THE ANALYSIS OF RUNOFF FROM TWO SMALL CATCHMENTS IN GRANITIC HILLY MOUNTAINS

Aritsune TAKEI, Sumiji KOBASHI and Yoshihiro FUKUSHIMA
Professor, Associate Professor, Associate, Department of Forestry, Faculty of Agriculture, Kyoto University, Kyoto, Japan

synopsis

We have made observations on the hydrological conditions in two small catchments, those are located in the south east direction of Lake Biwa, and consisted of weathered granite. They have 2.66 ha and 5.99 ha, respectively, and are aparted about 4 km from each other. We intended to clarify the influences of physiographical and biological conditions on the water and sediment yields of small catchments.

In this paper, we discussed on the long term characteristic of runoff, and the estimation of direct runoff from separated storm. The principal results are as follows.

1. The one catchment (Kawamukai) has 50-55% in annual runoff ratio, and the other (Kiryu) has an inclination to produce more runoff. Kawamukai has steep topography and poor vegetation in comparison with Kiryu.

2. The direct runoff in separated storm is less than 30% of total precipitation of the duration, in both catchments.

3. The characteristic of base flow in terms of the time to reduce the rate by half is 13.5 days in Kawamukai, and 16.4 days in Kiryu, respectively.

4. The volume of sediment yield is $15.7 \text{ m}^3/\text{km}^2/\text{year}$ in Kawamukai and $2.8 \text{ m}^3/\text{km}^2/\text{year}$ in Kiryu.

5. The estimation of storm runoff hydrograph from small catchments corresponding to hyetograph is fairly satisfied by the application of Sugawara's tank-model, and characteristic of the used model must to give the hydrological expression of the catchment within the scope of this circumstance.

résumé

Nous avons observé aux conditions hydrologiques en deux petits bassins, qui sont situés du sud-est du Lac Biwa, et faits du granit desagréré. Un bassin est 2.66 ha. carrés, et l'autre est 5.99 ha. carrés. L'un est éloigné de 4 km. depuis l'autre. Nous voulons clarifier les influences des conditions geomorphologiques et biologiques sur le volume d'eau et de sediment en deux bassins.

Dans ce traite, nous discutons les particularités du volume d'eau que nous avons observé pendant de longues années et la supputation du volume d'eau direct par chaque orage. Les résultats principaux sont ainsi qu'il suit.

1. Le coefficient du volume d'eau en Kawamukai (un bassin) est 50-55 %, et il a de l'inclination pour être plus grand en Kiryu (l'autre bassin). Les particularités geomorphologiques en Kawamukai sont qu'il est plus raide et plus faible qu'en Kiryu.

2. Le volume d'eau direct par chaque orage est moins de 30 % de la précipitation totale durant tout temps en tous les deux.


4. Le volume de sediment est $15.7 \text{ m}^3/\text{km}^2/\text{an}$ en Kawamukai, et $2.8 \text{ m}^3/\text{km}^2/\text{an}$ en Kiryu.

5. Le calcul du hydrographe du volume d'eau par les orages correspondant à hyetographe s'accorde avec l'application de Sugawara Modèle du Réservoir. Nous en concluons que le modèle usagé est disponible en hydrology en des circonstances de ces bassins.
We have two observation plots in the southern part of Shiga Prefecture. The location of these plots is about 35 degrees of north latitude and 136 degrees of east longitude, and the region is formed by hilly mountains of granite. The one, Kiryu observation catchment was selected for the investigations on the circuration of water and minerals in forest land, in 1968. The other, Kawamukai observation catchment is about 4 km distant from the former plot to the south-west direction. This catchment was selected for the observation of sediment yield, by Ministry of Construction, in 1962.

Although both catchments are consisted of similar geology, there are significant differences in the type of vegetation. In Kiryu, the catchment is almost covered with fairly well grown forest of Pinus densiflora, Chamaecyparis obtusa etc.. On the other hand, the growth of vegetation in Kawamukai is poor, notwithstanding the execution of the special afforestation for erosion control. Though upper vegetation is predominated by Pinus Thunbergii and Pinus densiflora, the portion of well grown lower vegetation composed of broad leaf trees is only 4.1 %, and almost portion of remains is occupied by poor or scarce lower vegetation. And then, the area of bare land or exposed rock bed forms as much as 7.4 %.

The dimensions of both catchments are shown in TABLE 1. The altitude of catchments is 190-255 m in Kiryu, and 175-220 m in Kawamukai, and they are regarded as the same. The direction of catchments is running to north north-west in Kiryu, and south-west in Kawamukai respectively. The average inclination of slopes is steeper in Kawamukai than in Kiryu. The factor of basin shape is greater in Kawamukai than in Kiryu, and the fact shows that the basin shape of former is wider than the latter. Yearly averages of temperature in the table are the values of 1973, since the values are regarded as the common value for both plots, on account of the fact that the each record in 1968-1971 is similar to it in 1973. The reason why Kawamukai plot has higher temperature than Kiryu plot, is considered to be the effect of catchment direction.

