# Runoff Model for Flood Forecasting

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## Abstract

The formation process of flood hydrograph in a river basin can be expressed by the combination of the conversion process from rainfall to runoff in divided sub-basins and the concentration process of the runoffs in a stream net. The objective of this paper is to develop a synthetic method of flood estimation based on such a concept. The tank model is employed for the conversion process and the modified time-area-concentration diagram for the concentration process. The hydrograph at the outlet of a basin is given by the convolution integral of the output from the tank model and the modified time-area-concentration diagram. The method of calculation of flood hydrographs is applied to five actual basins, and the values of parameters of the tank model are identified for each basin. After investigating the relation between the identified parameters and the geological features of the basins, several calculations on other basins are carried out for verification of the relation. Then, a synthetic method of flood estimation can be introduced for flood forecasting.


## 1. Introduction

Water-control structures such as dams, levees, etc., offer a positive method of reducing or eliminating the damages caused by flooding. The design flood of these hydraulic structures is determined by taking account of economic and political factors. When a flood which exceeds the design flood occurs, anti-flood operations such as temporary reinforcement of levees, evacuation of people, etc., provide an ultimate means of reducing flood damage. Such anti-flood operations are carried out on the basis of flood forecasting available. Usually, the official announcements of flood warning are communicated through a flood warning system including mass media like radio, television, etc.. These announcements, however, cover a fairly wide area, so that the announcements are not always effective for the prediction of a flash flood occuring locally. In these situations, it is to be desired that the flood forecasting for a specified local area be carried out by the people by themselves who are living in that area.

It is not necessary to mention that flood forecasting should be based on flood estimation by using a runoff model which gives the relation between input rainfall and output of runoff. In the circumstances that the people not being specialists in the field of hydrology but yet must still forecast by themselves a coming flood in the specified local area, the runoff model used in flood estimation should satisfy the following conditions. First, it goes without saying that the flood hydrograph should estimate accurately. Second, the calculation technique should be not too complicated. Thirdly, it is desirable that parameters in the runoff model correspond to the basin characteristics. The third condition would be valuable in the case where there is no past flood datum in the basin.

The authors have been making intensive studies on the runoff process of flood in a river basin. One of the basic concepts is that the formation process of a flood hydrograph in a river basin is expressed by the combination of the conversion process from rainfall to runoff in divided sub-basins and the concentration process of the runoffs in a stream net. In a previous paper,[1] the conversion process of rainfall to runoff was studied using the detailed observational results obtained in the Ara experimental basin, and the physical runoff model was presented. Subsequently, the role of the stream net in the formation process of a flood hydrograph in a river basin was examined.

Based on these results, the authors present here a useful method of estimation of a flood hydrograph, which is available for local flood forecasting.

## 2. The runoff process in divided sub-basins

The physical runoff model of a divided sub-casin is shown in Fig. 1, developed in the previous paper.[1] The model was constituted by the observational results in the sub-basin, Umegatani, of the Ara experimental basin shown in Fig. 2. The slope element which consists of four strata as shown by Fig. 1(a) is proposed to represent the hydrological events observed at the actual slope. $L$ is initial loss of rain-water at each layer, $f$ is infiltration rate to each layer and $r_e$ is effective rainwater to each flow component. All flows along the slopes in Fig. 1(a) are governed by Darcy's law and go down to a channel. The output from the slope element is to become the input for the channel element together with the channel precipitation. The flow in the channel element is characterized by an open channel flow with lateral inflow which is distributed along the channel. Consequently, the runoff model of the sub-basin can be constituted as shown in Fig. 1(b). For the Ara experimental basin, all parameters in Fig. 1 could be determined by observational results of hydrological events and the relationship of water balance.

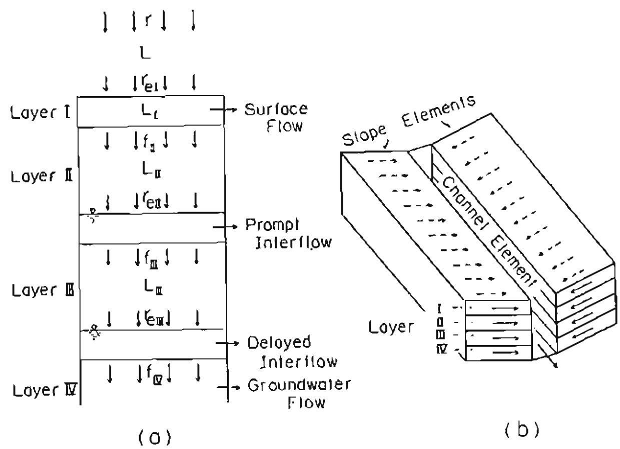


Fig. 1. The physical runoff model constituted by means of the observational results in the Ara experimental basin.

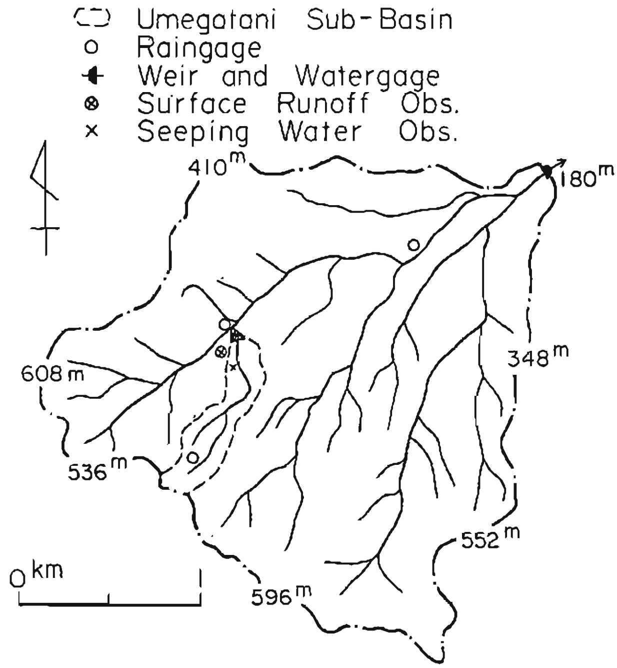


Fig. 2. The Ara experimental basin.

