Environ. Sci., Hokkaido University	10 (2)	313～323	Dec. 1987

Runoff Characteristics in the Lake Toya Basin, Hokkaido

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Abstract

Water discharge to Lake Toya and the runoff characteristics in the basin were investigated to obtain data of the inflow that controls the lake water and to determine the hydrological characteristics of the lake basin, especially in the Mt. Usu region. River runoffs were observed on Nov. 29–30, 1983 at 55 sites in 87 sub catchments of the lake basin. The 87 sub catchments were grouped into 8 regions, from considerations of the respective geological conditions. With the data of the mean specific runoffs and the geology of the 8 regions, the Lake Toya basin was classified into three major hydrological regions: (1) a moderate specific runoff region composed of Neogene andesites; (2) a high specific runoff region composed of Neogene andesites overlain by Toya Pumice Flow sediments; and (3) a low specific runoff region composed of Quaternary volcanic rocks from the Usu volcano. It was determined that the Mt. Usu region is hydrologically characterized by the properties of the low specific runoff region.

Key Words: Specific runoff, Runoff characteristic, River runoff, Lake basin, Catchment.

1. Introduction

Lake Toya is located approximately 60 km southwest of Sapporo in Hokkaido, it is a caldera lake formed by volcanic activity in the Pleistocene. The lake and its surrounding area have been designated as a national park under the name Shikotsu-Toya. It is one of the most famous recreational area in Japan because of its beautiful views. Red salmon is cultured in Lake Toya and the lake water is used for electric power generation, the water supply, and the irrigation. As the lake is closely related to both sight seeing and human life, hydrological studies are necessary to control and conserve the lake water. However only very limited studies have been performed so far.

The Usu volcano is at the south edge of the Lake Toya basin. After the 1977 eruption of the volcano, large scale mud and debris flows occurred repeatedly in the summit atrio and the somma slope leading to the Lake Toya. These mud flows have stopped now because of a pause in the volcanic acitivity and the stabilization of the new tephra of 1977–78 eruptions. Hydrological studies of the Mt. Usu region also have importance to help with prevention of natural disasters.

The main purpose of this study is to obtain basic data of the inflow that controls the lake water. A secondary purpose is to determine the runoff characteristics of the basin, especially in the Mt. Usu region. The paper describes data of the river discharge measured at 55 sites and discusses the runoff characteristics in the Lake Toya basin and the Mt. Usu region.

2. Study area

Lake Toya is a circular lake which has a small island, Nakajima, in the center of the lake (see Figure 1). The width of the lake is approximately 11 km (E–W) by 9 km (N–S). The area of the lake surface and its drainage basin are approximately 70 km^2 and 101.6 km^2. The Lake Toya basin is a part of the Osaru River basin extending on the eastern side of the lake. The lake water discharged from the southeast corner of the lake through the Sobetsu River to the Osaru River. The number of inflowing rivers are 50 to 60 including very small streams. The largest inflowing river is the Horobetsu River at the northern edge of the lake. The lake water is used for electric power generation, water supply, and irrigation to surrounding areas. The water level of Lake Toya is mainly controlled by human utilization of the lake water (i. e. Urano, 1987).

