Safety of dams of flood detention basins - design flood criteria

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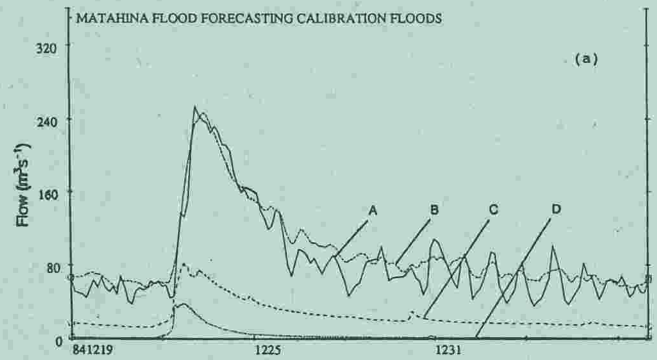

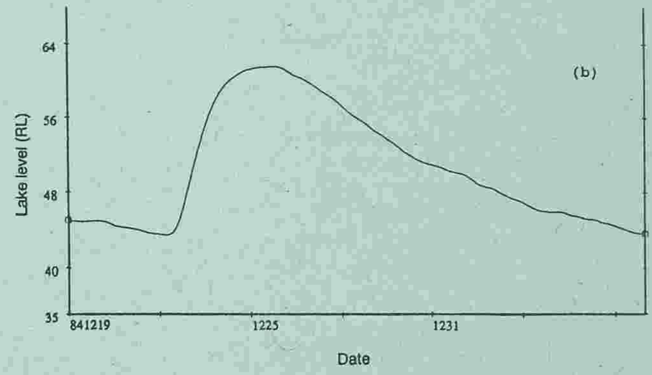

Fig. 2 (a) Lake level and outflow data from a 1984 flood were used to estimate lake inflow (A). The flood forecasting model produced a good simulation of the inflow (B), using data from the Whirinaki at Galatea (C) and Waihua at Gorge (D). (b) Estimated lake level hydrograph during the 1984 flood, assuming an initial lake level of ~ RL45.

floods they are not. The comparison of forecast and actual flows is good. The lake levels which would have resulted had this flood occurred during dam repair are presented in Fig 2(b). Unfortunately there is no means of assessing how accurate this forecast is. Curves such as this were used to assess:

(a) the probability that the excavation would be inundated and/or the crest would be overtopped, and
(b) the likely length of time the excavation would remain inundated.

During dam repair Cyclone Bola hit the east coast of the North Island causing widespread flooding in catchments adjacent to the Rangitaiki. The forecasting system correctly predicted that the Rangitaiki would not flood and construction continued unabated. Subsequent analysis of the rainfall during the cyclone showed that the Rangitaiki was in a "dry slot".

ECONOMICS

The cost of the risk analysis and implementation of the flood forecasting system was offset by savings in design and construction costs. With loss of generation costing $25,000 per day, unnecessary delays in construction were expensive. On the other hand, the cost of damage if protection were not put in place would have been enormous. Thus, the forecasting system allowed engineers and managers to make more informed decisions on the impact of flooding and then take the necessary action, if any.

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SAFETY OF DAMS OF FLOOD DETENTION BASINS – DESIGN FLOOD CRITERIA

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ABSTRACT The linear regulations, which have been carried out in the last few decades at numerous courses of rivers led to an aggravation of the flood risk downstreams. Today flood protection is run as a combination of retention, local measures and passive flood protection. Realization of the measures of flood retention is growing more and more difficult, not least because of the growing demands of environmental compatibility and safety – first of all against an uncontroled overtopping of dams. In addition to that the uncertainty in the estimation of design flood induced the water authorities to set up safety principals for the dimensioning of flood spillways, which seem to be very high compared to other fields. In the determination of design floods for flood spillways the specific marginal conditions of retention basins are rarely taken into account. The contribution deals with the setting up and the evaluation of design floods, in which case the possible various marginal conditions of detention basins are regarded. A regionalization model is used, which is suitable in combination with a multivariate statistical method also for unobserved watersheds for the evaluation of design flood hydrographs of certain probabilities.

INTRODUCTION

In an interdisciplinary workshop recommandations have been worked out in the last few years for the planning, building and management of flood detention basins for the county of Styria/Austria. The following contribution is concerned with the part "design of flood spillway" of the chapter Hydrology. In most cases up to now the design has been made in accordance with large storages for water power plants, without regarding the specific qualities of detention basins. The design flood is defined as the peak runoff (a univariate value), which can be discharged by the spillway outlets under special conditions, without endangering the dam or other important parts of the construction. Mostly it has not been considered, that there exists a spectrum of hydrographs (different combinations of peak and volume) for each probability, from which the decisive event and the resulting peak flow has to be found out, while considering the retention.

