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AN EVALUATION SYSTEM FOR RUNOFF LOADING FROM A SMALL DRAINAGE BASIN - IN VIEW OF RUNOFF COMPONENT

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ABSTRACT; An evaluation of runoff loading including water quality from drainage basin is an essential tool for the water environmental management. This study is carried out from a standpoint in which the two runoff components(surface-inter flow and groundwater) are different in loading of water quality. This paper examines an evaluation for runoff loading from a small drainage basin as viewed from runoff components. The contents are as follows: (1) The relationship between total runoff and observed water quality with respect to TP, TN, and pH at non-rainfall time is outlined (2) By using the whole observed data at both non-rainfall and rainfall times, the relationship between the hydrograph of runoff components separated by one-side numerical filter and the above water qualities is considered (3) The relationship between the separated runoff components and the qualities separated by the components are mentioned. And an evaluation of water quality as viewed from the runoff components is conducted.

KEY WORDS; evaluation of water quality; water resource management; component separation model

1. Introduction

Planning and managing for water environment in the urban and mountain districts, it is properly needed not only to control runoff, but also to forecast the inflow to rivers on a short term period. At that time, the inflow to rivers is closely related to a diffuse pollution. Therfore, if the storm inflow can be predicted, the management of the water quality for catchment areas and policy for environmental conservation etc. are possible.

For that, better analysis tools are required to understand the runoff process and storm prediction. At present, a strict/deterministic formulation of a model for runoff analysis has not yet been established sufficiently because of the following reasons; (1) uncertainty of the spatial/time distribution of quantitative input/output in the hydrological system including various factors such as geographical and geological features in the inner part of basins; (2) difficulty of formulation of the nonlinear process contributing to the hydrological circulation in a basin; (3) complex process involved in the time-varying nature of developing urban basins is not well understood.

So far, a variety of models with respect to runoff analysis have been proposed. These models can be classified into two categories[1)2)]. The basic difference between the two categories is that one is represented by one-component system(linear form: rational method, unit hydrograph and AR model etc.,; nonlinear form: storage function method, Volterra-Wiener model, and kinematic model etc.), whereas the other is represented by multi-component system (storm water-storage function method, tank model and component separation AR method etc.) based on reliability of input data and the presence of appropriate parameters of the drainage basin.

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With respect to conduct inflow prediction for runoff, we consider that it is first necessary to grasp the characteristics in each small catchment area, and after that to grasp the whole characteristics are also possible by means of integrating them. Therefore, examination of short-term runoff prediction for grasping the above characteristics is very important as a first stage.

In this study, we use the one-side numerical filter for separating the runoff components (surface-inter flow and groundwater). The model is applied to the upper basin including mountain and urban districts in the Neyagawa River in the east part of Osaka, Japan where time lag for runoff loading seems to be minor effect because of the small catchment area.

If the prediction of those two components is possible, by using the relationship between the water quality and separated runoff, it is possible to predict the loading of water quality. Therefore, by accumulating the data including the various kinds of relationship, it is possible to manage the water quality from the basin. The possibility of component separation have been examined by Hino, M. et al[3)4)5)] and our studies[6)7)8)].

Based on the idea mentioned above, this study is carried out from a standpoint in which the two runoff components are different in loading of water quality. This paper examines an evaluation for runoff loading from a small drainage basin as viewed from runoff components.

2. Separation of runoff components

The feature of this model is to separate the runoff components from the river drainage basin into two components(groundwater, surface-inter flow) or into three components(groundwater, inter flow, and surface flow).

In general, when plotting the relationship between $\ln(Q_0/Q)$ and time τ concerning the runoff recession, the hydrograph after the peak discharge, it is known that the shape of hydrograph consists of two or three straight line segments which have reading obtainable slopes (where Q_0: peak discharge, Q: discharge at the time τ). In the case which consists of two straight lines, the section of the first straight line corresponds to the part of the recession of the surface-inter flow, and the section of the second to the groundwater flow Q'. Therefore, the slope of the second straight line yields the recession of groundwater flow. Now assuming that the discharge of the intersection point is Q_0', their relationships are as follows:

$$\ln(Q_0'/Q') = -\alpha t, \quad \text{or} \quad Q' = Q_0'\exp(-\alpha t) = Q_0'\exp(-t/Tc) \tag{1}$$

where α = coefficient of the groundwater flow recession
Tc = time constant for the groundwater flow recession, $Tc = 1/\alpha$.

