The flood forecasting by a series storage type model

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SUMMARY: The series storage type model is a structure, composed of storage type models laid vertically in series. The storage type model, which is the element of the series type structure, is based on the hypothesis that both discharge and infiltration are functions of the amount of water stored in the ground.

In the case of low rainfall, water passes through the first structure at the top of the series model and it runs off from the second or third structure with a smoothed hydrograph and time lag. Heavy rain however results in water discharging from the first structure as a flood. The discharge from the second or third structure forms the gradual fall of the hydrograph after the flood.

This model seems to be useful for runoff analysis in general, including floods.

RÉSUMÉ : Le modèle de la série de volumes d'accumulation est constitué de volumes d'accumulation séparés, placés à des cotes différentes. Le modèle d'un volume d'accumulation séparé est basé sur l'hypothèse supposant que le débit et l'infiltration sont fonctions des réserves en eaux souterraines.

Quand il pleut et que la pluie n'est pas intense, l'eau passe à travers la première structure, située en haut du modèle, et descend à la deuxième ou à la troisième structure avec un hydrogramme aplani et retardé. Quand il pleut intensément, l'eau descend de la première structure comme une crue. La variation de débit de la première à la deuxième structure représente l'abaissement graduel de l'hydrogramme après la crue.

THE SERIES STORAGE TYPE MODEL

The series storage type model is a structure, composed of storage type model, laid vertically in series as shown schematically in fig. 1. The storage type model which is an element of the series type model is based on the hypothesis that both discharge and infiltration are functions of the amount of water stored in the ground (fig. 2). These

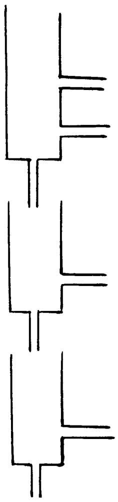

FIGURE 1

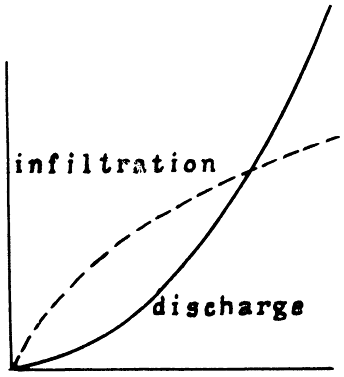

FIGURE 2

curves can be approximated by jointed segments (fig. 3) which can be represented by a structure shown in fig. 4. On the assumption that infiltration is proportional to the amount of stored water, the storage type model is represented by a simpler one shown in fig. 5.

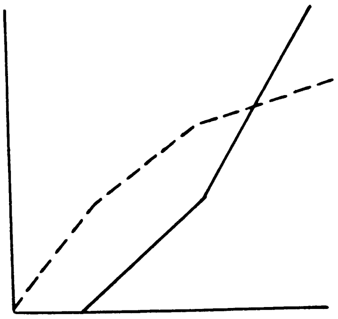

FIGURE 3

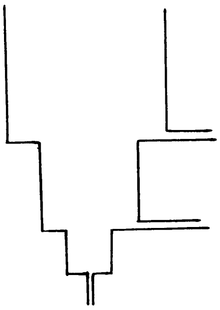

FIGURE 4

In spite of the merit that it can represent automatically the non linear character of the runoff phenomena, the storage type model has the defect that it is not so sensitive to rainfall intensity. But in reality, especially in a small basin, high intensity rain causes a higher peak of flood discharge than would be caused by the same amount of rainfall at lower intensity. It is difficult to explain this phenomenon by the storage type model.

To modify this defect the series storage type model is constructed by laying storage type structures vertically. The rain is put into the vessel at the top. The water in each vessel runs off partly through outlets at the side, and partly through the outlet at the bottom to the next vessel. The former represents the discharge and the latter infiltration. The series storage type model may have physical meaning in that it corresponds to the zonal structure of the undergroundwater shown in fig. 6.

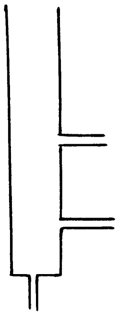

FIGURE 5

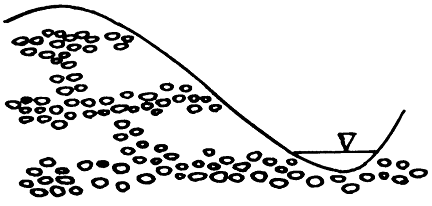

FIGURE 6

The series storage model works as follows. If it rains at high intensity, the model indicates the state shown in fig. 7a, in which the output from the upper vessel plays the main part. This component corresponds to a high flood discharge of short duration.