Table 1 shows meteorological data of the Toya Limnological Station at the

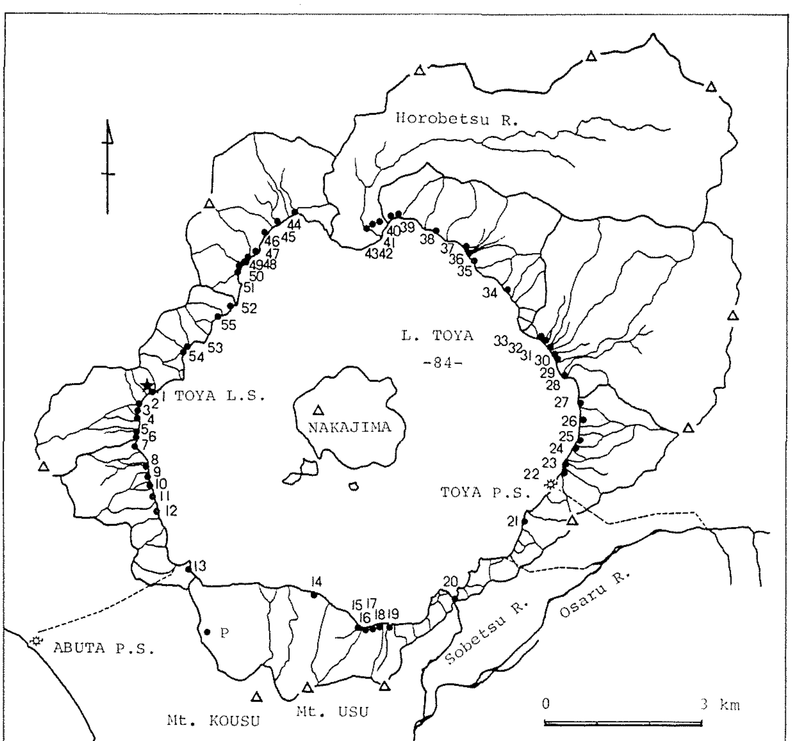

Figure 1. Lake Toya basin and its sub-catchment area. Numbering point shows measuring site of river discharge.

Table 1. Annual temperature and precipitation at Toya Limnological Station

Year	Mean Temperature (°C)	Precipitation (mm)
1981	9.6	1689.8
1982	10.7	985.4
1983	10.1	1237.3
1984	9.8	929.5
1985	10.1	1064.0
Mean	10.1	1181.2

west side of the lake. The mean annual temperature and the mean annual total precipitation for the five years 1981–1985 at this station are 10.1°C and 1181 mm. Approximately 30% of the total precipitation falls as snow, and 512 mm/year is estimated to evaporate from the lake, Kondo (1981).

The geology and geomorphology of the Lake Toya basin are closely related to volcanic activity in the Pleistocene when the Toya caldera was formed. Most of the bed rock in the basin is Neogene andesite. In the northeast and western parts of the basin, there are the mountains made of these Neogene andesites. These areas are rich in geomorphological undulations. In the northwest and northern area, the plateaus are extended. These plateaus are composed of Neogene andesites overlain by Toya Pumice Flow sediment. In the southern area, there is the composite volcano, Mt. Usu, shaped at the Holocene after the Toya caldera formation. The bed rocks of the Mt. Usu region are considered to be the Neogene volcanic rocks named Nottoko Lava (i. e. Ota, 1956, Yamaguchi et al., 1980). The surface of this region is composed of Quaternary volcanic rocks and ash from the Usu volcano. Alluvial fan sediments, which are the secondary sediments of those volcanic rocks and have the high hydraulic conductivity, are widely distribution at the foot of the mountain in the lake side.

3. Method

The Lake Toya basin, except the Nakajima area which is excluded from the discussion because of lack of data, was divided into 87 sub-catchments. All river discharges were measured on Nov. 29–30, 1983 at 55 sites in the 87 sub-catchments. The discharges were measured by gauging the speed of the flow at 1–7 sections in a cross line of the river. A photoelectric current meter was used and a one point method was adopted in the measurement of the flow speed in each section. There were some precipitations the day before the mesurement as shown in Fig. 2. The weather conditions during the measurements were cloudy.

The river water at each site was also collected, and the water quality of these samples have been reported by Sakai et al. (1986).

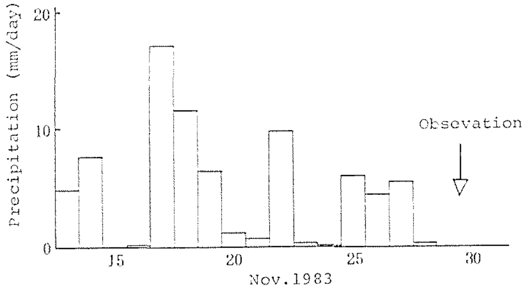

Figure 2. Precipitation at Toya Limnological Station before the measuring.