Similarly, the coefficient of the surface-inter flow component can be determined as the slope of straight line which corresponds to the discharge from which the groundwater flow component is subtracted. The separation of components is carried out in this study by using the filter frequency characteristics of a "dashpot" system where we determine the value of parameter δ. In general, the value of parameter δ is $\geqq 2$ in the case of groundwater flow. Next, by using the one-side numerical filter shown in Eq.(2) for time varying input which shows the stage before the present time, the one-side low frequency numerical filter $W(k) = W(k\Delta\tau)$ represented by the scattering indication at $\Delta\tau$ intervals is set up. Using the observed total discharge Q(t), the groundwater flow component $Q'(t)$ may be separated[2)].

$$W(\tau) = C_0 \exp(-C_1 \tau / 2) \cdot \sinh(\sqrt{C_1^2/4 - C_0} \cdot \tau) / \sqrt{C_1^2/4 - C_0} \quad (\tau \geqq 0)$$
$$W(\tau) = 0 \quad (\tau < 0) \tag{2}$$

$$C_0 = (\delta / Tc)^2 \tag{3}$$

$$C_1 = \delta^2 / Tc \tag{4}$$

$$Q'(t) = \alpha \Sigma W(k) Q(t-k) \tag{5}$$

where $Q'(t)$: groundwater flow, k: 1, 2, 3, ···, p, α : coefficient of weight

By taking away $Q'(t)$ from the total flow $Q(t)$, the surface-inter flow component $Q''(t)$ can be determined.

$$Q''(t) = Q(t) - Q'(t) \quad (\geqq 0) \tag{6}$$

Furthermore, if the rainfall intensity is very high, we might separate the flow into three components.

3. Model application to drainage basin

3.1 Description of basin and observed data

The location of the basin is shown in Fig.1. The basin is drained by small channel which is located in the east part of Osaka, Japan. The length of the channel is 2.385 km, and the catchment area is 1.45 km². The gradient of the watercourse at the runoff gauging station is 1/320. The channel at the gaging station is concrete lined rectangular and 5.0 m wide, which has a roughness coefficient of 0.015. As the basin is relatively small, we include the concentration process and propagation time in the river stream flow in the model. In the case in which we have plural rainfall observation stations, the area mean rainfall was used by simply averaging the rainfall at the same time. About 72 % of the catchment area is almost covered with both bushes and a small part of the pine trees, and the other part comprises of urban area (≒ 11 %), field area (≒ 7 %), golf course (≒ 6 %) and road area (≒ 5 %). In this study, we select Site k_1 as a stream gaging station.

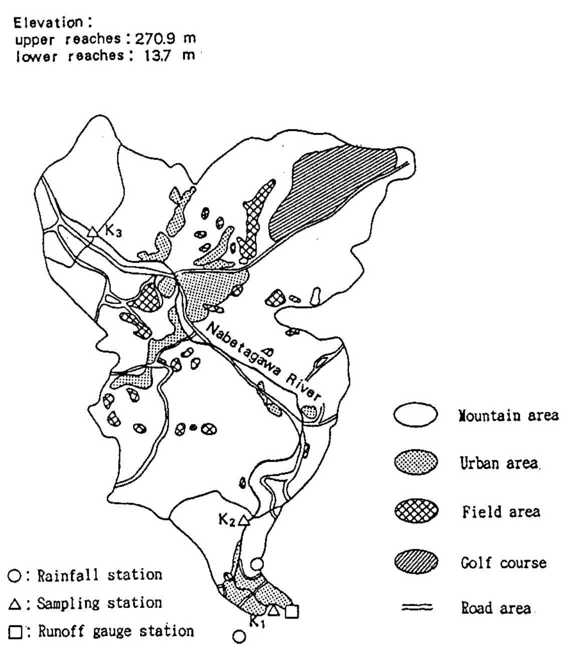

Fig. 1 Study Basin and Sampling Site.

