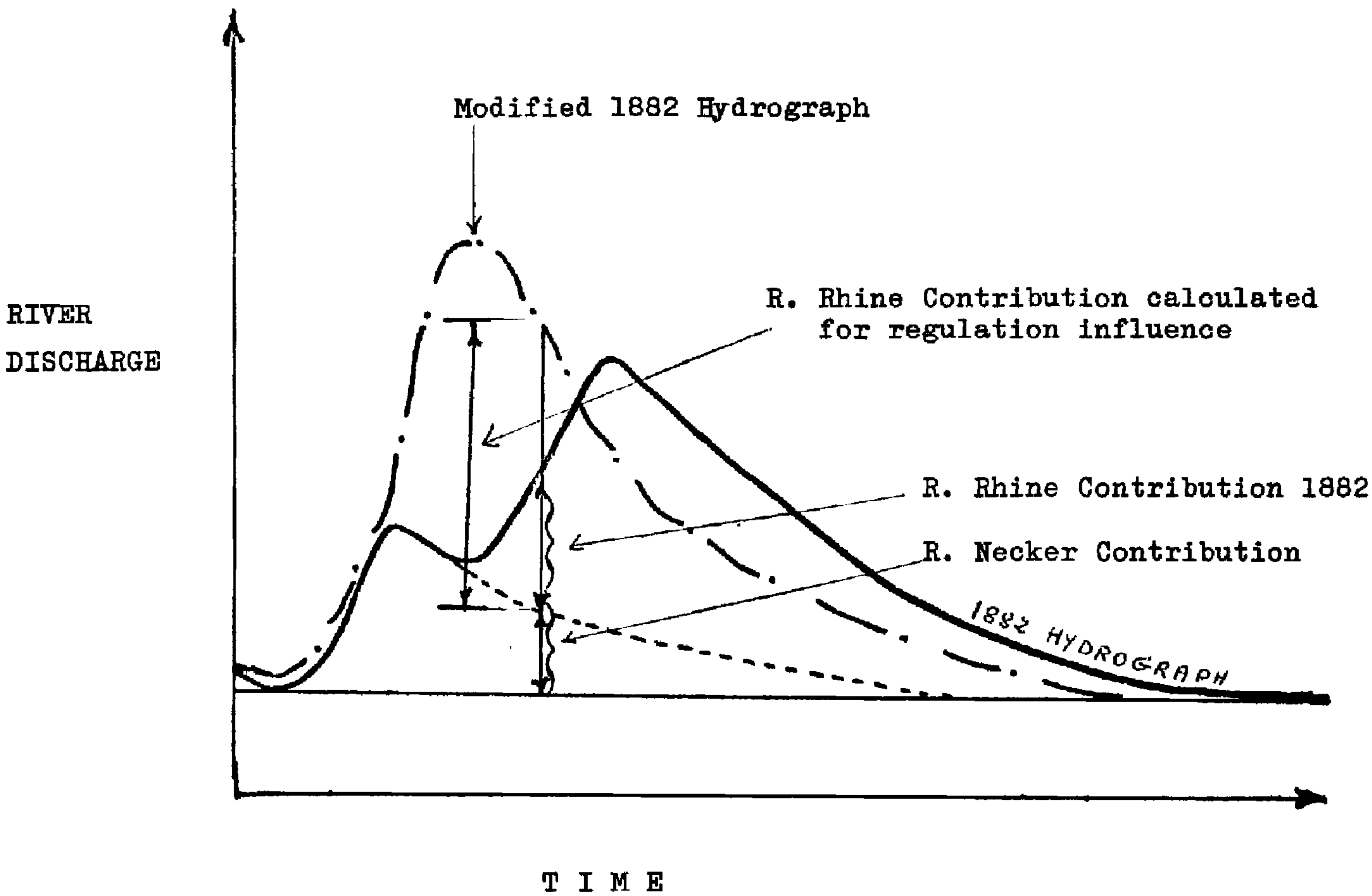


Figure 2.6 - The relative effect that river regulation works would have on recorded flood hydrograph of 1882 in the River Rhine, computed by digital hydraulic model.

approximately 50 per cent afforestation seems to be optimum in reducing peak discharges due to consequential differential melt periods in open and afforested areas.