### 3. The role of the stream net in the formation process of a flood hydrograph

Generally, a river basin can be divided into many sub-basins which include only one link of a stream net as introduced by Shreve[8], if a specified sub-basin is regarded as that of the lowest order. It is very normal to understand that the outer divided sub-basins have no essential difference between each other in the sense of a runoff field. Under the assumption of a linear channel, the inner sub-basins have the additional function of transmitting the inflow from the adjacent upper sub-basin to the outlet of the inner sub-basin. That is, the inner sub-basins can be regarded as the fields with the same function as that of a outer sub-basin and the additional function of transmission of flood flow. After separating such a transmission function of the channel segment of higher order in an inner sub-basin, the runoff intensities from all divided sub-basins can be assumed approximately to be proportional to their drainage area.

Applying such assumptions of separation and proportionality to a watershed under consideration, a modified time-area-concentration diagram can be introduced. Fig. 3 is the modified time-area-concentration diagram for the Ara experimental basin.[1] This diagram is obtained on the basis of the stream order of Umegatani sub-basin, but some revision in the division of watershed were carried out in order to assure the assumption that the runoff intensity from a sub-basin is proportional to the drainage area. In this diagram, the ordinate shows the area-ratio of a sub-basin to the Umegatani sub-basin and the abscissa is the concentration time from the outlet of a sub-basin to the

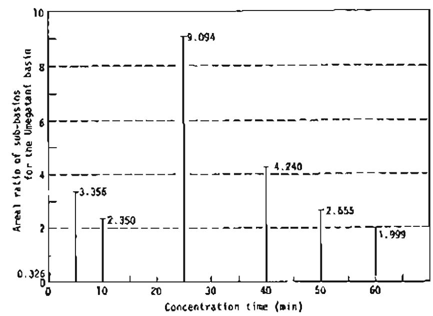


Fig. 3. The modified time-area-concentration diagram of the Ara experimental basin.

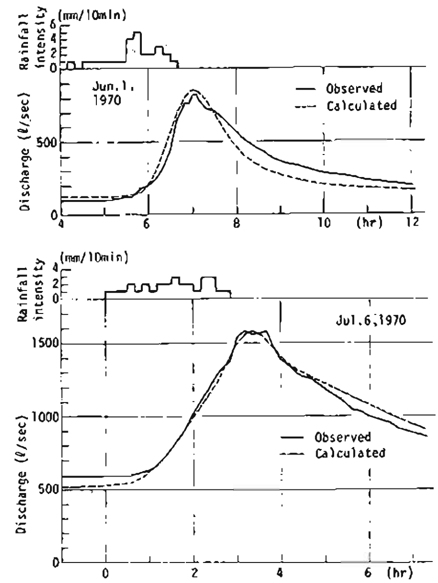


Fig. 4. Hydrographs calculated by convolution integral of the outflow from the Umegatani sub-basin and the modified time-area-concentration diagram.

outlet of the whole basin. The large values of ordinate in this diagram show the sum of area-ratios of sub-basins which have a nearly equal concentration time. The propagation speed is assumed to remain constant in the whole stream net.

The computational example of the resultant hydrograph from the whole basin by the use of Fig. 3 and the hydrograph from the Umegatani sub-basin is shown in Fig. 4. In spite of the simple assumptions of linear superposition and propagation, the computed and observed hydrographs show a good agreement.

The understanding described here with respect to the role of the stream net in the formation process of a hydrograph in a river basin is very significant and applicable in solving the important problem of flood forecasting.

## 4. Estimation of a flood hydrograph

Due to the results obtained above, the estimation of a flood hydrograph can be carried out as follows. 1) The river basin under consideration is divided into a suitable number of sub-basins. 2) The modified time-are-concentration diagram is drawn up. 3) The flood hydrograph from the specified sub-basin which is picked out from the divided sub-basins, is calculated. 4) The flood hydrograph at the outlet of the river basin is calculated by the convolution integral of the hydrograph from the specified sub-basin and the modified time-area-concentration diagram.

### 4-1. Modified time-area-concentration diagram

First of all, the river basin under consideration is divided into a suitable number of sub-basins. The division is carried out with a certain stream order, but, on the other hand, it is needed that the following conditions are satisfied. The necessary conditions of division are that the area of each divided sub-basin be practically equal to each other and that the number of sub-basins be more than 20. The first condition is necessary to assure the assumption that the runoff intensities from all divided sub-basins are proportional to their drainage areas. The second condition results from getting a good accuracy of computation, that is, the accuracy of the estimation of a flood hydrograph goes down when the number of sub-basins is less than 20. A very large number of sub-basins, however, is not practical.

The abscissa of the modified time-area-concentration diagram represents the propagation time of flood wave from a sub-basin outlet to the whole basin outlet. The propagation speed of a flood wave used in the decision of propagation time is assumed constant by the assumption of linear channel and decided by the past observed hydrographs. In the case where we can get past data at two locations, the propagation speed of a flood wave is calculated by the time difference of flood peaks at two locations. In the case where we can get past data only at one location, the propagation speed of a flood wave is estimated by $dQ/dA$ curve in which $A$ is the area of water cross section and $Q$ the discharge rate. If there is no observed data, the propagation speed is to be assumed.

Thus, the modified time-area-concentration diagram having the ordinate of a sub-basin area can be obtained.

If there is areal distribution of rainfall which is peculiar to the basin, the diagram must be drawn up separately for each main tributary beforehand.

