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Relationship between Base Flow and Basin Area of Small Mountainous Basins at the Tokyo University Forest in Aichi and in Chiba

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Introduction

To clarify rainfall-discharge processes, much attention has been paid to the relationship between hydrological characteristics and bedrock geologies. MUSHIAKE *et al.* (1981) examined the effects of basin geology on river flow and concluded that the low water discharge of Quaternary volcanic basin was larger than that of granite basin and Tertiary volcanic basin, and that of Paleozoic basin and Mesozoic basin was the smallest of all. They also showed that the tendencies of the recession curves were almost identical at the granite basins. HIROSE *et al.* (1994) showed the difference in runoff characteristics of four basins with different geological bedrock. They concluded that the characteristics of discharge at a limestone basin were quite different. ONDA (1994) showed the hydrological characteristic differences between two types of geological bedrock by comparing temporal discharge and electrical conductivity at a granite basin and a Paleozoic sedimentary basin. By coupling this data with geographical characteristics, he suggested that those two basins had different water paths. He also showed the spatial distributions of specific discharges of these two basins by observing the discharge quantities of adjoining tributaries along a main stream. KOMATSU and ONDA (1996) collected data on the detailed spatial variation of specific discharges and investigated the relationship between specific discharge and altitude at the measured point. TSUJIMURA *et al.* (2001) investigated the spatial distributions of specific discharges at four adjoining basins and concluded that the subsurface water moved between these basins. JITOUSONO *et al.* (2000) observed specific discharge along a main stream in a volcanic area to develop a method for predicting slope failures. They pointed out that a changing point of specific discharge was closely related to a geological boundary.

These researches reported the importance of bedrock geology to understand hydrological processes in mountainous basins. The quantity of soil water flowing into bedrock on a mountainous slope is a very important component of rainfall-discharge processes. Water flow in bedrock is closely related to deep failures and affects the quantity of stream flow. Water resources such as stream flow decrease when soil water infiltrates bedrock and increase when water in bedrock gushes out and returns to the stream. The quantity of soil-water flow into bedrock, however, cannot be directly measured. Therefore, the mechanism of bedrock flow has not been clarified.

The purpose of this article is to collect detailed information of spatial distribution of base flow in the Tokyo University Forests and to analyze the rainfall-discharge processes including water flow into bedrock. For this, we selected two basins with different types of geological bedrock; the Shirasaka weathered granite basin in the University Forest in Aichi and the Toriisawa Tertiary basin in the University Forest in Chiba. Understanding the spatial discharge distribution in the Shirasaka basin is significant because a long-term observation of discharge and various analyses have been carried out in the Shirasaka basin.

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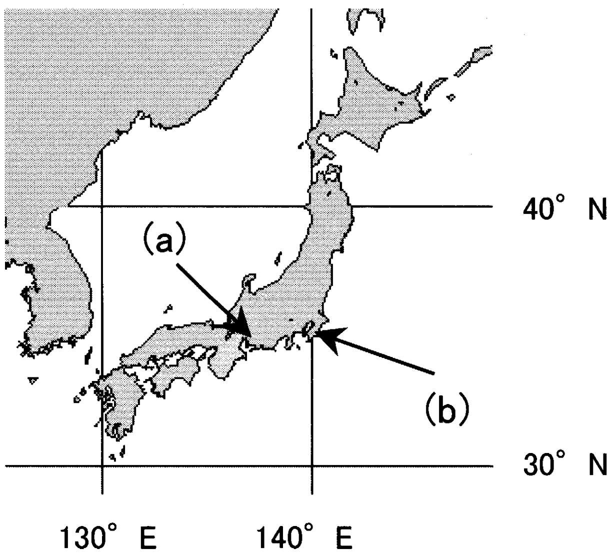

Fig. 1. Location of study sites. (a) Shirasaka basin, (b) Toriisawa basin.