In the case of low intensity rain however, the model indicates the state shown in fig. 7c, in which the output from the third vessel predominates. The state shown in fig. 7b is the intermediate case. The water runs off from the second or third vessel gradually with a smooth hydrograph and a time lag given automatically while the water is transferred from the upper vessel to the lower one. The runoff from the second or third vessel forms the gradual tail of the hydrograph which appears at the end of the flood.

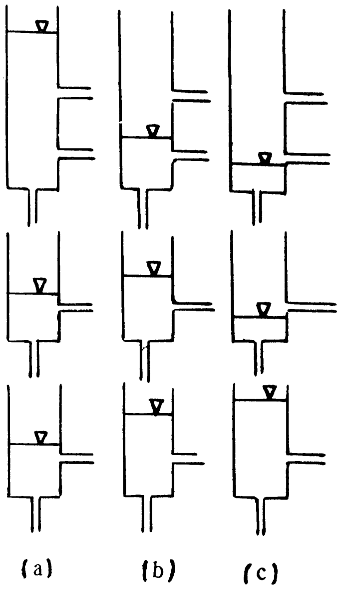

FIGURE 7

The difficulty of the series model is that we have no mathematical method to determine the parameters, because of its non-linear character. They must be determined by iteration.

THE METHOD OF DERIVING FLOOD DISCHARGE FROM PRECIPITATION

1 Precipitation data at several points are necessary regardless of the basin area. Three points are required even for a small basin, though five or six suffice for a large basin. The representative character of a set of rain gauges cannot be predicted a priori but must be determined by comparing the observed discharge with the obtained result derived from the precipitation data.

2 The precipitation data at each point are transformed into runoff by a series storage type structure. In some cases the precipitation must be multiplied by some appropriate constant before transformation into discharge. Or if there are many rain gauges in the basin we may classify them into several groups and make an average for each group. Then the derived data are transformed into discharge.

3 The estimated discharge is obtained by summing up the derived series, transformed from the precipitation at each point, with appropriate weight and time lag.

4 In some cases the deformation of hydrograph is taken into account as explained later.

When all parameters are definite and given, numerical computation is quite easy. For example, in the case in which hourly precipitation at several points is transformed into hourly discharge, it takes only few minutes to perform the computation even by hand. Transformation of precipitation into runoff by a series storage type model is performed with ease by using tables which are given to each vessel respectively.

THE DEFORMATION OF THE HYDROGRAPH

One way to deal the deformation of the hydrograph in transmission is to use a hydromechanical method, but the empirical method which we will explain here is rather simpler. Ease of application and goodness of fit tend to the contradictory requirements but the simple method may have sufficient meaning even if it does not fit so well.

Deformation of the hydrograph by storage type model

The flood hydrograph is flattened and smoothed while it recedes. This result can be given by the storage type model of fig. 8a or by one on the assumption that output is proportional to the square of stored water. This assumption also applies for the series storage type model which transforms the precipitation into discharge and can be approximated by the model of fig. 8b.

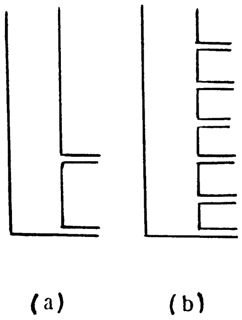

Figure 8

Transmission of a flood

It takes time for a flood to pass from an upper river gauge to a lower one. A first approximation is to set the transmission time as constant. But in reality velocity varies with discharge. We can assume that the velocity V is proportional to the 4th root of the discharge Q,

$$V \propto Q^{1/4}$$

because the river depth h is proportional to $\sqrt{Q}$, and velocity is proportional to $\sqrt{h}$. On the assumption that the inclination of the river bed is large enough, so that the surface inclination is nearly equal to that of the river bed, the transmitted hydrograph is obtained as follows.

Let $\{Q_n\}$ be the time series of hourly discharge at some river gauge A. Discharge Q_n reaches another lower river gauge B with time lag $CQ_n{}^{-1/4}$, where c is some constant, because velocity is proportional to $Q^{1/4}$. Accordingly time series $\{Q_n\}$ with equal time intervals at A is transformed at B to the one with unequal time intervals.

discharge	Q_0	Q_1	Q_2	...	Q_n	...
time at A	0	1	2	...	n	...
time at B	$0+cQ_0^{-1/4}$	$1+cQ_1^{-1/4}$	$2+cQ_2^{-1/4}$	...	$n+cQ_n^{-1/4}$...	