### 4-2. Flood hydrograph from a divided sub-basin

The physical runoff model of a small mountainous basin was obtained as explained in Chapter 2. The calculation of a flood hydrograph from a divided sub-basin is to be done using such a physical runoff model. However, the runoff process on a slope is essentially non-linear and has the character that some of the rain-water remains in it and does not runoff into a channel. Therefore, much observational data is necessary

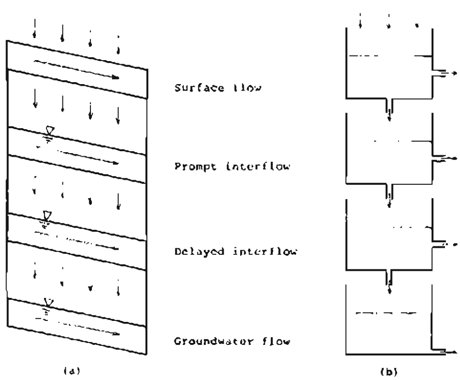


Fig. 5. Correspondence between the physical runoff model and the tank model.

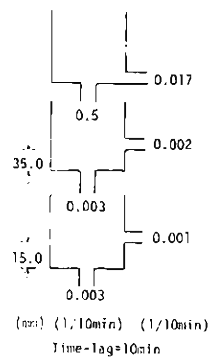


Fig. 6. The tank model used in the runoff calculation in the Umegatani sub-basin.

for the identification of parameters used in the physical runoff model. So, in this section, a runoff model which expresses approximately the physical process of runoff on mountain slope and whose parameters can be easily identified is introduced.

Fig. 5 shows the correspondence between the physical runoff model of the slope obtained in Chapter 2 and tank model proposed by Sugawara.[3] In the physical model, rain-water infiltrate from the upper layer to the lower layer, while soil moisture in the lower layer increases. When the soil moisture content at the vicinity of the bottom boundary of lower layer reaches saturation, the flow along the slope direction appears. That is, the physical runoff model consists of infiltration-storage process for the vertical direction and a propagation-transformation process for slope direction.

For the vertical process, the tank model shown in Fig. 5(b) can be considered to express approximately the infiltration-storage process in Fig. 5(a). In the tank model, the outflows from the outlets of the side wall and the bottom of a tank are assumed to be proportional to the height of water surface above the outlets. For the slope direction, it is needed in the tank model to express the propagation-transformation process in Fig. 5(a) by a set of conversion processes of the storage type as well as time-lag.

Fig. 7 shows the comparison between the hydrographs calculated by the runoff model shown in Fig. 1 and the hydrograph calculated by the tank model shown in Fig. 6. In Fig. 6, the first tank seems to represent the sum of the surface runoff and the runoff by channel precipitation. In the Ara experimental basin, the runoff component resulting from channel precipitation holds a dominant part of the runoff through the duration of rainfall, so that, the height of the outlet of the side wall corresponding to the initial rainfall loss in the first tank is put at 0. The second and third tanks seem to represent the

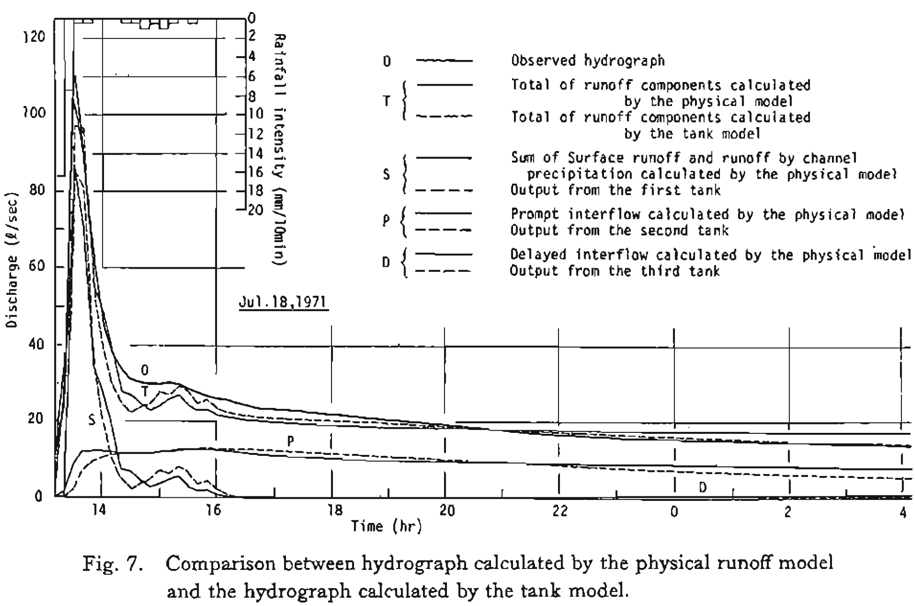


Fig. 7. Comparison between hydrograph calculated by the physical runoff model and the hydrograph calculated by the tank model.

prompt and delayed interflow, respectively. It is seen from the results of numerical calculations used to find the values of parameters by trials and errors method that, for the second and third tanks, the heights of outlets of the side walls become to be approximately equal to the initial losses of corresponding soil strata in the physical runoff model shown in Fig. 1. Then, after the heights of the outlets of the side walls of the second and third tanks set to be the same with the values of the initial losses in the physical runoff model, the values of the remaining parameters can be found out by trial and error. In order to represent the process of propagation-transformation for the slope direction, only the time-lag is introduced in the model, because the conversion process of storage type seems to give a small effect on the propagation-transformation process comparing with the propagation process. Thus, the tank model shown in Fig. 6 was obtained.

In Fig. 7, the hydrographs calculated by the physical model and the tank model show a good agreement even for each flow component, so that, the tank model will be able to be used instead of the physical runoff model.

The merits of using the tank model instead of the physical runoff model are that the parameters of the tank model can be identified relatively easily, as is done often in Japan in the estimation of long-term runoff, and the effective rain-waters are automatically determined in the process of calculation. Moreover, it seems that some parameters of the tank model directly correspond to the basin characteristics which appear in the physical runoff model.