CHOICE OF DESIGN PROBABILITY

As there are significant changes in the conditions of regime and climate in the course of several thousand years, there is no hydrological value, of which one can say, that it is reached or exceeded in average every 5000 or 10000 years. Moreover in extreme cases like these just the term "exceedance probability" should be used.

Talking about an additional risk - caused by a dam break of a detention basin - for the population living downstreams, the resulting damage has to be compared with the damage, which occurs with a flood anyway, which is higher than the design flood. It has to be considered that with an extreme flood in the height of the Q_{5000} or Q_{10000} greatest damages would ensue also without a dam break and an evacuation of population would be probably necessary.

The certainty, with which a darn break has to be prevented, depends on the following criteria:

Possible damage: It has to be distinguished, whether and in which distance there are settlements, industries, single buildings or agticultural areas and to which extent lives of men, which cannot be measured in terms of money, are endangered.

Type of dam: Most sensitive earth dams react to an overtopping. Concrete dams are only threatened, if the stability is decreased by an erosion at the sides or on the bottom caused by an uncontroled overtopping. This danger can be diminished by appropriate measures. The same is valid on principle also for other types of dams, which may be overflowed.

In the theoretical case of dam break first of all the storage volume (up to the highest water level - in respect to the design runoff) is of importance, besides the water level and in a minor degree the geometry of the basin. Especially with very small basins the height of a dam break wave is neglectable in comparison to the design flood itself.

Safety of operation of discharging outlets: Flood spillways and if possible also the bottom outlet are to develope in such a way, that a blocking by wood can practically be excluded respectively that no diminishing of the runoff capacity occurs. Basically there has to be distinguished between catchments, which are mainly forested or not. According to the type of construction a partial blocking of the spillway has to be expected. Emergency outlets allow a fast discharging of the filled basin also with a blocked bottom outlet and clear the storage for possibly following floods. The accessibility of the construction - especially of the flood spillway - in case of an event is of relevance too. Early warning systems increase the total safety, depending on the basin inflow or on the water level.

MARGINAL CONDITIONS

According to the mentioned criteria the exceedance probability of the design flood has to be set up. This certainty then is a fixed value, which should not be provided with an additional amount by assuming the simultanuous occurrance of improbable marginal conditions. These conditions, which can be supposed will be shown as follows:

a) It is expected - as a compromise -, that the basin is filled up to the crest of the flood spillway, when the design flood occurs. The design flood peak is evaluated by the relevant inflow hydrograph regarding the retention in the storage from the crest of spillway up to the highest water level. The retention is neglectable with basins, which have a small surface in relation to the volume.

b) The freeboard in the case of design flood is dependend on the type and size of the construction. It is the vertical distance between the storage level in the "extraordinary design case" (according to the design flood) and the lowest point of the dam crest. General uncertainties in the estimation ought to be considered where they occur and should not be compensated by an additional freeboard.

Because there are no observations available in practice concerning the simultaneous occurance of a certain precipitation together with a wind of a certain direction and velocity, guide lines for the freeboard f_w (for the height of wave run-up), f_c ("constructive" freeboard), and the total freeboard f are given in the following Table, with reference to investigations of the DVWK (1990). For large basins and in special cases detailed investigations are necessary (KOEHLER, 1988). The peak-load allowance of the spillway has to be considered too.

With concrete dams the determination of the freeboard is dependent on the geological conditions downstream respectively on the securing protection of this area. In case of a dam, where an overflow is allowed in its whole with the mentioned definition of freeboard is not applicable. In this case a protection of the sides right over the highest water level (according to the design flood) is of importance. Because of the low velocities in this area the tractive stress is mostly likewise small.

c) It is supposed that the bottom outlet is closed and not operating. According to the way of construction of the spillway the possibility of a partial blocking has to be investigated and if necessary taken into account (up to 50%).

d) Other basins situated upstream are supposed to operate in a normal way.