4. Result and discussion

(1) *Sub-catchments of the Lake Toya basin*

Figure 1 shows the 87 sub-catchments in the Lake Toya basin excluding the Nakajima area. Each sub-catchment includes not only the area of the river basin but also the discharge area for surface and subsurface flow. The water collected in these sub-catchments is discharged to the lake from the river, the lakeshore, and the lake bottom.

The term "basin" indicates the catchment area of a particular river. Only river water is considered at the water discharged from the basin and one point, such as the mouse of the river, is supposed to be the outlet of the basin. The Lake Toya basin has only one outlet, the Sobetsu River, which flows from the southeast corner of the lake to the Osaru River. In this case, the outlet of the lake basin is southeast corner of the lake.

The outlets of the sub-catchments showed at Figure 1 are the shoreline of the lake, and all river water, surface water and subsurface water is discharged from the shoreline to the lake. Therefore these sub-catchments may be slightly difference from the general basin. They are element areas of the main basin, the Lake Toya basin.

(2) *Specific runoff of 8 regions in the Lake Toya basin*

The sub-catchments in the Lake Toya basin were grouped into 8 regions, from considerations of the respective geological and geomorphological conditions. Tables 2, and 3 show the river discharges measured on Nov. 29–30, 1983 at 55 sites (see Figure 1) and the total discharge in each region. The total discharge of all the rivers was 2.29×10^3 liter/s and the mean specific runoff was 2.37×10^{-7} m/s. Fig. 4 shows the relationship between the catchment area and the specific runoff in each of the 8 regions. The regional characteristics can be summarized as follows ;

(a) Toya village region

The bed rocks are mainly the Neogene andesites "Mukaitoya Lava". In this region, a plateau covered by Toya Pumice Flow sediments spouted by volcanic activity in the Pleistocene extends from the basin to its borders. The mean specific

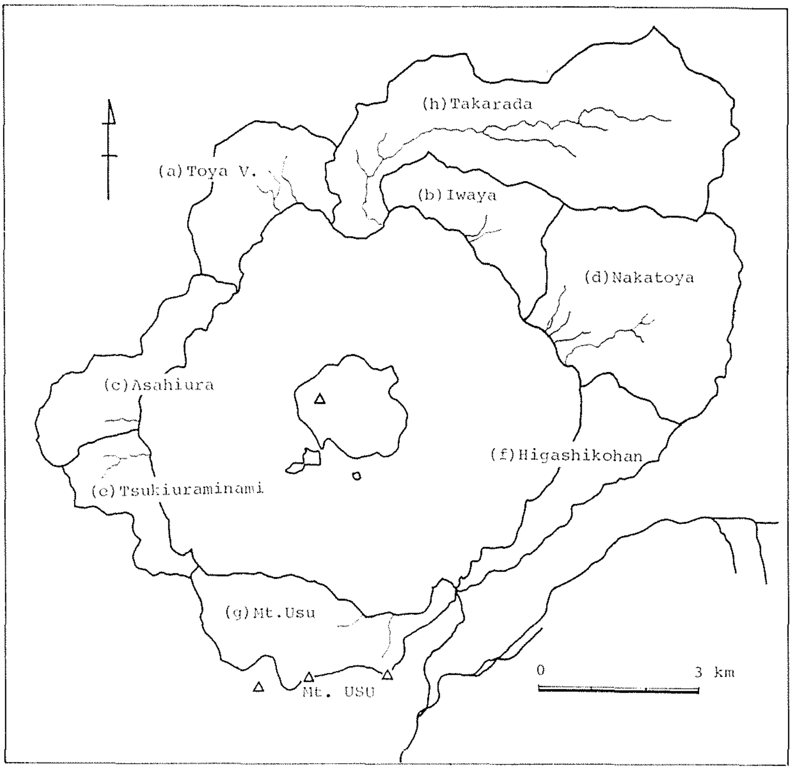

Figure 3. Sub-regions of Lake Toya basin.

runoff was 4.42×10^{-7} m/s, the largest value of the 8 regions.