On the basis of these reasons, the tank model has been employed to calculate a hydrograph from a divided sub-basin. The structure of the tank model used in this paper is shown in Fig. 8. The fourth tank corresponding to the groundwater runoff is not considered in this case, because a flood problem is under consideration. A flood hydrograph from divided sub-basin, which is calculated through the tank model shown in Fig. 8, has the dimension of mm/hr.

The flood hydrograph at the whole basin outlet can be obtained by the convolution integral of the hydrograph from sub-basin and the modified time-area-concentration diagram.

If there is areal distribution of rainfall as mentioned before, a hydrograph from each sub-area is calculated using the rainfall data which represents that of the area and the diagram drawn up separately for the each sub-area. The flood hydrograph at the whole basin outlet can be obtained by superposition of these hydrographs from the sub-areas.

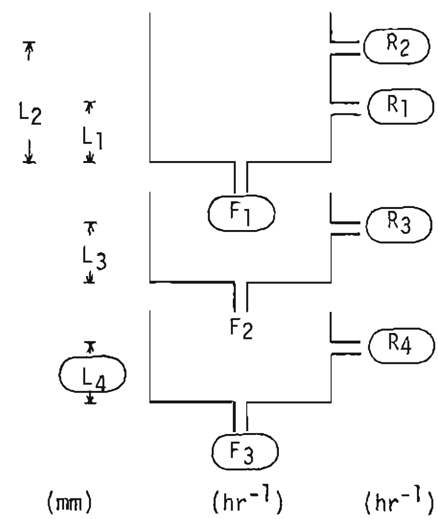


Fig. 8. The tank model used in the calculation of hydrograph from a divided sub-basin.

## 4-3. Examples of calculation

The method of calculation of flood hydrographs introduced in Section 4-1 and 4-2, that is, the runoff model for estimation of flood hydrographs, is applied to 5 actual river basins in Japan.[4] The values of parameters identified are listed in Table 1. and the results of calculations for identification are shown in Figs. 9, 10, 11, 12, 13. The parameters enclosed by a square are intended to become the same values for each river basin.

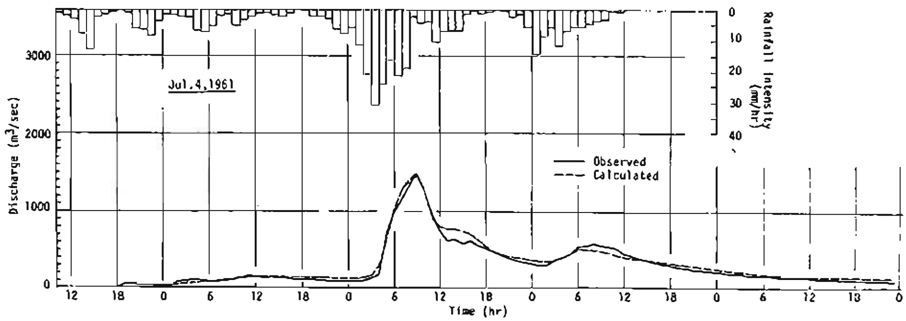


Fig. 9. Computational example of flood hydrograph at Kohira in River Chikugo.

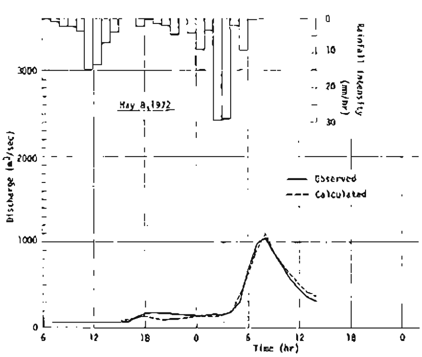


Fig. 10. Computational example of flood hydrograph at Minamihatajiki in River Basen.

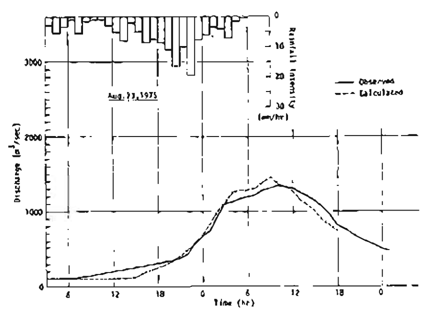

Fig. 11. Computational example of flood hydrograph at Kiyohorobashi in River Yuubari.

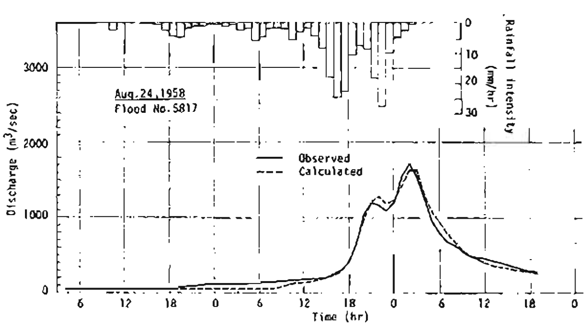


Fig. 12. Computational example of flood hydrograph at Tsukigase in River Kizu.

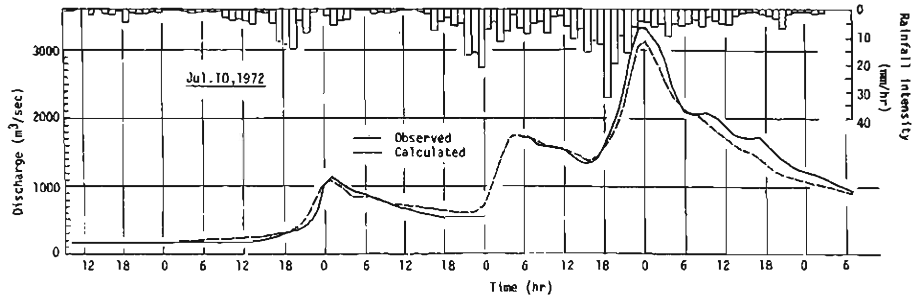


Fig. 13. Computational example of flood hydrograph at Mino in River Nagara.