For the design flood not the return period is chosen (for instance Q_{1000} or Q_{5000}, but a multiplying factor f_{100}, that shows, how many times higher the design flood is, than the peak flow with a return period of 100 years, which can be evaluated fairly well. First of all a regional factor f_r is determined, which defines the upper limit of the relation between the peak flow of an exceedance probablility of 0.0002 and the Q_{100}, which corresponds to an exceedance probability of 0.01. A certainty of 0.9998 means - correct hydrological data provided - that on average about every 167. generation will go through an exceeding of the capacity of flood spillway.

$$f_r \geq \left(\frac{Q_{0.0002,\,i}}{Q_{0.01,\,i}}\right)_{max} \tag{1}$$

Uncertainties in the design fundamentals lower this value, but this is compensated by the fact that not every exceeding of the design flood must result in a dam break, and in most cases an evacuation of the population, which might live in the danger zone, will be possible at that time especially by early warning systems. The regional factor fr lies, according to the regime, approximately between 1.3 and 2.2. It has to be determined by from extensive statistical analyses of regional runoff observations. If significant interdependences to the catchment characteristics ensue, they will have to be taken into consideration.

f_r can be reduced in accordance with the special conditions, in order to get the factor

f_{100} (for $f_t \cdot f_s \cdot f_d > 1$ it is set $f_t \cdot f_s \cdot f_d = 1$).

$$f_{100} = 1 + (f_r - 1) \cdot f_t \cdot f_v \cdot f_p \tag{2}$$

f_t Reducing factor concerning type of dam

f_s Reducing factor concerning size of detention basin

f_d Reducing factor concerning "damage potential"

The mentioned reductions are specified in Table 2. The sizes of the basins are stated in Table 3 and the groups D1 to D3 which occur under "damage potential" are shown in Table 4.

Table 1. – Freeboard depending on the type of damand storage volume.

storage volume	concrete dams	earth dams		
	$f = f_w$	f_w	f_c	f
< 100000	0–0.5	0.5–0.7	0–0.3	0.5–1.0
100000 to 500000	0–0.7	0.7–1.0	0.3–0.5	1.0–1.5
> 500000	0–1.0	1.0–1.3	0.5	1.5–1.8

Table 2. – Reduction of the factor f_r for the determination of the design flood for flood spillways.

type of dam (f_t)	earth dam	1
	concrete dam	0.5
size of basin (f_s)	large	1
	mediumsized	0.8
	small	0.4
damage potential (f_d)	D1	1+w
	D2	0.9+w
	D3	0.7+w

an early warning system exists $w = 0$
otherwise $w = 0.2$

Table 3. – Classifying of detention basins according to their size.

	basin volume [m^3]	maximal dam height [m]
small basins	0 – 100.000	0 – 5
mediumsized basins	100.000 – 500.000	5 – 15
large basins	> 500.000	> 15

Table 4. – Definition of the "damage potential" and classifying in groups.

D1	endangering of human life settlements, main traffic routes
D2	like D1, but detectable reduction of 'danger potential'
D3	agricultural areas

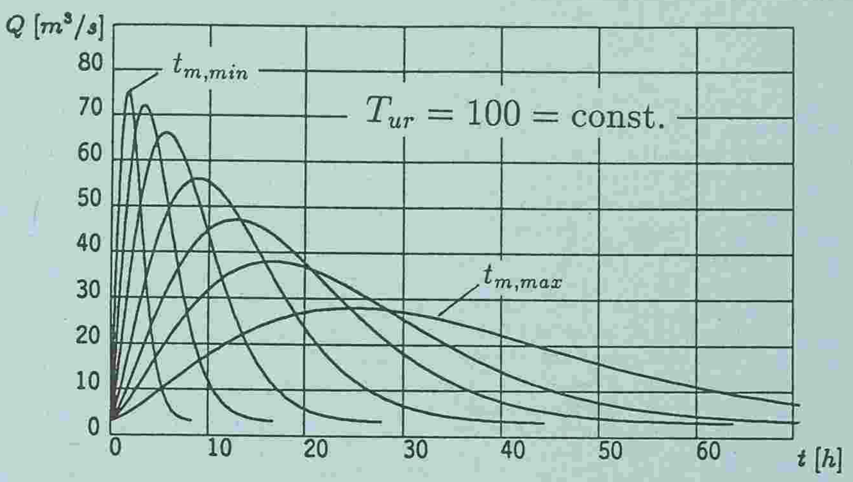

Fig. 2 "Design hydrographs": Flood hydrographs of constant bivariate probability.

It has to be emphasized that in case of such an extreme event with an exceedance probability of 0.0002 (corresponds to a theoretical return period of $T_n = 5000$) - which is the highest flood peak, which can be discharged just without damage of the construction - greatest, catastrophical damages downstream will have to be faced, already before reaching the peak. This, of course, is also the case if there is no detention basin. A "natural" catastrophy takes place already before the dam is endangered.