(b) Iwaya region

The bed rocks in this region consist of Neogene volcanic rocks, the "Osaru River Formation". The size of the sub-catchments is relatively small. Some had fans with a specific runoff value of approximately 2.0×10^{-7} m/s. The mean value in this region was 1.00×10^{-7} m/s because of the existence of the catchments without rivers. It belongs to the group with small values.

(c) Asahiura region

In this region, there are many of the small catchments which have steep slopes. The bed rock consists of Neogene Nottoko Lava and Neogene Asahiura Lava. There is also a plateau covered by Toya Pumice Flow sediments in this region as in the Toya Village region. The mean specific runoff was 2.64×10^{-7} m/s, relatively high for the 8 regions.

(d) Nakatoya region

The land form in this region is characterized by mountains with many undulations like in the Iwaya region, but the sub-catchments are almost all larger than in the Iwaya region. The bed rock is mainly Neogene Osare River Formation. The mean specific runoff in this region was 2.75×10^{-7} m/s.

(e) Tsukiuraminami region

The bed rocks are the Neogene andesites named "Tsukiura Lava", partially

Table 2. Catchment areas andriver discharges at 55 sites on Nov. 29–30, 1983

Station No. (Region)	Catchment Area (km²)	Discharge (l/s)	Specific Runoff (10^{-7} m/s)	Station No. (Region)	Catchment Area (km²)	Discharge (l/s)	Specific Runoff (10^{-7} m/s)
1 (c)	0.26	8.99	3.46	29 (d)	2.93	52.3	1.98
2 (c)	2.49	65.9	2.65	30 (d)		5.81	
3 (c)	0.17	4.85	2.85	31 (d)	3.69	136	3.69
4 (c)	0.30	9.29	3.10	32 (d)	2.68	103	4.83
5 (c)	1.46	21.1	1.70	33 (d)		26.5	
6 (c)		3.71		34 (b)	0.35	7.18	2.05
7 (e)	0.39	5.06	1.30	35 (b)	0.40	7.97	1.99
8 (e)	1.89	47.7	2.52	36 (b)	1.83	19.0	1.04
9 (e)	0.10	0.87	0.87	37 (b)	1.25	23.0	1.84
10 (e)	0.06	0.91	1.52	38 (b)	1.08	13.5	1.25
11 (e)	0.46	8.62	1.87	39 (b)	0.95	2.53	0.298
12 (e)	0.50	3.70	0.74	40 (b)		0.30	
13 (e)	0.60	5.00	0.83	41 (h)		4.44	
14 (g)	2.93	3.52	0.12	42 (h)	30.0	26.4	3.13
15 (g)	0.77	4.51	0.586	43 (h)		907	
16 (g)		1.26		44 (a)	2.39	89.0	3.72
17 (g)	1.09	0.36	0.213	45 (a)	2.40	155	6.56
18 (g)		0.70		46 (a)	0.67	21.1	3.86
19 (g)	0.73	0.93	0.127	47 (a)		4.75	
20		25.4*	—	48 (a)	1.24	4.70	4.48
21 (f)	0.60	5.85	0.975	49 (a)		50.8	
22 (f)	0.64	7.56	1.18	50 (a)	0.80	16.8	4.03
23 (f)	2.14	46.8	2.19	51 (a)		15.4	
24 (f)	0.50	10.0	2.00	52 (c)	0.45	22.1	4.91
25 (f)	0.17	0.34	0.20	53 (c)	0.43	35.2	8.19
26 (f)	0.26	0.78	0.03	54 (c)	0.50	21.9	4.38
27 (f)	1.02	4.00	0.39	55 (c)	0.29	6.21	2.14
28 (d)	10.54	237.0	2.25				

* Discharge from the Lake

Table 3. Particulars of the regions and total river discharge on Nov. 29–30, 1983