This intention is to develop the synthetic method of calculation of a flood hydrograph, because the estimation of a flood hydrograph is often desired for a basin in which the discharge has not been measured in the past. The tank model has the character that the values of parameters vary with area of basin. Therefore, it is considered that the average area of divided sub-basin becomes nearly equal for these 5 basins, as shown in Table 1.

The time-lag TL are also listed in Table 1. These correspond to the propagation-transormation process for the slope direction as mentioned in Section 4-2.

## 4-4. Geological and geomorphological investigations

For the development of the synthetic method of calculation of a flood hydrograph, the parameters whose values are different for each basin should be correlated with the basin characteristics. These parameters are considered firstly to be connected with the geological character of basin. Fig. 14 shows the geological features of 5 basins and Table 2 shows the component ratio obtained on the basis of Fig. 14. By the comparison between Table 2 and the values of $L_1$, $L_2$, $L_3$ and $F_2$, the following relations appear.

The Palaeozoic strata is strong against water erosion and is little weathered. This characteristic is connected with the values of $L_3$ and $F_2$ in River Nagara. Usually, the amount of storage water in a basin of Granite during low flow period is between those in the basins of the Quaternary volcanic rock and of the Palaeozoic strata. This characteristic is connected with the value of $F_2$ in River Kizu. The Tertiary strata has a similar character to the Palaeozoic strata with respect to the amount to storage water during low flow period. So that, $L_3$ and $F_2$ in River Yuubari become the same as that in River Nagara. It seems that the small values of $L_1$ and $L_2$ in River Yuubari are determined by either the Tertiary or the Quaternary strata being used as paddy fields.

TL, in Table 1, is the time-lag which gives a shift of time for the output from the tank model, and relates to the propagation time of rain-water on a mountain slope. The propagation times is decided by $k \sin\theta/\gamma$ and $L_s$, in which $k$ is the permeability coefficient, $\theta$ the inclination angle of slope, $\gamma$ the effective void ratio and $L_s$ the length of slope. $k$ and $\gamma$ are governed by geological features, while on the other hand, $\theta$ and $L_s$ are geomorphological factors. The comparison between geomorphological factor $L_s/\sin\theta$ and TL for each river basin is shown in Table 3, in which $L_s$ is the average of

Table 1. The values of parameters identified for five river basins.

| Name | Drainage area ($km^2$) | Number of sub-basins | Average area of sub-basins ($km^2$) | $L_1$ (mm) | $L_2$ (mm) | $L_3$ (mm) | $L_4$ (mm) | $F_1$ ($hr^{-1}$) | $F_2$ ($hr^{-1}$) | $F_3$ ($hr^{-1}$) | $R_1$ ($hr^{-1}$) | $R_2$ ($hr^{-1}$) | $R_3$ ($hr^{-1}$) | $R_4$ ($hr^{-1}$) | TL (hr) | $\omega$ (m/sec) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| R. Chikugo Kohira | 533 | 37 | 14.4 | 40 | 75 | 15 | 15 | 0.12 | 0.08 | 0.01 | 0.10 | 0.15 | 0.05 | 0.01 | 0 | 3.78 |
| R. Basen Minamihatajiki | 664 | 40 | 16.6 | 30 | 60 | 15 | 15 | 0.12 | 0.08 | 0.01 | 0.10 | 0.15 | 0.05 | 0.01 | 1 | 4.18 (2.75) |
| R. Kizu Tsukigase | 615 | 35 | 17.6 | 15 | 60 | 15 | 15 | 0.12 | 0.05 | 0.01 | 0.10 | 0.15 | 0.05 | 0.01 | 1 | 4.00 |
| R. Nagara Mino | 1076 | 62 | 17.4 | 30 | 75 | 5 | 15 | 0.12 | 0.04 | 0.01 | 0.10 | 0.15 | 0.05 | 0.01 | 1 | 4.17 |
| R. Yuubari Kiyohorobashi | 685 (1115) | 40 | 17.1 | 15 | 40 | 5 | 15 | 0.12 | 0.04 | 0.01 | 0.10 | 0.15 | 0.05 | 0.01 | 2 | 4.0* 2.5* |

$\omega$ is propagation speed of flood wave, * assumption

Table 2. Component ratio of geological features in five river basins.

| Name of basin | Quaternary | Tertiary | Mesozoic | Palaeozoic | Volcanic rock | | Granite | Welded tuff | Volcanic ash |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Andesite | Rhyolite | | | |
| Kohira | 0.02 | 0.06 | — | — | 0.55 | — | — | 0.33 | 0.04 |
| Minamihatajiki | 0.10 | 0.06 | — | 0.05 | 0.30 | 0.33 | 0.16 | — | — |
| Tsukigase | 0.04 | 0.13 | — | 0.02 | 0.25 | — | 0.56 | — | — |
| Mino | 0.01 | — | 0.08 | 0.50 | 0.22 | 0.18 | 0.01 | — | — |
| Kiyohorobashi | 0.21 | 0.74 | 0.05 | — | — | — | — | — | — |

(area/2)/(channel length) calculated for each divided sub-basin, and $\sin\theta$ is the average of all divided sub-basins. In Table 3, there is no clear relation between $L_s/\sin\theta$ and TL. So that, TL seems to be mainly governed by geological features. The small