3.2 Results and discussion

As the catchment area in this study is relatively small, the runoff process and the propagation time are collectively included in the model. For intensity of rainfall and runoff prediction, an interval of 15 min was set considering the attainment time of the stormwater observed at Site K_1.

The runoff separation by numerical filtering, together with both time-variant rainfall and the change of water quality, is shown in Fig.2. It can be seen from the figure that, the behavior of the water qualitis are quite similar to the hydrograph of the total runoff, and however, TN is quite a bit different from other two qualities after the the peak of discharge.

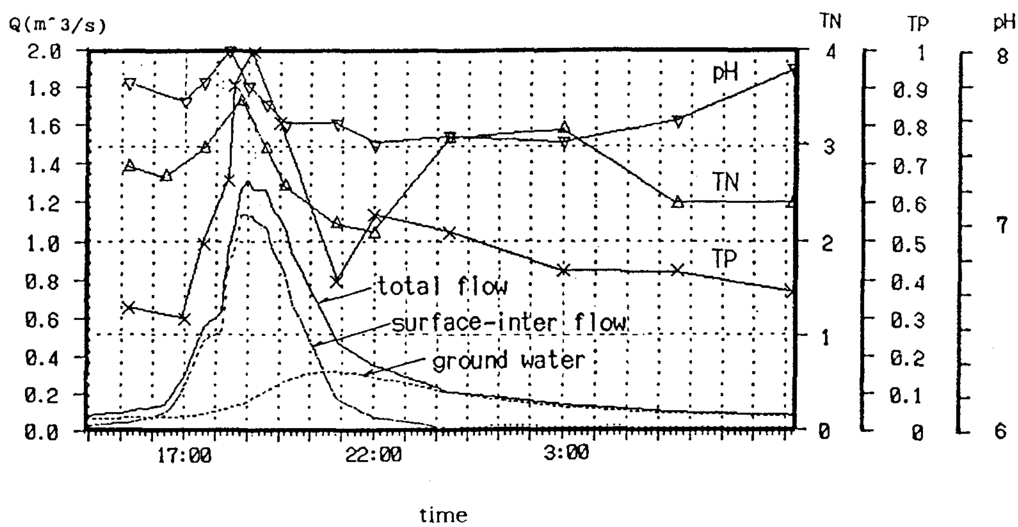

Fig. 2 Runoff Separation by Numerical Filter and Observed Water Qualities (Example).

Fig.3 shows the relationship between the groundwater discharge Qg and the water quality as indicated by TPg and that between the surface-inter flow Qs and the water quality TPs. Moreover, Fig.4 show both Qg-TNg and Qs-TNs, while in Fig.5 both Qg-pHg and Qs-pHs. It is considered from Figs.3~5 that as TP/pH are governed by the discharge. This is due to the influence by the surface water, and pH is influenced by the rainfall having a high acidity (acid rain). On the other hand, TN is not changed so much in comparison with the other two qualities. And in Fig.2, we can see the phenomenon in which after the peak of the TN, the value increases again. It is clear from Fig.4 that this is due to the presence of the increase of groundwater component[9).

The relationships between Qg and TPg/TNg/pHg were obtained under non-rainfall condition, and the relationship between Qs and TPs/TNs/pHs are determined based on the following relations.

$$Qt \cdot TPt = Qg \cdot TPg + Qs \cdot TPs \qquad (7)$$

$$Qt \cdot TNt = Qg \cdot TNg + Qs \cdot TNs \qquad (8)$$

$$Qt \cdot pHt = Qg \cdot pHg + Qs \cdot pHs \qquad (9)$$

where

Qt: total discharge

TPt,TNt and pHt: observed water quality corresponding to the sampling discharge Qt

In this study, we can see more clearly the relationship between the discharge Q and the water qualities in view of runoff component. Looking the water qualities separated by the runoff components, it is understood that the differences of the runoff characteristics are clear. Therefore, if the run-off components can be predicted, the characteristics of the polluted distinction in the drainage basin may also be able to evaluated.