DETERMINATION OF FLOOD HYDROGRAPHS FOR CERTAIN RETURN PERIODS

A flood hydrograph is a multi-dimensional event. In order to make direct statistical analysis feasible, a flood event FE_r is characterized by the pair of values "volume of direct runoff" V_D and "peak of direct runoff" Q_D. By a bivariate statistical evaluation (SACKL, 1987, BERGMANN & SACKL, 1989) lines of equal probability are achieved, which show an elliptic course (Fig. 1). Each pair of values along this line can be converted into a flood hydrograph by the assumption of a standard hydrograph typical for a region and by the addition of an intermediate baseflow (Fig. 2). From these hydrographs the one has to be selected, which produces, after retention in the detention basin (at least in the storage between the crest of spillway and the highest water level), the highest peak flow through the flood spillway.

Determination of flood peaks Q_r

There are numerous formulas to access flood peaks of certain return periods on the basis of only very few catchment characteristics. Such formulas have been developed for specific areas, this is why a transference is not permissible and can lead to enormous errors in estimation. Apart from smallest constructions the T_r–years flood peaks in unobserved watersheds have therefore to be found out through an estimation formula, which has to be developed regionally. In this respect the runoff samples of all the regional water gauges have to be evaluated statistically first of all. In addition to that, characteristics are evaluated for the river site that has been investigated itself, and the regional water gauges, which are relevant for the flood regime. As examples these characteristics are the watershed area, the length of the main valley, an index of circularity, the distance from the centre of the watershed to the detention basin, the intermediate altitude and slope of the area and the river network, the stream density, the portion of forest and indices, which describe the geology, vegetation and the soil. Topographical characteristics can be determined automatically by a computer program from the digital terrain model for Austria (50-meter square grid raster). This program allows among other tasks also the automatic determination of hypsogram (dependence of altitude and area), hypsoklinogram (dependence of slope and area), exposition and optional profiles (e.g. along watercourses).

With the help of a multiple regression analysis interdependences are examined and a regional empirical formula for peak flow estimation is developed. In this respect the number of the regional observed water gauges has to be higher than about to times the number of considered catchment characteristics.

In this way the value for Q_{100} is determined. The remaining T_r–years peak flows can be obtained through a distribution, which is typical for the region. As an example the following simple formula is shown for the estimation of the Q_{100}, which has been developed for small and mediumsized watershed areas in West Styria (SACKL, 1988).

$$Q_{100} = 6.71 \cdot A_E^{0.542} \cdot C^{0.219} \cdot \left(\frac{L_S}{L}\right)^{-0.33} \cdot S_L^{0.016} \cdot D_S^{0.236} \cdot V_F^{-0.169} \quad (3)$$

In this formula A_E means the watershed area in km^2, L the length of main valley in km, L_S the linear distance of the centre of the watershed to the basin outlet, C the index of circularity $(C = \sqrt{2\,A_E/\pi/L})$, S_L the mean slope of the main valley, D_S the stream density and V_F the vegetation index (for this example the portion of forest).

Determination of flood volumes of direct runoff $V_{D,r}$

The estimation is made according to the following formula:

$$V_{D,r} = A_E \cdot h_{p,r}\,(d_p) \cdot \psi V\ [m^3/s] \quad (4)$$

$h_{p,r}\,(d_p)$ is in this case the T_r–years height of precipitation with the relevant rainfall duration d_p, which is assumed as the T_r–years time to peak of flood events $t_{p,r}$. In unobserved watersheds the best method is the determination of a regional relation factor f between the time of concentration T_C of a watershed and the time to peak $t_{p,r}$. *For this, statistical investigations of the times to peak* t_p at the regional observed water gauges are needed. It has to be examined with which "time of concentration"-formula the best correlation can be achieved.

$$t_{p,r} \approx d_p \approx f \cdot T_C \quad (5)$$

The height of precipitation $h_{p,r}$ is then taken from regional rainfall duration curves for the duration $d_{p,r}$. The so called "statistical runoff coefficient"