The time series at B with unequal time intervals can easily be matched to the one with equal time intervals by interpolation.

There are two ways of transformation; firstly deformation of the hydrograph by storage type model is performed and secondly the effect of transmission is calculated, or vice versa. The result is nearly the same regardless of the order of operation.

EFFECT OF A NARROW CHANNEL

In some cases, the flood hydrograph is deformed by a narrow channel. The deformation is caused by the storage of water resisted by the channel, that is, the discharge through the channel does not increase so much as the storage increases as fig. 9 shows.

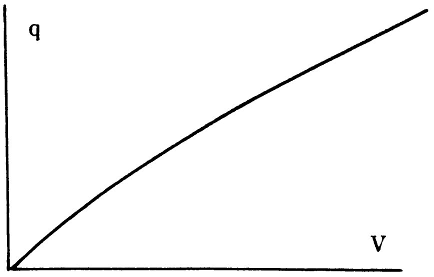

FIGURE 9

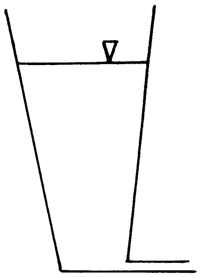

FIGURE 10

The relation between discharge and storage must be given empirically, but if there are no empirical data we must assume a relation such as:

$$V = q + cq^2,$$

where q is the discharge through the channel and V is the storage above the channel measured by the volume unit equal to (discharge unit) × (time unit). This relation can be simulated by the storage type model of fig. 10. In the above equation, q is nearly equal to V, when V is small. As we perform the computation in the form of a time series, if the storage is small, the output is nearly equal to the storage. Accordingly the input turns into output scarcely deformed by the transformation. That is, the water runs freely through the channel, when the river stage is low. This is the reason why the coefficient of q in the above equation is set at unity.

The above equation has only one parameter c, which is characteristic of the narrow channel, and which is determined by iteration.

METHOD OF COMPUTATION

The series storage type model has many parameters which are determined only by iteration because of its nonlinear character. Moreover many rain gauges must have their own respective optimum and time lags which are also determined by experiment.

It is seldom that we have enough data to analyse, but we frequently complete the data by estimation based on assumptions, the justification for which can be proved only by experiment.

The need for the high speed computer results from these circumstances. The National Research Center for Disaster Prevention has made a hybrid computer for this purpose. The series storage type model is simulated by the analog part, while the digital input and output is given or obtained using the digital part, which is used also for setting parameters or for iteration.

It seems to be better to use the high speed digital computer because of its wide adapatbility. TOSBAC-3400 of National Research Center for Disaster Prevention is a high speed computer of medium size. It takes an average about $5\ \mu$/sec. per operation so that, in computation of floods, computing time mostly depends on the speed of the line-printer. This computer has two 1/0 channels to which A/D and D/A converters are attached as a part of the 1/0 instruments.

In analysing unknown phenomena under restricted conditions, the most important discrimination must be a human synthetic one, even it is subjective in character, although we do not neglect objective discrimination by the computer. To foster this synthetic ability of discrimination it is important to have visual images of many phenomena. The D/A converter is useful for this purpose. For example, using the D/A converter and a pen-recorder we can obtain a trace of the hydrograph far faster than using a line-printer.

La méthode du gradex pour le calcul de la probabilité des crues à partir des pluies

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RÉSUMÉ : Les auteurs ont cherché à mettre au point une méthode pratique, s'appuyant sur un nombre minimum d'hypothèses physiques et statistiques simples, qui sont résumées comme suit :

1. La fréquence $f(R)$ de la précipitation journalière en un lieu est à décroissance exponentielle simple : $Lf(R) \sim -R/a$ quand R est grand et cela est encore vrai de la précipitation moyenne étendue à un bassin versant. La paramètre « a », dit « *Gradex* », est fourni par quelques années d'observations pluviométriques journalières de bonne qualité; il varie en France entre 4 et 60 mm/jour selon la région et les saisons.
2. En période de hautes eaux, quand on approche de la saturation du bassin versant, tout accroissement $\mathrm{d}R$ de la précipitation produit un accroissement $\mathrm{d}Q$ du débit qui tend à devenir égal à $\mathrm{d}R$.

On en déduit que, sur le graphique de Gumbel, la loi du débit a une courbure positive et tend vers une asymptote parallèle à la loi de la pluie, dont la pente est le gradex.