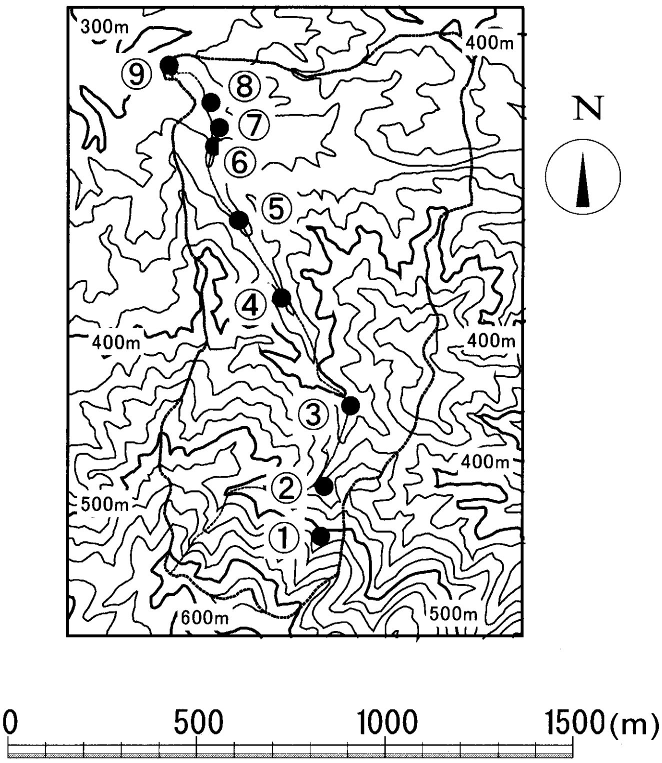

Fig. 2. Topographical map of Shirasaka basin. Black circles represent the points where water flows were observed.

In each basin, the ratios of specific discharge along a main stream were observed and the differences of water flow into bedrock were examined by comparing the distributions of specific discharge and electrical conductivity of each basin.

Method

1. Study areas

Two different geological study areas were selected to see the differences of specific discharge (Fig. 1). One study area, the Shirasaka basin, is located in a deep weathered granite area (Fig. 2). The other study area, the Toriisawa basin, is located in a Tertiary sedimentary rock area (Fig. 3). Basic information of these two basins is shown in Table 1.

The Shirasaka basin is situated in Aichi Prefecture, Japan, at the Tokyo University Forest in Aichi. Almost the whole basin is covered with trees; the percentage of bare land area is low (NAIYANAN *et al.*, 2000). An asphalt road crosses the basin from east to west at the lower part of this basin. A drainpipe for the main stream is installed under the road. The rainwater on this road runs out to outside of the basin. The area of this road inside the basin is about 0.6 ha, less than 1% of the basin area, so it has very little effect on the discharge amount. Inside this basin, we observed stream water flow at 9 points (see Fig. 2). We catalogued the basin areas of these points in Table 2, including following observed specific discharge data. The smallest basin area in Shirasaka basin is 2.6 ha, and the largest

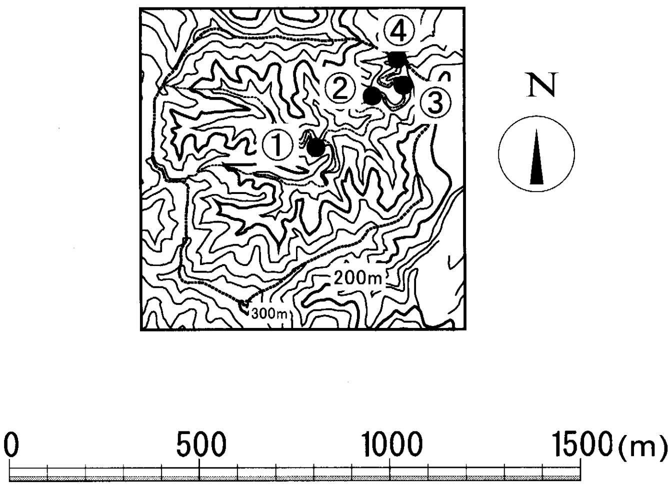

Fig. 3. Topographical map of Toriisawa basin. Black circles represent the points where water flows were observed.