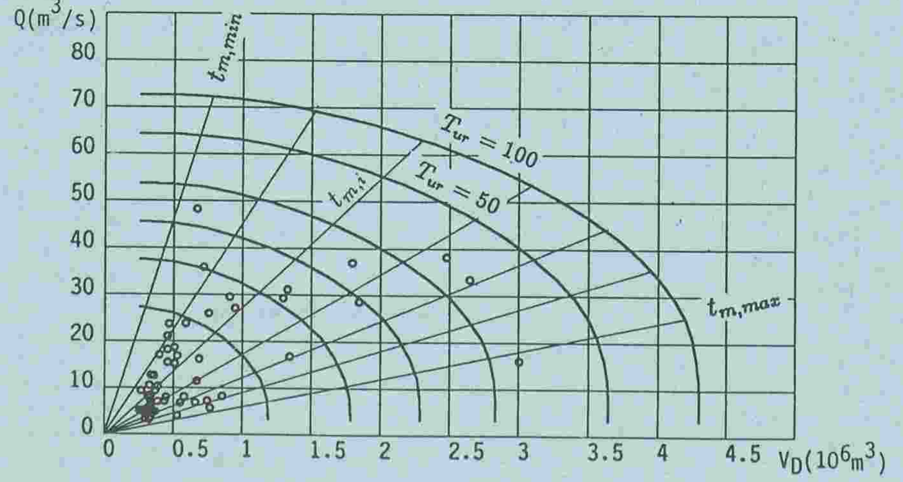

Fig. 1 "Design curves": Lines of constant bivariate probability of V_D, Q_D (probability of occurance of V_D, Q_D in the upper right quadrant).

$$\psi V = \frac{V_{D,r}}{A_E h_{p,r}} \quad (6)$$

means the relation between a direct flood volume and the precipitation volume for a certain return period (not the same as the runoff coefficient ψ of single events) and is converted from regional statistical analysis of flood volumes $V_{D,r}$. Investigations have shown that this coefficient that is necessary for the calculation of $V_{D,r}$ in unobserved watersheds, lies approximately between 0.25 and, maximally 0.40, according to the character of the watershed (vegetation, geology, urbanization, slope). In one region it mostly varies within narrow limits and is practically independent of the return period T_r.

Assumption of the "initial" baseflow

The mean baseflow at the begin of a flood event (for the flood season) is basically independent of all characteristics of the following flood. It is assumed to be a multiple of the mean flow MQ (according to the flow regime). High factors show for instance watersheds of relative high altitude or northwards oriented areas.

Assumption of a typical standard hydrograph

The standard hydrograph, which is typical for a certain area has to be estimated by regional investigations. Different analytical approaches are used (MENDEL, 1968; SACKL, 1987). The "standard hydrograph" shape is dependent e.g. from the size, from storage and flood rooting conditions in the catchment.

Assumption of the range of "peak runoff time" $t_m = V_D/Q_D$

The estimation of the limits $t_{m,min}$ and $t_{m,max}$ with which flood events occur, is done in an appoximative way by straight lines through the origin (Fig. 1). For $t_{m,min}$ and $t_{m,max}$ empirical values are estimated according to the size of the watershed. For mediumsized and large retention basins and watersheds more detailed investigations have to be carried out, in order to find a relation to the time of concentration of the area, for instance.

Finally the "design curves" (Fig. 1) and the "design hydrographs" (Fig. 2) can be determined.

Evaluation of the "relevant" design event

If a reduction of the peak flow by retention is not taken into consideration, the peak runoff of the corresponding probability is sufficient for the dimensioning. Otherwise the event has to be evaluated being relevant for the design, which shows the highest peak runoff after the retention, mostly corresponding to the mean "peak runoff time" t_m.

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HOW TO ESTIMATE THE IMPACT OF FLOOD DETENTION BASINS ON THE DOWNSTREAM FLOOD REGIME

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ABSTRACT This paper deals with the presentation of a detailed model, which enables to calculate the relation between basin parameters and flood hydrographs. The knowledge of this interaction is important for the estimation of the changed hydrographs due to changes in the basin which have an effect on the basin parameters used in the model. Those parameters are a flow time parameter and a runoff volume parameter. The spatial distribution of those parameters is based on a systematical division of the basin into square grids. First a normalized, unretended basin specific mass-transport-diagramm is calculated. Then a linear routing model is taken as the missing link between this diagram and the basin specific standardized flood hydrograph which is derived by evaluating measured hydrographs.

INTRODUCTION AND PROBLEM DEFINITION

The planning of water resources management measures is no more limited to single measures. In a modern concept efforts have to be made to find integrated solutions which consider environmental aspects as well as financial ones in connection with a maximum of efficiency.

The increasing demand for extending residential, industrial, agricultural and traffic areas on the one hand, and the need to preserve nature reserves and to create new recreation areas on the other hand, lead to a controversal situation, which only can be solved by exact and careful regional planning. This of course includes the protection of the environment against men's activities as well as the protection of civilization including human life against natural desasters.

In order to be able to evaluate the impact of changes in the basin on the downstream runoff, it is necessary to use a model, which makes it possible to find a direct relation between e.g. flood prevention measures upstream and the effect on a critical point downstream.

In this paper a model is presented, which calculates basin related sythetic hydrographs in which the runoff portion of any subbasin can be identified easily.

PROPOSED MODEL

The proposed model, which is able to meet with the above discussed requirements, combines statistical flood hydrology with elements of regionalization. The model is easy enough to handle to be used in engineering practice, because only elements of well known hydrological models are used and all the information needed can be