Annual precipitations are nearly the same in both plots. Explaining in detail, the tendency that Kiryu has slightly larger values than Kawamukai, is recognized in annual amount and also in monthly amount. The range of variation are fairly large, 1,469-1,989 mm in Kiryu and 1,415-1,969 mm in Kawamukai respectively, during the period of 1969-1973. Heavy rains are observed generally in rainy season of Jun. to Jul., and typhoon season of Aug. to Sep. in this region.

1. Water balance

Runoff is measured by rectangular notch in both catchments. The fluctuations of coefficient of annual runoff are shown in Fig.1. They show the range of 60.4-77.0 % and the average of 70.8 % in Kiryu during 4 years from 1970 to 1973, and the range of 42.9-59.1 % and the average of 55.0 % in Kawamukai during 11 years from 1963 to 1973. The former has higher coefficient of runoff and larger variation range than the latter. Coefficient of annual runoff is passably steady in Kawamukai as shown in the figure. The discharge loss (precipitation minus runoff) are 523.4 mm/year and 730.6 mm/year on the average, in both catchments. The discharge loss of the latter is bigger by 200 mm/year than the former's, in spite of poor vegetation cover. Although we were unable to assign the causes of the phenomenon, it was supposed that they were attributed to uncertained local geology or topography. The values of Potential Evapotranspiration calculated from Thornthwaite's method adopting the monthly temperature in 1973, were 718 mm in Kiryu and 769 mm in Kawamukai. The result gives too much value comparing with the observed amount in Kiryu, while Kawamukai's data is reasonable.

Monthly water balances in 1973 are summerized in TABLE 2. Potential Evapotranspiration of Thornthwaite's method is shown in the table as a comparison, as yet we could not interpret whether the method was suitable or not for this region. In either case, it is certain that the moisture deficit has occurred in July and August of this year. We were unable to point out any individuality of both catchments within the scopes of the data.

2. Characteristic of base flow

In order to find the characteristic of base flow, we have drown the re-
cession curves of hydrograph in the durations of no precipitation, on loga­
rithmic paper. Then, we measured the period to reduce the rate by half (T),
within the range of which regarded as a straight line, the discharge at the
beginning of the range, and the continuing duration (in days) of straight
recession. Fig.2 shows the standard recession curves in summer (Jun.-Aug.)
and in winter (Dec.-Mar.), which were obtained from the data of their duration
exceeded 6 days.

The figure shows that the recession curve is expressed as the exponential
curve, which has a fixed number in each season (summer or winter), and each
site. The difference between seasons is remarkable in Kiryu, while it is less
significant in Kawamukai. In summer, both catchments have nearly the same
curve, particularly within the range of 1.2-2.8 mm in discharge rate, and the
period (T) becomes short in both catchments. In winter, the period (T) becomes
very long in Kiryu, but the difference between seasons in Kawamukai is slight,
especially when the rate was less than 1 mm.

The causes why such a difference is given between both catchments, will
be attributed partially to the vegetation covers and their evapotranspiration
abilities, but we should not ignore the situation that the storage mechanism
of base flow is essentially the subject for a future study.

3. Sediment yield
Sediment yield from the catchment was measured at the setting basin in
the upstream of gauging weir. The sediment is measured by volume once a day
in Kawamukai, and at irregular intervals in Kiryu;
Annual sediment yield in Kiryu was 2.8 m³/km²/year on the average of 7
years during 1968-1974, and 15.7 m³/km²/year on the average of 13 years during
the amount of 8.2 m³/km²/year, then the latter yielded more sediment than the
former obviously. The causes why the latter yields much sediment are regarded
as the effect of poor vegetation and steep topography in Kawamukai. Yielded
sediment was supposed to be washed out from stream bed in the catchment,
because no landslide and no remarkable surface erosion have occured in this
observation period. Since we could not find any notable change in the situation of sediment in streams within the period, almost equivalent amount of sediment produced in slopes might be washed out through streams, in ordinary years, if
they were in a state of equilibrium.

On the other hand, annual sediment yields were not distributed uniformly
through the period, but had a wide variation from year to year. For example, the maximum amount was 2.7 times of the average value (15.7 m³), and the minimum
amount was 1/17 of the average, during the period of 1962-1974. Furthermore,
the 48 % of total amount during 1962-1971 have been yielded on the occasions of
only four heavy rains, which had rainfall intensities over than 30 mm/hr.