Table 1. Topographical and geological features of study sites.

	Shirasaka	Toriisawa
Watershed area (ha)	88.5	39.4
Longitude (N)	35° 12′	35° 12′
Latitude (E)	137° 10′	140° 10′
Elevation (m.a.s.l.)	2946–629	1213–328
Length of the main stream (m)	1933	1258
Average gradient of the main stream (%)	17.3	9.9
Geology	Deep weathered granite	Tertiary sedimentary rocks

is 88.5 ha corresponding to the observed points.

The Toriisawa basin is situated in Chiba Prefecture, Japan, at the Tokyo University Forest in Chiba. Almost the whole area is covered with trees. We observed stream water flow at 4 points (see Fig. 3). The smallest basin area in Toriisawa basin is 12.0 ha, and the largest is 39.4 ha corresponding to the observed points.

2. Methods of measuring stream flow and electrical conductivity

We measured stream flow manually by three methods; using a bucket and a stopwatch, using a propeller-type flow meter and cross section of the stream, and reading water level at a measuring weir. Where the stream flow is small and the bedrock is exposed, we used a bucket, a stopwatch and a mess cylinder and collected the entire flow. Where the bedrock is exposed but the stream flow cannot be gathered with a bucket, we use a propeller-type current meter with a 2.5-cm diameter propeller. The propeller rotations are converted into water flow velocity. We measured the water flow speed with this current meter every 20 cm horizontally and a minimum of three points vertically. We also read a staff gauge at the outlet of the Shirasaka basin for measuring water level at the weir and calculated stream flow by a hydraulic formula.

Electrical conductivity was measured with a hand-held electrical conductivity meter along the main stream.

3. Calculation of specific discharge and ratio of specific discharge

The value of specific discharge is calculated by dividing stream water flow by the basin area and described by water depth per day in the Table 2 and 3. We determined the basin

Table 2. Basin areas and specific discharge of each observed point at Shirasaka (weathered granite).

Point No.	Basin area (ha)	Specific discharge (mm/day)	
		2001/7/31	2001/11/2
1	2.58		1.07 (0.86)
2	3.28		1.23 (0.99)
3	17.44	0.52 (1.12)	1.39 (1.12)
4	40.22	0.46 (1.01)	1.63 (1.31)
5	49.41		1.03 (0.83)
6	55.04	0.55 (1.18)	1.36 (1.10)
7	55.10	0.51 (1.10)	
8	57.15	0.53 (1.16)	1.44 (1.16)
9	88.50	0.46 (1.00)	1.24 (1.00)

Numbers in parentheses represent ratio of specific discharge.

Table 3. Basin areas and specific discharge of each observed point at Toriisawa (Tertiary).

Point No.	Basin area (ha)	Specific discharge (mm/day)			
		2002/8/20	2002/9/13	2003/1/8	2003/5/7
1	11.96	1.16 (0.52)	0.33 (0.30)	0.43 (0.37)	0.25 (0.25)
2	34.86	1.88 (0.84)	0.76 (0.70)	0.84 (0.73)	0.58 (0.58)
3	36.47	1.77 (0.79)	0.78 (0.72)	0.82 (0.70)	0.55 (0.55)
4	39.43	2.23 (1.00)	1.09 (1.00)	1.16 (1.00)	1.00 (1.00)

Numbers in parentheses represent ratio of specific discharge.

area by topographical terrain for calculating specific discharge.

We observed the stream water flow several times in both the Shirasaka basin and the Toriisawa basin. The specific discharge values were standardized by the specific discharge values at certain points of each basin because the specific discharge values of different dates and places cannot be directly compared. In practical terms, we used the value of specific discharge at the outlet of each basin to calculate the ratio of specific discharge. Therefore the ratios of specific discharge at the outlet of the Shirasaka and Toriisawa basin are calculated to be 1.0. In addition, in order to focus on the characteristics of base flow, we omitted the data when the stream flow at the outlet of basin changed quickly during the observation day.