General effects on precipitation induced floods are not clearly understood. Different vegetation and rural land management cause differences in soil water consumption and retardance to runoff. In many cases drainage works, such as surface grips in afforested areas, can cause increased speed of runoff and confuse the over-all impact.

Flood plain occupation and control

2.3.2 Flood hazard normally reduces as the height of land surface above river bank level increases. With the exception of natural or man-made levees, the existence of old water course depressions, and so on, this often means that flood hazard also tends to reduce with distance from the river. If therefore for social or economic reasons flood plain occupation cannot be avoided, it is reasonable to suggest that it be controlled and where possible confined to those flood plain areas involving least risk. This idea has given rise to the concept of flood plain zoning.

By consideration of the variability in flood hazard over a flood plain, zones are established firstly to identify the different degree of danger and potential damage, and secondly to de-limit through legislation, type and density of occupation. There are many varieties of zoning which can be developed, but the one outlined in the Guidelines for Disaster Prevention* to generalize the basic idea is rational and serves to explain the idea further. Three zones are identified (Figure 2.8).

(a) Prohibited Zone

This is that region of the flood plain which is counted an essential part of the floodway, whose velocities and discharges contribute significantly to total flow. Development in this area is not allowed, to avoid damage to the developer or adverse flood effects upstream affecting other flood plain occupants. Use is predominantly of the non-structural type, such as cattle grazing,

(b) Restricted Zone

This is the area of flood plain where inundation is not too frequent and contributes little to the total flood discharge; velocities are low. Limited building development and planned agricultural activity are feasible and probably desirable, such land use patterns being commensurate with the flood hazard. In this zone, restriction not only applies to density and use but also to design criteria such as minimum ground floor level permitted and permanent flood proofing arrangements for buildings. The limiting boundary of this zone is usually related to the water surface profile of the "design" flood (e.g. a flood peak discharge that occurs with an average frequency of say 1 in 100 years),

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* Guidelines for Disaster Prevention, Volumes 2 and 3. Office of the United Nations Disaster Relief Coordinator, United Nations, Geneva, 1976.

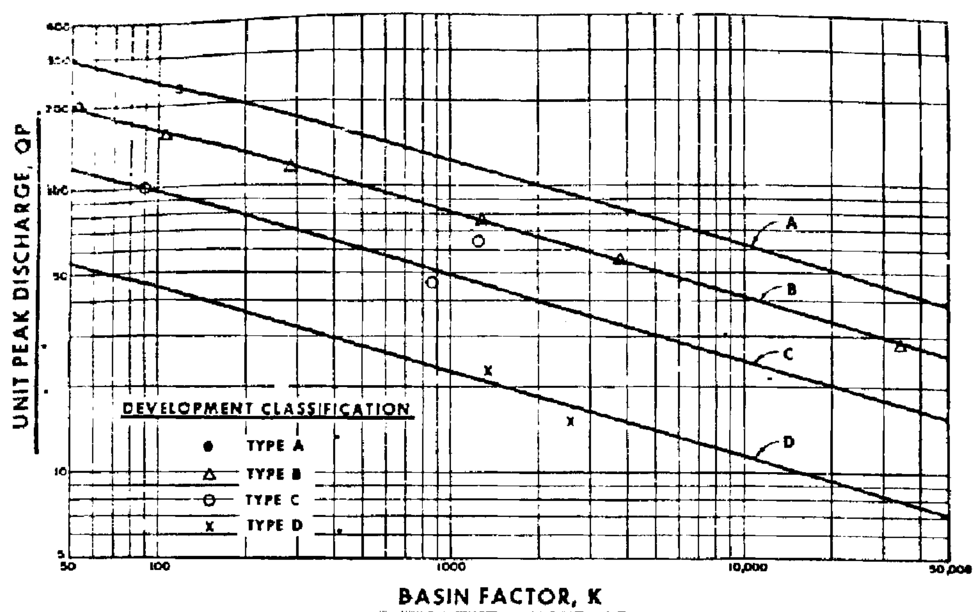

Figure 2.7 Effects of watershed development on peak discharge.