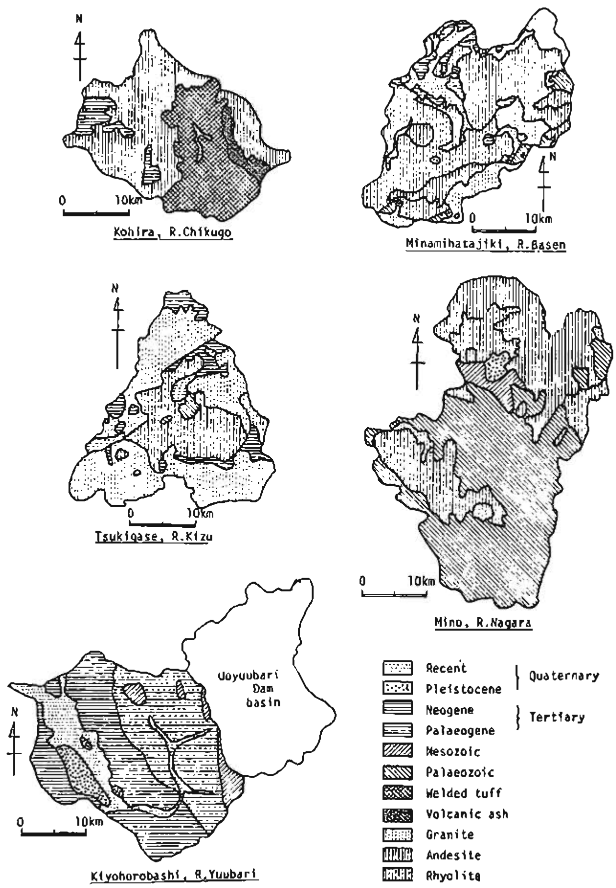


Fig. 14. Geological features of the five river basins.

Table 3. The geomorphological factors and TL.

| Name of basin | $L_s$ (Km) | $\sin\theta$ | $L_s/\sin\theta$ | TL (hr) |
|---|---|---|---|---|
| Kohira R. Chikugo | 2.25 | 0.313 | 7.19 | 0 |
| Minamihatajiki R. Basen | 3.03 | 0.227 | 13.3 | 1 |
| Tsukigase R. Kizu | 2.12 | 0.246 | 8.62 | 1 |
| Mino R. Nagara | 2.88 | 0.513 | 5.61 | 1 |
| Kiyohorobashi R. Yuubari | 2.33 | 0.213 | 10.9 | 2 |

value of TL in River Chikugo is connected with the character of the Welded tuff which is more porous than the others. The large value of TL in River Yuubari must be connected with the large areal ratio of paddy field.

### 4-5. Synthetic method of flood estimation

In order to verify the relations, obtained in the previous section, between the param-

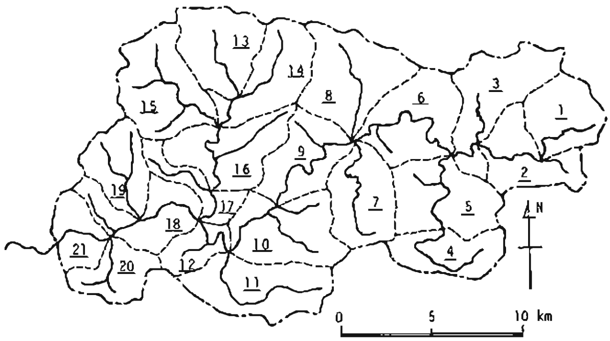


Fig. 15. Oono basin in River Yura.

eters listed in Table 1 and the geological features, the flood runoff estimations were carried out for several river basins. First, Oono basin was chosen as the basin of the Palaeozoic strata. Fig. 15 shows Oono basin (346 km²) of River Yura and division into 21 sub-basins. The whole basin of Oono is covered with the Palaeozoic strata. Fig. 16 shows the modified time-area-concentration diagram of the basin based on the division shown in Fig. 15 and on the assumption of propagation speed of flood

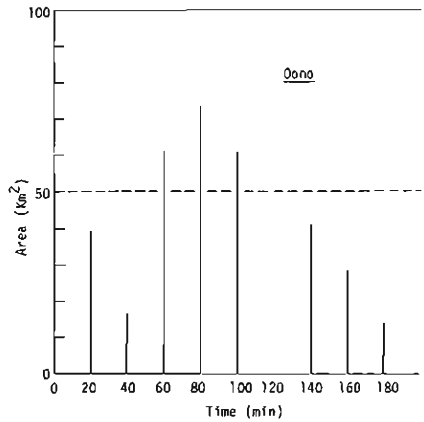


Fig. 16. The modified time-area-concentration diagram at Oono.

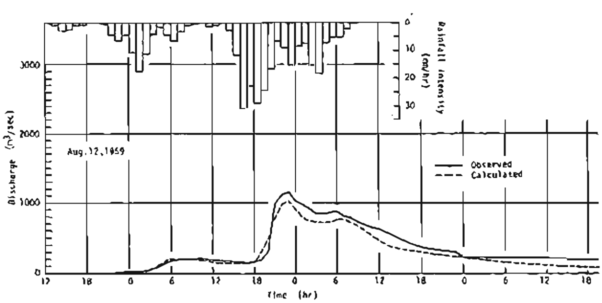


Fig. 17. Computational example of flood hydrograph at Oono.

wave in a channel to be 4.0 m/sec. The computational example of a flood hydrograph, using the values of parameters developed for River Nagara which is mainly covered with Palaeozoic strata, is shown in Fig. 17. The input data of rainfall are calculated using the arithmetic mean of observed results of raingauges in the basin. The calculated hydrograph agrees practically with the observed one.

