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

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 controversial 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

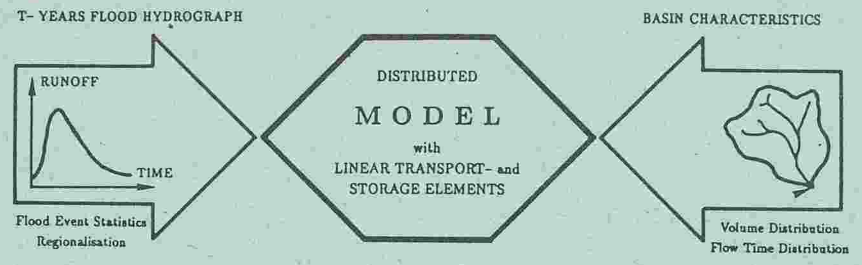

Fig. 1 Distributed model

obtained from the hydrological service and geographical maps or geo-data banks.
The distributed model consits of two major parts: the statistical part based on a regionalisation and the rainfall-runoff model based on the basin characteristics (Fig. 1).

Statistical investigations
The first of the two main parts of the model is the determination of the relevant flood hydrograph at the point of the watercourse where the influences have to be investigated. The return period T_r of this hydrograph is ordered either by the involved authorities, or has to be chosen according to the wanted degree of protection. The estimation of the local flood hydrograph can be done directly by analysing measured runoff hydrographs at the investigated point of the watercourse or, if there are no long-term observed runoff data for this point which is the usual case, the hydrograph has to be calculated using a regionalization formula. This regional flood-formula is based on a statistical analysis of measured hydrographs of hydrologically compareable basins.

Analyses of flood events
The two parameters which characterize best a flood event, are the peak Q_D and the volume V_D of direct runoff. For the estimation of the flood volume it is necessary to delimitate the flood hydrograph. The beginning of a flood event usua]ly can be found easily, the determination of the end of an event however poses some problems. If we assume, that there is a linear increase of the baseflow during an event, we can use the quotient ε between the volume of direct runoff V_D and the volume of the increased part of the baseflow V_K (Fig. 2) as the separation criterion.

$$\varepsilon = \frac{V_D}{V_K}$$

By those means the single event hydrographs are found and in addition to the two

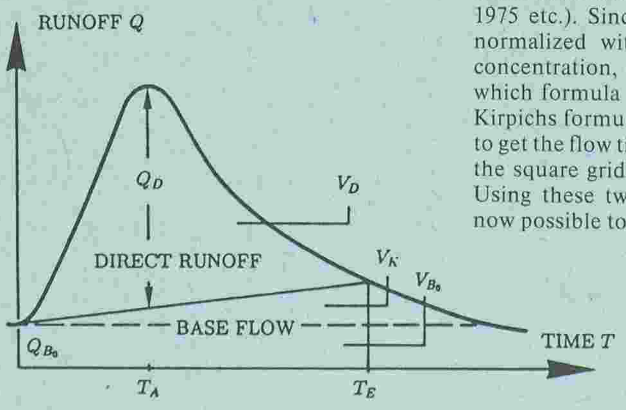

Fig. 2 Characteristic parameters of a flood event

parameters mentioned above, the time to peak T_A and the initial base flow Q_{BO} are analysed for each event.
The standard volume V_S and the peak runoff time T_M can be derived as comparison parameters.

$$S = \frac{V_D}{Q_D T_A}\ ,\ T_M = \frac{V_D}{Q_D} \qquad (2, 3)$$

Determination of the basin specific standard hydrograph
The model which is used to calculate the standard hydrograph for a particular basin, is based on a systematic division of this basin in equally sized squares. The size of such an element has to be chosen according to the actual problem and the desired accuracy of the results. The model (Bergmann & Richtig, 1988), which is concepted as a rainfall-runoff model, uses two parameters to determine the distribution of the flood volume in space (basin area) and time (flow time to the basin exit).
In order to calculate the proportion of a single square on the total flood volume, a local runoff-coefficient ψj has to be determined for each square. It is assumed, that this coefficient is constant during an event. The estimation of those values is very uncertain, however for the model it is only important to estimate the relations between the runoff coefflcients as good as possible. We calculate the runoff coeffIcient proportionally to the forested part of the respective square. As parameter, the so called "flood volume weight" φ_j is estimated by normalizing the runoff coeffizient ψ_j for each square.

$$\varphi_j = \frac{\varphi_i}{\Sigma\ \psi_j} \qquad (4)$$

Then a runofftime-coefficient T_C is estimated for each area unit. There are several formulas in use to calculate the times of concentration, depending on different basin characteristics (Carter, 1961; Kreps, 1975 etc.). Since the flow time has to be normalized with the maximum time of concentration, it is of minor importance which formula finally is used. In our case Kirpichs formula (Kirpich, 1940) is applied to get the flow time isochrones 0, 1, 2...*R* for the square grid of the basin.
Using these two sets of parameters, it is now possible to calculate the runoff hydrograph in two steps. First the non retended mass-transport-hydrograph is computed. This is done by the time correct superimposing of the weighed runoff volumes of the area units.