We could point out the fairly well correlations between sediment yield and
total rainfall or total runoff in some fixed duration time. For example, Fig.3
shows the correlation between sediment yield in a duration of rainfall and the
runoff amount in 24 hr.. It seems to be the best expression of the relations,
because the other cases, in which were used the rainfall or runoff amount
within some different duration time for abscissa, showed more scattered
distributions of data. In this case, the points represented as black circles
are closely corrlative to the runoff amount. The points of empty circles are
containing the extraordinary example, which are explained by their exceptional
circumstances. Then, it is satisfactory to consider that the yielded sediment
must be washed out mainly from stream bed.

4. Analysis of storm runoff
We estimated the hydrograph of storm runoff by the application of Sugawara-
's Tank-model. The calculations have been done from the begining of abrupt
ascending of hydrograph, to the time when the direct runoff was vanished (2-3
hr. after the end of rainfall). We examined to make the model valid in every
cases as well as possible. The results are as follows.
1) The model is satisfied by tanks of less than three stories (Fig.4).
The capacities of holes (value of B) are 0.1 for the upmost story, 0.05 for
4.4

the second story and 0.03 for the lowest story. They are the same in both catchments, and valid for almost every storms. This is that the fundamental character of infiltration in both catchmen does not differ with each other essentially.

2) In Kiryu, an almost universal model can be fitted through every storms. The following constants are given, namely $a_{11} = 0.02$, $h_{11} = 4$ for upmost story, $a_{21} = 0.02$, $h_{21} = 5$ for second story. The fact that the universal model was fitted, may be contributed to the influences of well grown forest bringing the steady runoff (Fig.5,6). In these figures, the characteristic values ($a$ or $h$) of models using at the calculations are shown in TABLE 3.

3) In Kawamukai, it is difficult to fit an universal model, because of the wide fluctuation of $a$ and $h$ values from storm to storm. The cause why such a variation appears is supposed that, the circumstances affecting to runoff were different from time to time, owing to the poor vegetation and devastated land surface.

4) In comparison with each other, Kawamukai catchment brings the larger peak flow and coefficient of total direct runoff than Kiryu, and these tendencies are increasing according to the increasing of rainfall intensity.

From the fact described above, we may conclude that the Tank-model is satisfactory for the analysis of storm runoff in small catchment.
Fig. 1. Variation of coefficient of annual runoff

\[ L = C_{luC}^{0.03} \]

Fig. 2. Standard recession curves

Fig. 3. Relation between runoff amount and sediment yield

Fig. 4. Type of model
Fig. 5. Hydrograph of storm runoff -1 (15th, July 1972)

Fig. 6. Hydrograph of storm runoff -2 (12th, July 1972)
### TABLE 1
Factors in Both Catchments

<table>
<thead>
<tr>
<th>name of catchment</th>
<th>Kiryu</th>
<th>Kawamukai</th>
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<tbody>
<tr>
<td>area, ha</td>
<td>5.99</td>
<td>2.66</td>
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<tr>
<td>average altitude, m</td>
<td>234</td>
<td>202</td>
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<td>average inclination of slopes, deg.</td>
<td>20.3</td>
<td>25.1</td>
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<td>coefficient of drainage shape</td>
<td>0.18</td>
<td>0.24</td>
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<tr>
<td>annual precipitation, mm (1969-1973)</td>
<td>1745</td>
<td>1686</td>
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<tr>
<td>annual air temperature, °C (1973)</td>
<td>12.4</td>
<td>13.6</td>
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### TABLE 3
The Characteristic Values (α, h) of Models

<table>
<thead>
<tr>
<th>Date</th>
<th>Location</th>
<th>α₁₁</th>
<th>α₁₂</th>
<th>α₂₁</th>
<th>α₃₁</th>
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<tr>
<td>15th, July 1972</td>
<td>Kiryu</td>
<td>0.02</td>
<td>0.06</td>
<td>0.02</td>
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<td></td>
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<td>0.02</td>
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<tr>
<td><strong>Kiryu</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P</td>
<td>170.5</td>
<td>85.0</td>
<td>22.0</td>
<td>290.5</td>
<td>140.5</td>
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<tr>
<td>D</td>
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<td>79.1</td>
<td>66.1</td>
<td>162.8</td>
<td>155.9</td>
</tr>
<tr>
<td>L</td>
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<td>5.9</td>
<td>5.1</td>
<td>127.7</td>
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<td>P.E.</td>
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<td>8.1</td>
<td>12</td>
<td>7.4</td>
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<td>7.0</td>
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<tr>
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<td>59.2</td>
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<tr>
<td>P</td>
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<tr>
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<td>48.8</td>
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<tr>
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<td>12</td>
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<td>80</td>
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<tr>
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<td>6.9</td>
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<tr>
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<td>97.8</td>
<td>74.4</td>
<td>173.5</td>
<td>151.0</td>
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P: precipitation,  D: discharge,  L: loss (=P-D), P.E.: Potential Evapotranspiration,  E: evapotranspiration [ E=(P-D)*P.E./P.E. ],  dS: change of storage [ dS=Pi-(Di+EI) ], S: storage,  i represents monthly value