Kurotsu basin was chosen as the Granite basin. Fig. 18 shows Kurotsu basin (189 km²) of River Daido whose geological feature is shown in Fig. 19. The modified time-area-concentration diagram of the basin, using the propagation speed being 4.0 m/sec, is given in Fig. 20. The computational example, using the same parameter values as River Kizu which is mainly covered with the Granite, is shown

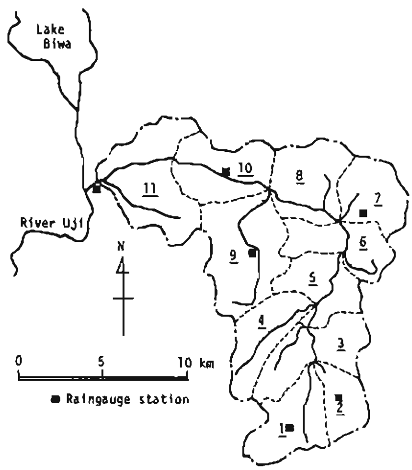


Fig. 18. Kurotsu basin in River Daido.

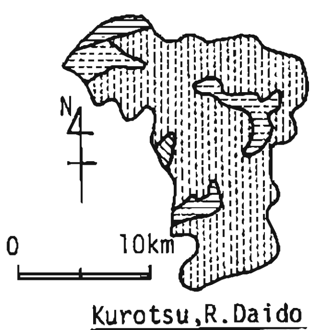


Fig. 19. Geological feature of Kurotsu basin.

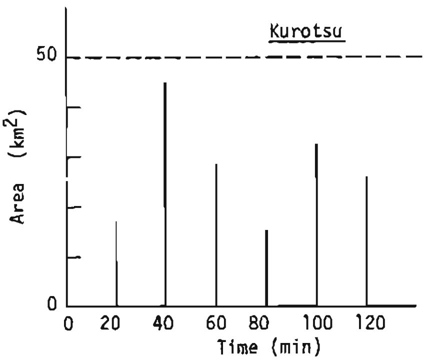


Fig. 20. The modified time-area-concentration diagram at Kurotsu.

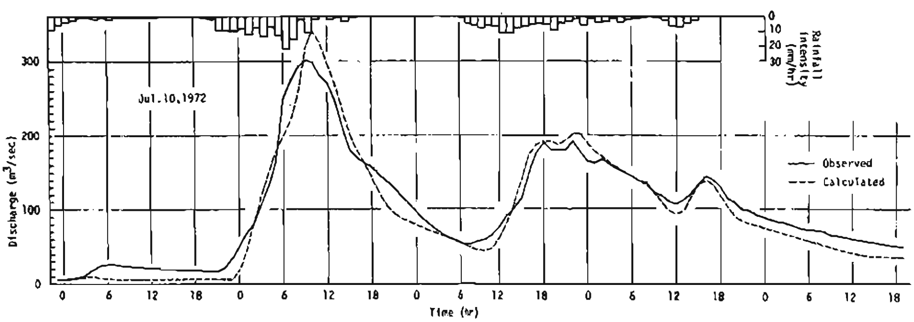


Fig. 21. Computational example of flood hydrograph at Kurotsu.

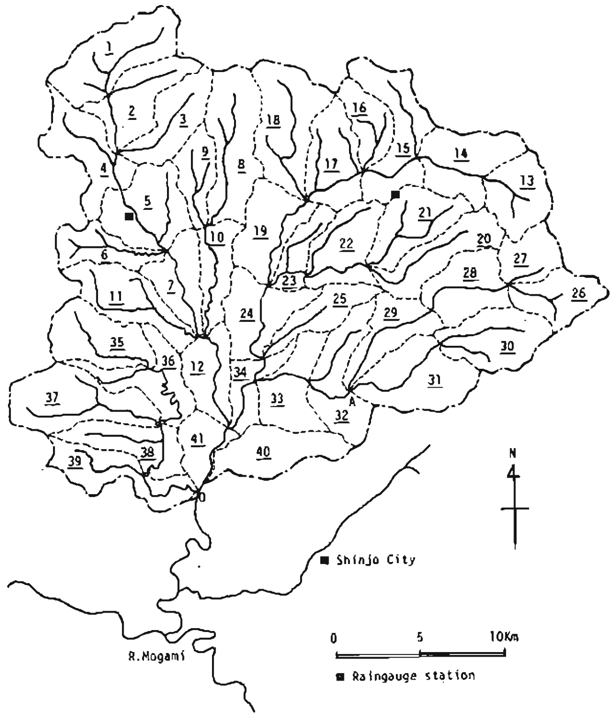


Fig. 22. Maki basin in River Mogami.

in Fig. 21. This case is not always suitable for verification, because the number of divided sub-basins is less than 20. The calculated hydrograph, however, agrees with the one actually observed.

Maki basin was chosen as the basin of the Tertiary strata. Fig. 22 shows Maki basin (618 km$^2$) of River Mogami. The distinctive feature of geology is that the Tertiary strata occupies 84% of the whole basin and the Quaternary occupies 13%, as shown in Fig. 23 and Table 4. The propagation speed of flood wave is assumed to be 4.0 m/sec in the mountain region and 2.5 m/sec in the channel section between A and 0 in Fig. 22, as done in River Yuubari. The obtained time-area-concentration diagram is shown in Fig. 24. The computational example of flood hydrograph, using the same values of parameters as River Yuubari which is mainly covered with the Tertiary strata, is shown in Fig. 25. The calculated hydrograph agrees roughly

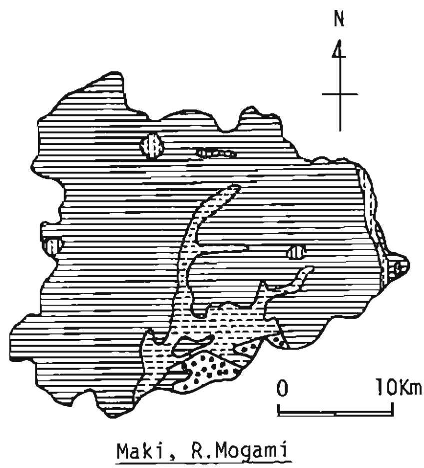


Fig. 23. Geological feature of Maki basin.

with the observed one.