Results of Spatial Discharge Distribution

Table 2 shows the specific discharge at the Shirasaka weathered granite basin. Figure 4 shows the relationship between the basin area and the ratio of specific discharge at each point. Though the basin area ranges from 2.6 ha to 88.5 ha and the discharge amount at the outlet of basin is quite different between these observed dates, the ratios of specific

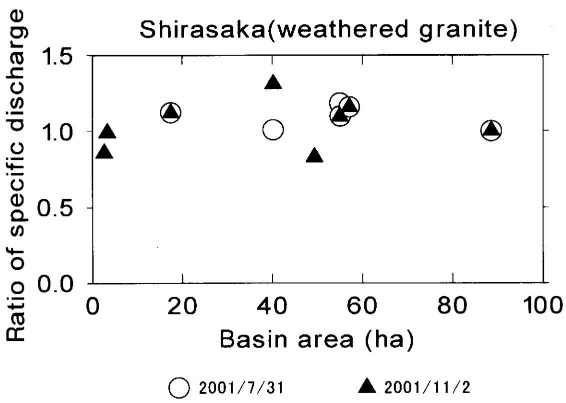

Fig. 4. Relationship between basin area and ratio of specific discharge in Shirasaka (weathered granite) basin.

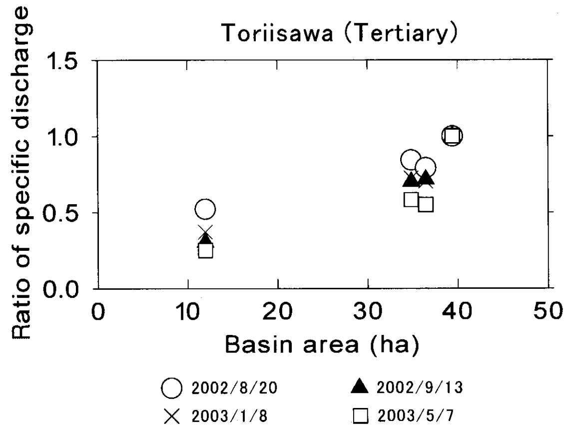

Fig. 5. Relationship between basin area and ratio of specific discharge in Toriisawa (Tertiary) basin.

discharges are approximately constant and between 0.8 and 1.4 at all locations. This means that the specific discharge of base flow is almost equal in this area despite the difference of the basin area or the inclination of slopes.

Table 3 shows the specific discharge at the Toriisawa Tertiary basin. Figure 5 shows the relationship between the basin areas and the ratio of specific discharge. Compared with the weathered granite basin, it is obvious that the ratios of specific discharge in Toriisawa increase with the increase of the basin areas.

Discussion

The characteristics of the ratios of specific discharge of the weathered granite basin and the Tertiary basin are quite different. To check the quality of discharged water, we observed electrical conductivities of stream flow on 2 November 2001 in the Shirasaka basin and on 5 December 2001 in the Toriisawa basin along the main stream. It can be stated that the water that infiltrated deeply into bedrock and stayed there for a relatively long time has high electrical conductivity because it has greater opportunity to make contact with rock and soil, and acquires more dissolved material. Figures 6 and 7 show the relationship between basin areas and electrical conductivity in the Shirasaka basin and the Toriisawa basin. These figures indicate that the electrical conductivity does not change as much in the Shirasaka weathered granite basin as in the Toriisawa Tertiary basin. The values of electrical conductivity in the weathered granite basin decreases as the basin area increases, but there was little difference between upstream and downstream. Judging from the spatial distributions of electrical conductivity, the values of electrical conductivity in the weathered granite basin were almost constant compared to the Tertiary basin. In the Toriisawa basin, the basin area and the electrical conductivities are strongly correlated. The electrical conductivity is almost proportional to basin area in Tertiary basin; the electrical conductivity increases with an increase of the basin area. This can be explained by an increase of dissolved material with increase of basin area. At the same time, the specific discharge increases with increase of the basin areas in the Toriisawa basin. Judging from the spatial changes of specific discharge and electrical conductivity in the Toriisawa basin, it can be stated that much water infiltrates into bedrock at the upstream basin and the infiltrated water containing many dissolved material gushes out through the bedrock at the downstream area in the Tertiary basin. In the Shirasaka, the rainfall-discharge