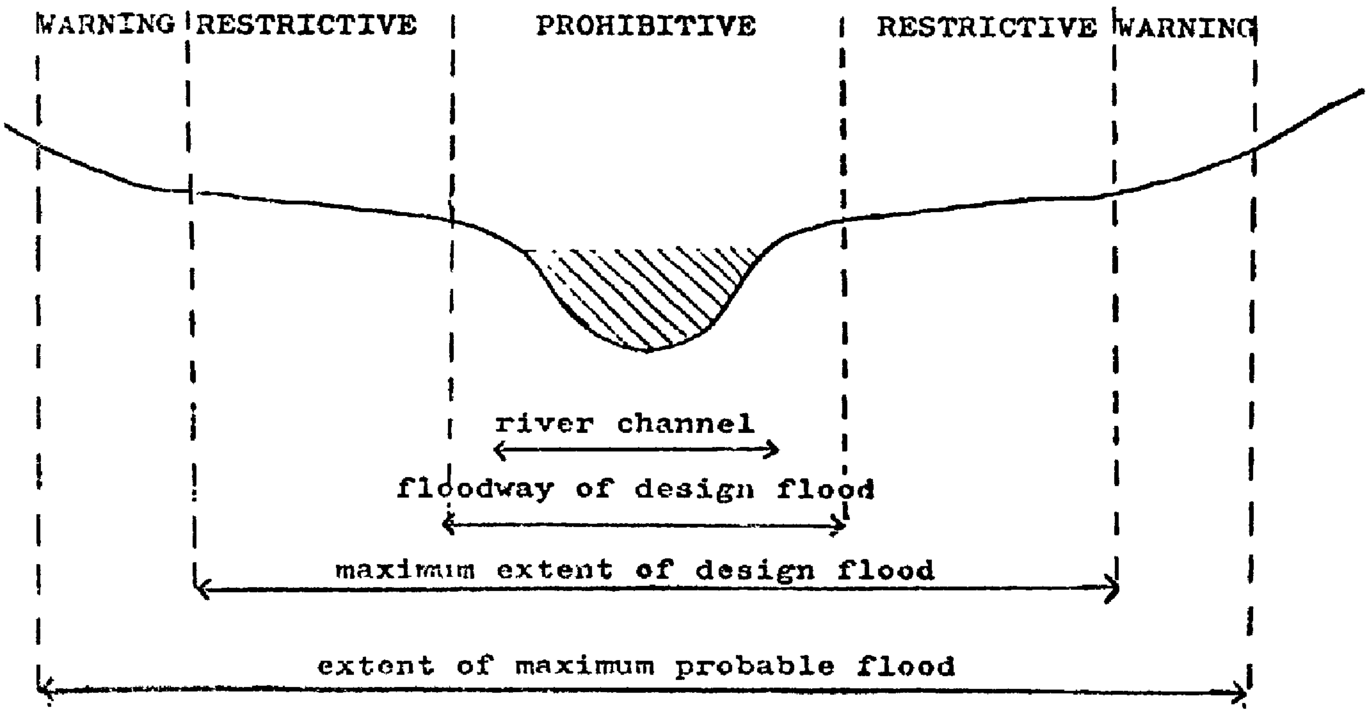

Figure 2.8 A flood plain zoned for land use regulation

(c) Warning-only Zone

Beyond the design flood level and up to the estimated maximum flood level, inundation is extremely rare and potential disaster therefore negligible. Would-be developers of flood plains are therefore simply warned and advised of the risks involved, of safe floor levels, etc, and allowed to make their own assessment of the worthwhileness of flood plain occupation. Little or no restriction is otherwise imposed in the interests of river flood disaster prevention.

Imposing zonalized flood plain occupation in the above manner helps to minimize the risk of flood disaster and prepares a community by planned development. Its identification also relates to time required for evacuation, and routes for access and evacuation. (Fig. 2.9) It also demonstrates the importance of a well-prepared and accurate assessment of flood hazard and why therefore some space has been given in this volume to describe briefly that aspect. (A detailed account of zoning is given in a separate volume in this series, Land-use aspects.)

Restrictions and building regulations

2.3.3 With or without flood plain zoning, an effective way of avoiding damage and disaster to individual property and structures is to incorporate in their design the ability to withstand inundation and high water velocities. Legislative regulations to ensure this is done are useful in protecting the welfare of individuals or whole communities and are particularly useful when incorporated as part of flood plain zoning regulations. It may be considered disaster prevention on a smaller scale than other measures but if it is applied at a regional or national level, the integrated effect might be just as substantial.