Moreover, River Chikugo and River Basen have quite similar parameter values. So that, it will be reasonable to consider that these values represent the character of the basin of Volcanic rock.

Due to these computational examples for the verification described above, the synthetic method of estimation of a flood hydrograph can be developed. Table 5 is obtained for the case where the average area of divided sub-basins is 15–18 km$^2$ as shown in Table 1 and Table 4. TL of 0 in the Volcanic rock corresponds to the basin of the Welded tuff. In the case where the total area of the Tertiary and the Quaternary occupies almost all parts of the basin, TL becomes 2 as seen in the computational examples of River Yuubari and River Mogami.

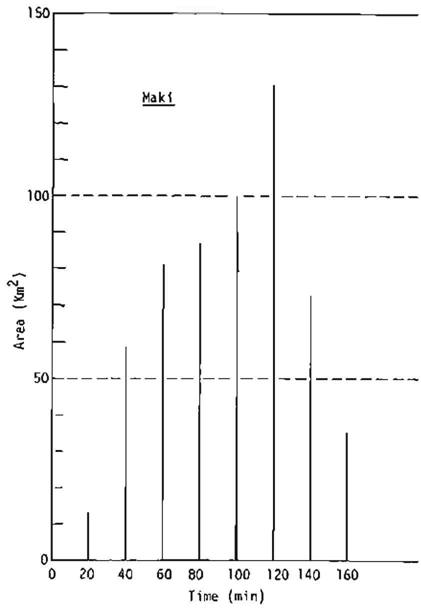


Fig. 24. The modified time-area-concentration diagram at Maki.

It should be noticed that Table 5 is available for the case where the average area of sub-basins is 15–18 km$^2$, and that the method developed here is used only for a mountain region for support of the assumption of linear channel. It is also important to recognize that the results using Table 5 give the first approximations, so that, the values of parameters should be adjusted after getting many observations of hydrographs.

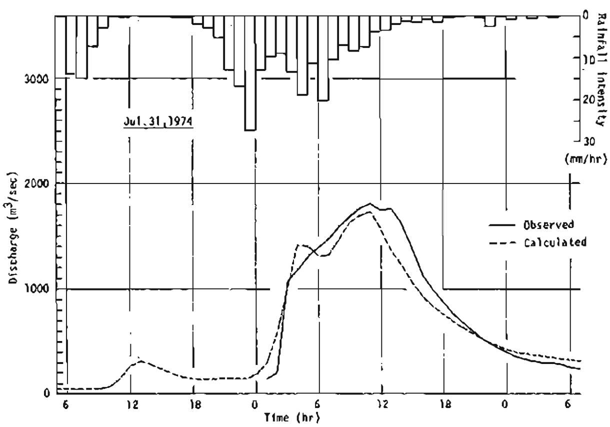


Fig. 25. Computational example of flood hydrograph at Maki.

Table 4. The basins used in the verification.

| Name of basin | Drainage area ($Km^2$) | Number of sub-basins | Average area of sub-basins ($Km^2$) | Geological features (ratio) | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | Quaternary | Tertiary | Palaeozoic | Andesite Rhyolite | Granite |
| Oono R. Yura | 346 | 21 | 16.5 | — | — | 1.0 | — | — |
| Kurotsu R. Daido | 189 | 11 | 17.2 | 0.12 | 0.06 | 0.01 | — | 0.81 |
| Maki R. Mogami | 618 | 41 | 15.1 | 0.13 | 0.84 | — | 0.01 | 0.02 |

Table 5. The synthetic parameters classified by geological features.

| Geological feature of basin | $L_1$ (mm) | $L_2$ (mm) | $L_3$ (mm) | $L_4$ (mm) | $F_1$ ($hr^{-1}$) | $F_2$ ($hr^{-1}$) | $F_3$ ($hr^{-1}$) | $R_1$ ($hr^{-1}$) | $R_2$ ($hr^{-1}$) | $R_3$ ($hr^{-1}$) | $R_4$ ($hr^{-1}$) | TL (hr) | $\omega$ (m/sec) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Volcanic rock | 30–40 | 60–75 | 15 | 15 | 0.12 | 0.08 | 0.01 | 0.10 | 0.15 | 0.05 | 0.01 | 1<br>0* | 4.0 |
| Granite | 15 | 60 | 15 | 15 | 0.12 | 0.05 | 0.01 | 0.10 | 0.15 | 0.05 | 0.01 | 1 | 4.0 |
| Palaeozoic | 30 | 75 | 5 | 15 | 0.12 | 0.04 | 0.01 | 0.10 | 0.15 | 0.05 | 0.01 | 1 | 4.0 |
| Tertiary & Quaternary | 15 | 40 | 5 | 15 | 0.12 | 0.04 | 0.01 | 0.10 | 0.15 | 0.05 | 0.01 | 2 | 4.0 |

* Welded tuff

## 5. Conclusions

As one of the studies concerning the formation process of a flood hydrograph in a river basin, the synthetic method of flood estimation is described. The conclusive remarks are as follows.

1) The formation process of a flood hydrograph in a river basin is expressed by combination of the conversion process from rainfall to runoff in divided sub-basins and the concentration process of the runoffs in a stream net.
2) The tank model is employed to calculate a hydrograph from a divided sub-basin in the light of observational results in the experimental basin. The merits of using the tank model instead of the physical runoff model are that the parameters of the tank model can be identified relatively easily and the effective rain-water are automatically determined in the process of calculation. Moreover, it seems that some parameters of the tank model directly correspond to the parameters of the physical runoff model developed by the authors.
3) The synthetic method of flood estimation using the tank model and the modified time-area-concentration diagram can be developed. The synthetic parameters classified by geological features is listed in Table 5. Accordingly, this approach is available as a successful runoff model for flood forecasting.

## References

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