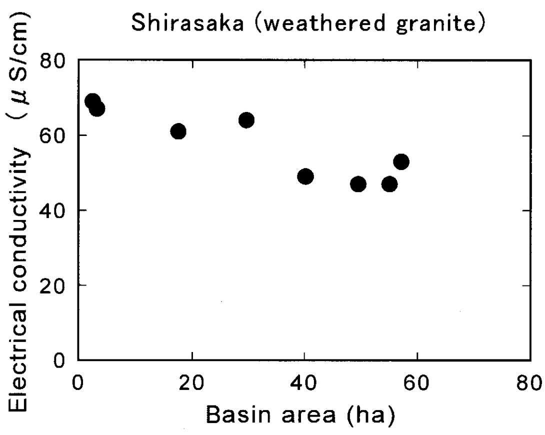

Fig. 6. Relationship between specific discharge and electrical conductivity in Shirasaka (weathered granite) basin.

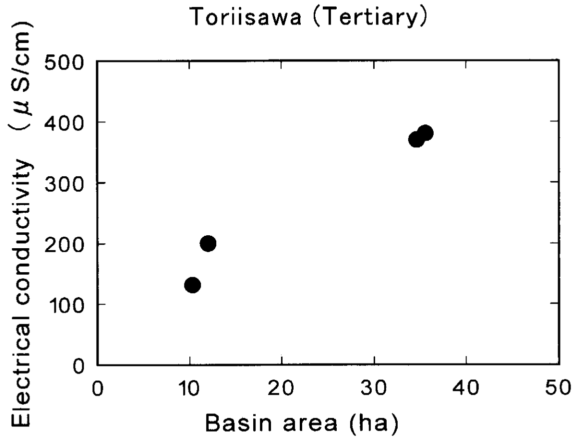

Fig. 7. Relationship between specific discharge and electrical conductivity in Toriisawa (Tertiary) basin.

processes are comparatively simple because the ratios of specific discharge are almost constant inside the basin.

It is difficult to estimate the speed or quantity of water infiltrating into bedrocks by these observed data. Further investigations into the relationship between discharge quantities, electrical conductivity and basin areas and related temporal changes are needed to understand the actual water movement in bedrock.

Conclusion

Definite differences in the characteristics of the ratios of specific discharges have been shown at two kinds of geological basins; the Toriisawa Tertiary sedimentary rock basin in the Tokyo University forest in Chiba, and the Shirasaka weathered granite basin in the Tokyo University forest in Aichi. Discharge quantities at 4 (12.0–39.4 ha) points in the Tertiary basin and 9 (2.6–88.5 ha) points in the weathered granite basin were measured. The ratios of specific discharge, which are calculated by dividing each specific discharge value by specific discharge value at the outlet of basins, vary from 0.25 to 1.0 at the Tertiary basin and from 0.83 to 1.31 at the granite basin. The specific discharge increases with increase of basin area in the Tertiary basin, whereas there is relatively little difference between the specific discharges in the granite basin. The electrical conductivities show the same tendencies as specific discharge. At the Tertiary basin, the electrical conductivity increases with increase of the basin area while it shows almost constant at the weathered granite basin. These results show that much water infiltrates into bedrock at the upstream basin and the infiltrated water containing many dissolved material gushes out through the bedrock at downstream area in the Tertiary basin.