Region	Area (km²)	Length of Lake-shore (km)	Number of Catchment	Mean Catchment Area (km²)	Maximum Relative Height (m)	Number of Measured River	Total Discharge (l/sec.)	Mean Specific Runoff (10^{-7} m/s)
(a) Toya V.	8.10	4.25	7	1.16	194	8	358	4.42
(b) Iwaya	7.58	4.98	12	0.63	477	7	73.5	1.00
(c) Asahiura	7.53	5.13	17	0.44	541	11	199	2.64
(d) Nakatoya	20.4	2.50	6	3.4	796	6	561	2.75
(e) Tsukiuraminami	5.12	4.18	11	0.46	458	7	71.9	1.40
(f) Higashikohan	7.42	6.75	20	0.37	461	7	75.3	1.01
(g) Mt. Usu	10.3	7.50	13	0.79	653	6	11.3	0.11
(h) Takarada	30.0	1.83	1	30.0	830	3	938	3.13
All region	96.5	37.8	87	1.11	830	55	2,290	2.37

overlain by Neogene Nottoko Lava. The sub-catchments have many gentle slopes. The mean specific runoff was relatively small, 1.40×10^{-7} m/s.

(f) Higashikohan region

The bed rocks consist of Neogene Osaru River Formation and Neogene andesite named "Takinoue Lava". Many of the sub-catchments consist of first order streams. Their mean area is the smallest of the 8 regions. The mean specific runoff of the catchments with fans was 2.0×10^{-7} m/s, and the overall mean value was 1.01×10^{-7} m/s. These values were similar to the Iwaya region.

(g) Mt. Usu region

The geology of surface is mainly the Quaternary volcanic rocks and ash from the Usu volcano. On the day of measuring there was little river discharge. The mean specific runoff was 0.11×10^{-7} m/s, the smallest of all the regions.

(h) Takarada region

The Horobetsu River in this region is the largest inflowing river. The alluvial plain extends near the mouth of the river. The whole area of approximately 30 km² is one sub-catchment. It is the largest of all the sub-catchments in the lake basin. The bed rock is mainly Neogene volcanic rocks. The specific runoff was 3.0×10^{-7} m/s.

(3) *Classification by runoff characteristics in the lake basin*

The data in this study are particular values at the time of measurement, and it is not possible to discuss the runoff characteristics of the Lake Toya basin by comparing with runoff data from other basins. In this study, the data were obtained for one basin with the same climate and at the same time. Therefore it is possible to evaluate the relative hydrological charactersitics of each region in the basin.

Figure 5 shows the relationship between the mean specific runoff and the mean area of sub-catchments in each of the 8 regions. There is no correlation