$$\bar{a}_i = \Sigma_{(i)}\ \varphi_j \qquad (5)$$

As the result we get the so called "mass transport diagram" (Fig. 3) with the total flood volume being "1".

$$\Sigma_1^R\ \bar{a}_i = 1 \qquad (6)$$

This method is similar to the time-area-method, however due to the grid structure of the model, it is possible to identify the flood volume proportion of every single square in this diagram.
In a second step the retention within the drainage basin is simulated using a linear routing formula.

$$a_i = C\ a_{i-1} + (1-C)\ \bar{a}_i \qquad (7)$$

The parameter *C* of the routing procedure depends on the storage coefficient K_a of the basin

$$C = e^{-\frac{1}{Ka}}\ ,\ K_a = -\frac{1}{ln\ C} \qquad (8, 9)$$

and has to be calibrated taking into account that the retended hydrograph has to meet with the following conditions:
The volume of the hydrograph has to be equal to the statistically determined standard volume $S = \frac{V_D}{P \cdot a_D}$

The separation quotient ε for delimiting the runoff event has to be the same as used in the flood event analysis.
The time to the peak T_p of the hydrograph and the peak discharge $Q_{D,max}$ have to be the unit value "1".
Once the proper routing parameter *C* is found, the standard hydrograph (Fig. 3) and its standard parameters standard time interval $\Delta\tau$ standard storage coefficient $\varkappa$, standard time τ and the standard runoff u_i can be calculated.

$$\Delta\tau = \frac{1}{P} \qquad (10)$$

$$\varkappa = \frac{1}{P} K_a \qquad (11)$$

$$\tau = \frac{i}{P} \qquad (12)$$

$$u_i = \frac{Pa_i}{a_D} \qquad (13)$$

T_r–Years flood hydrograph
The design flood events are computed using the same characteristic parameters as described before. If there are measured data for the investigated point of the watercourse, the discharge and the flood volume can be obtained directly using bivariate statistical methods. For ungauged sites a regionalization has to be made in order to gain a flood formula for the region, to calculate the peak flow with the given return period. For that reason the measured flood peaks of gauges in hydrologically similar

basins are statistically analyzed and the flood peak discharges with the relevant return period are calculated. Using those peak discharge values, the regional flood formula depending on basin characteristics is calibrated by a multiple linear regression method (Sackl, 1987). In our case the following basin related parameters proved to have a significant influence on the flood peak discharge: the catchment area A_E, the length of the main watercourse L, a circularity index C_b, basin shape index L_C/L, the mean slope of the main watercourse I, the discharge net density S_D and the portion of the forested part F. An example for the result of such a regionalization for East and West Styria in southern Austria is given below.

$$Q_{100} = 6.7 \cdot A_E^{0.542} \cdot C_b^{0.219} \cdot (Lc/L)^{-0.33} \cdot I^{0.016} \cdot S_D^{0.236} \cdot F^{-0.169} \qquad (14)$$

The shape of the T_r–years hydrograph is given by the standard hydrograph as described before. After adding the baseflow $Q_{B,O}$, the basin specific design hydrograph for the given return period is complete.
The important feature of this procedure is the fact, that the runoff contribution of each square can be identified in this hydrograph. Therefore it is easily possible to recalculate the equivalent T_r–years hydrograph for changed runoff conditions e.g. caused by the construction of detention basins which changes the distribution of the flood volume in time, or by the change of the landuse which in-or decreases the flood volume, or caused by a combination of both types of man made changes, like the construction of a detention basin in order to compensate the negative effects of deforestation on floods.

EXAMPLE OF APPLICATION

The most important question in connection with the planning of detention basins is the question about the effectiveness of those structures regarding an event of a certain return period. If we want to know more about the influence on the relevant design hydrograph for some critical point downstream, we can use the above described model as follows (Fig. 3): First the characteristics of the design flood event are calculated by regional statistical investigations. Then the basin behind the investigated point is devided into equal sized squares and the runoff coefficients and flow times of the single squares are determined. Using those parameters, the flood volume weights and the isochrones are calculated as input for the mass transport diagram. Then the standard hydrograph and its characteristic values are computed using the linear routing formula with the calibrated routing coefficient. Now the design hydrograph with the chosen return period for the case that there is no detention basin, can be found, using the standard hydrograph together with the given characteristics of the decisive flood event. In order to estimate the influence of the detention basin, the subbasin affected by the flood retention, the corresponding part in the mass transport diagram of the whole basin and the partial hydrograph of the subbasin are calculated. To get the retended design hydrograph with the same return period as above for the whole drainage basin as the desired result, the output hydrograph at the detention basin is calculated and superimposed with the partial hydrograph of the unchanged subbasin.