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Summary

We investigated the relationship between basin area and specific discharge of base flow at two basins underlaid by different types of geological bedrock to find the differences in discharge characteristics. We selected the Toriisawa basin at the Tokyo University Forest in Chiba, a Tertiary sedimentary rock, and the Shirasaka basin at the Tokyo University

Forest in Aichi, a weathered granite basin. We measured discharge quantities at 4 (12.0–39.4 ha) and 9 (2.6–88.5 ha) points respectively. The ratios of specific discharge, which were calculated by dividing each specific discharge value by the specific discharge value at the basin outlet, varied from 0.25 to 1.0 at the Tertiary basin and from 0.83 to 1.31 at the granite basin. At the Tertiary basin, the specific discharge increased with an increase in basin area, whereas there was relatively little difference between the specific discharges at the granite basin. The electrical conductivity showed the same tendencies as specific discharge. At the Tertiary basin, the electrical conductivity increased with an increase in the basin area while it remained almost constant at the weathered granite basin. These results indicate that much water infiltrates into bedrock at the upstream basin and this infiltrated water containing much dissolved material re-emerges through bedrock at the downstream area in the Tertiary basin.

Key words: specific discharge, basin area, bedrock infiltration, electrical conductivity

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東京大学愛知演習林および千葉演習林の山地小流域における基底流出量と流域面積の関係の差異について

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要　　旨

降雨流出過程の相違を明らかにする目的で，異なる基盤地質における流域面積と比流量の関係を解析した。解析対象流域を新第三紀層堆積岩の千葉演習林内鳥居沢流域と風化花崗岩地帯の愛知演習林内白坂流域とし，鳥居沢流域内で 4 地点 (12.0～39.4 ha)，白坂流域内で 9 地点 (2.6～88.5 ha) 渓流流量を測定した。比流量比を，流域出口での比流量で流域内の各比流量を除して計算したところ，比流量比の値は鳥居沢流域で 0.25～1.0，白坂流域で 0.83～1.31 であった。また，鳥居沢流域内では流域面積が増大するに従い比流量も増加するが，白坂流域内では流域面積に関わらず比流量は比較的差が無いという特徴が見られた。電気伝導度の調査でも同様の傾向が見られ，鳥居沢流域内では流域面積の増大に伴い電気伝導度の値が増加することが分かった。これらのことは，上流の流域で基岩への深部浸透が多くあり，これが下流の河道に湧出しているという新第三紀層流域の基底流出形成機構の特徴を示している。

キーワード: 比流量，流域面積，基岩浸透，電気伝導度

Relationship between Base Flow and basin Area of Small Mountainous Basins at the Tokyo University Forest in Aichi and in Chiba

Katsushige SHIRAKI and Kyosuke IGARASHI

We investigated the relationship between basin area and specific discharge of base flow at two basins to find the differences in discharge characteristics. We selected the Toriisawa basin, a Tertiary sedimentary rock, and the Shirasaka basin, a weathered granite basin, and measured discharge quantities. At the Toriisawa basin, the specific discharge and electrical conductivity increased with an increase in the basin area, whereas there were relatively little differences between specific discharges at the Shirasaka basin. These results indicate that the seepage flow containing much dissolved matter from bedrocks has a great influence on the base flow in the Toriisawa basin.

A Study of Forest Function Valuation and Zoning Based on GIS Technique for Asahi Forest

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Satoshi TSUYUKI, Takuya HIROSHIMA and Jungsoo LEE

First, a GIS (geographic information system) database for Asahi-Forest was constructed to obtain forest information and to support vegetation management. Second, based on this database, forest functions were quantitatively evaluated in terms of function potential. There were four evaluated functions; "water conservation", "preservation of the public health and culture", "land conservation" and "timber production". Third, zoning of the forest was accomplished by using synthetic methods with four criteria which included the mathematical method of Hierarchical Cluster Analysis.