Restrictions and regulations have a combinatorial effect in protecting property and structures. They normally relate to planning the layout of construction sites, raising minimum foundation or floor levels, making structures unavoidably subject to waterlogging and high velocities of flow safe against foundation and structural failure, keeping water out of inundated buildings, and making special internal provision where ingress of flood water might occur. (A detailed account of these measures is given in a separate volume, Engineering aspects.)

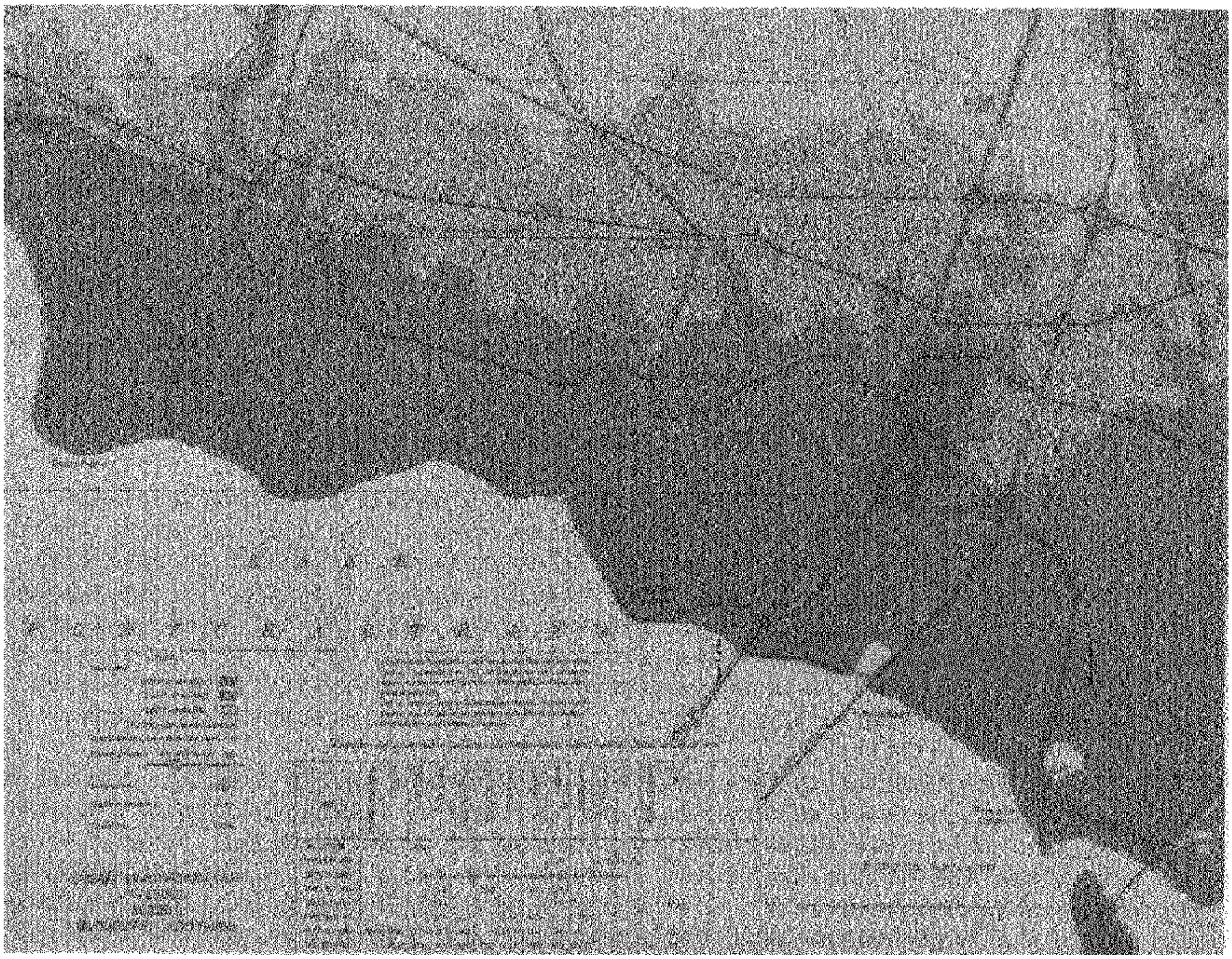

Fig. 2. 9 Flood plain zoning and storm evacuation map