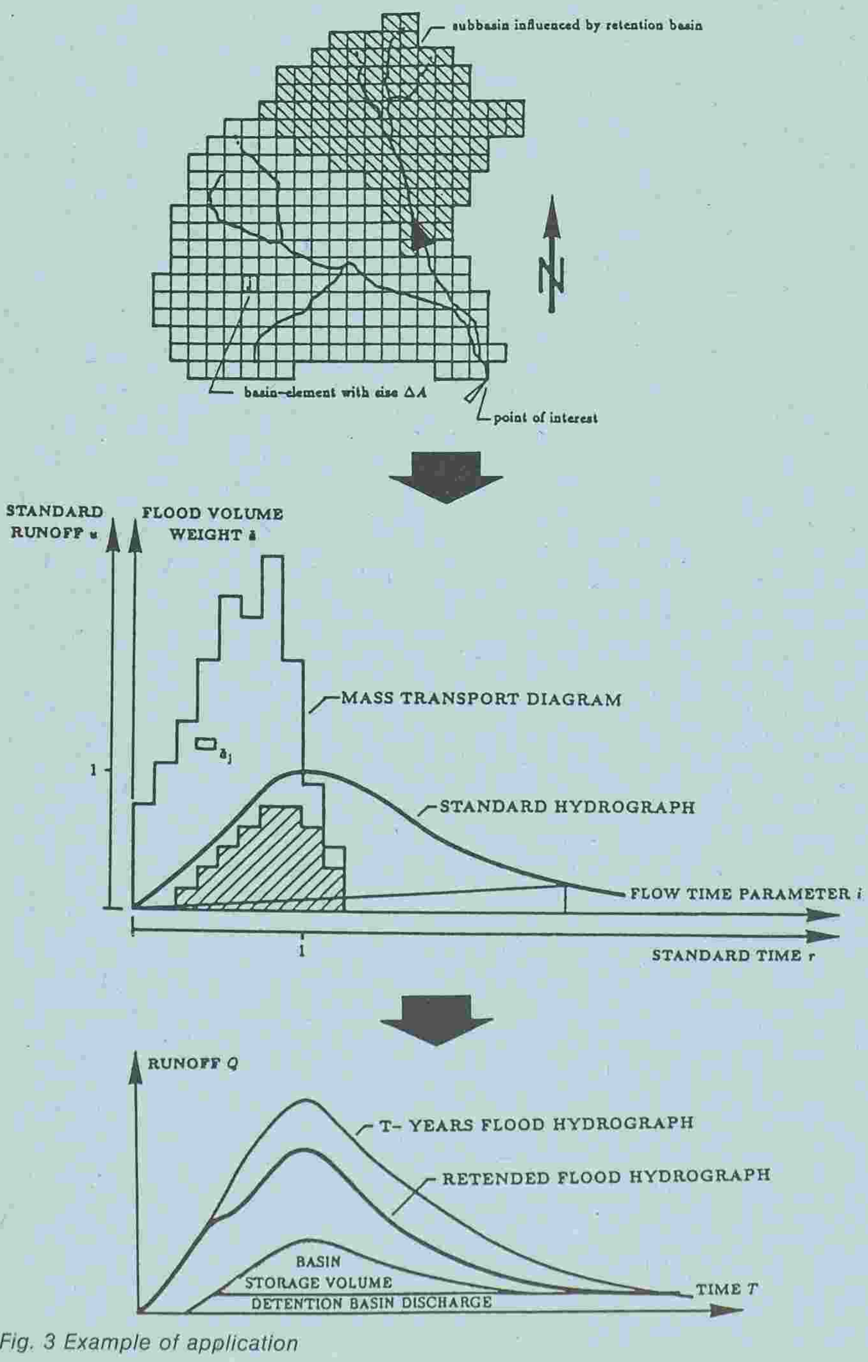

Fig. 3 Example of application

SUMMARY AND CONCLUSIONS

The detailed runoff model which is described in this paper is concepted in a way, that by using just catchment characteristics which can be easily obtained from topographic maps, it is possible to investigate the effects on the runoff caused by any kind of changes in the basin. This is made possible, because the square grid model enables one to identify the runoff proportion of every single square in the hydrograph. So, when changes in the catchment area take place (quicker or slower runoff, changed runoff-coefficient) it is possible to correct this hydrograph according to the new runoff regime. This also offers the possibility to estimate the influences of flood prevention measures upstream on design hydrographs of a certain return period downstream or makes it possible to investigate historical events regarding the question what would have happened if at that time retention basins e.g. had already been built.

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