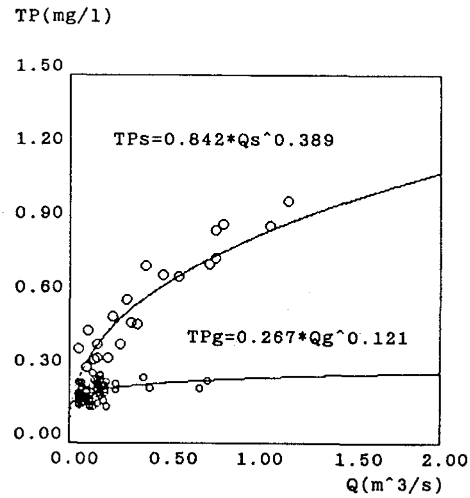

Fig. 3 Relationship between Runoff Components Qs,Qg and Water Qualities TPs,TPg.

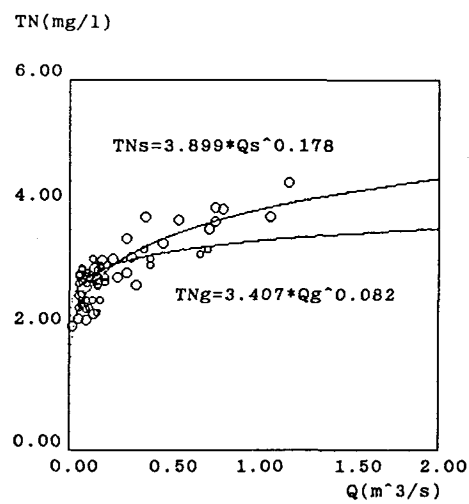

Fig. 4 Relationship between Runoff Components Qs,Qg and Water Qualities TNs,TNg.

4.Conclusion

From the results of the observation and analysis in the examined basin, the following conclusions are obtained:

(1) Relationship between runoff components and water quality exists, and, especially for TP and pH have a marked tendency for the relationship.

(2) It is able to forecast the loading of water qualiy by means of prediction of runoff components.

In order to examine the total environmental system, a further study for water quality due to seasonal change in vegetation, rainfall, point source and so on in the basin is required.

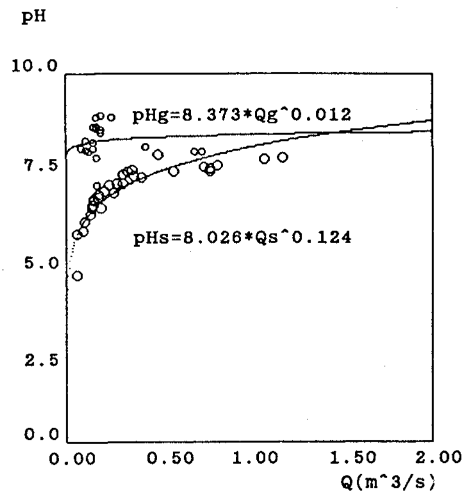

Fig.5 Relationship between Runoff Components Qs,Qg and Water Qualities pHs,pHg.

References

1)Murota, A., et al: River Engineering, Gihodo Publishing Co., 1988.

2)Hino, M. et al: Suimon Ryushutsu Kaiseki(Hydrological Runoff Analysis), Morikita Publishing Co., Tokyo, 1985.

3)Hino, M. and Chi Hong Kim: "A study on flood forecasting by the separation AR method and kalman filter" , Proc. of JSCE, No.351/11-2, 1984

4)Hino, M. et al: Numerical Forecast of Flood - A First Step -, Morikita Publishing Co., Tokyo, 1989.

5)Hino, M.: "Practice in online flood prediction by a desk-top personal computer", Proc. 31st Japanese Conf. on Hydraulics, 1987.

6)Hiratsuka, A.et al: "Runoff analysis using a component separation method -In view of both quantity and quality of the runoff component" , Proc. 6th Int. Conf. on Urban Storm Drainage, 1993.

7)Shigemitsu, S. et al: "Numerical forecasting of storm runoff by using component separation AR method" , Journal of Osaka Sangyo Univ., Natural Sciences, No.95, 1994.

8)Hiratsuka, A. et al: "A study on flood forecasting using a component separation method" , Proc. Int. Conf. on Modelling, Testing & Monitoring for Hydro Powerplants, 1994.

9)K.E.Bencala, et al: "Modelling within the Stream-catchment Continuum", Modelling Change in Environmental Systems, John Wiley & Sons Ltd, 1993.