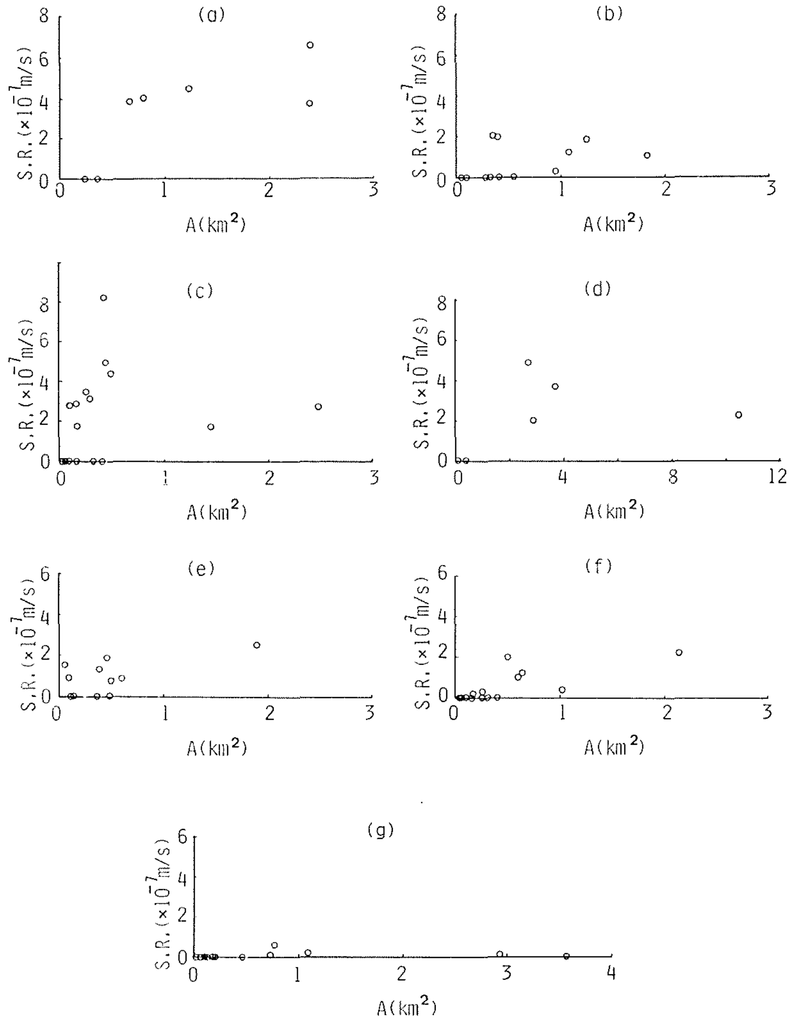

Figure 4. Relationship between the specific runoff and the sub-catchment area in each region: (a) Toya V., (b) Iwaya, (c) Asahiura, (d) Nakatoya, (e) Tsukiuraminami, (f) Higashikohan, and (g) Mt Usu. (h) Takarada is excluded as the whole area is one catchment.

between the two parameters in Fig. 5 for all the 8 regions.

Classifying into the three geological groups (1) the regions composed of the Neogene andesites, (2) the regions composed of the Neogene andesites overlaying the Toya Pumice Flow sediments, and (3) the region composed of the Quaternary volcanic rocks from the Usu volcano, there appears a linear correlation between the specific runoffs and the catchment areas except for the third group which have only one point in the Mt. Usu region. Each group has a tendency to increased mean specific runoff with increasing the mean catchment area. Each group has its own slope of tangent of the increase.

In the first group, three regions, (b) Iwaya, (e) Tsukiuraminami and (f)

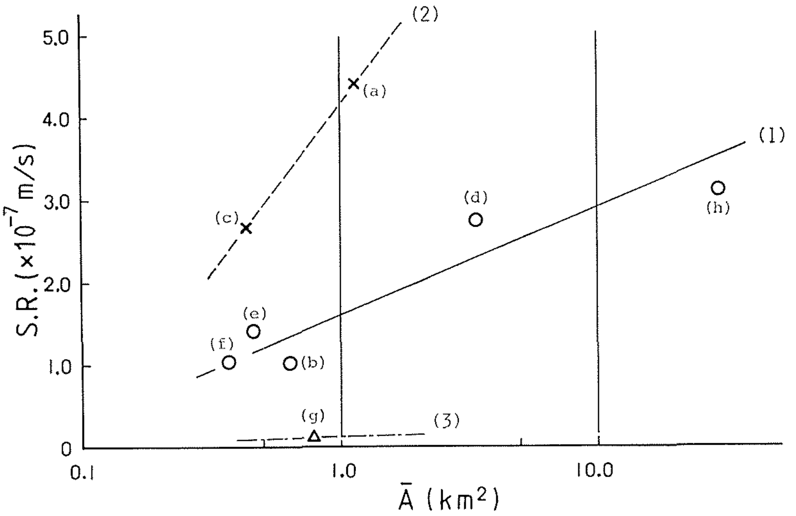

Figure 5. Relationship between the mean specific runoff and the mean catchment area in each region. (1) The region composed of the Neogene andesites. (2) The region composed of the Neogene andesites overlain by the Toya Pumice Flow sediments. (3) The region composed of the Quaternary volcanic rocks.

Higashikohan, are composed of almost only small catchments which are suitable to first order streams. The (d) Nakatoya region has some catchments including fans, and in the (h) Takarada region, the catchment has an alluvial plain. It is, therefore, considered that the increase in the specific runoff with the increase in the catchment area in the first group is due to geomorphological conditions in the sub-catchments in each region.

Based on the data in the U. S. A. reported by Renard (1977), Pilgrim et al. (1982) have describe that in humid areas, runoff increased with catchment size as a result of the baseflow contribution. A tendency similar to this is shown in Figure 5. Figure 5 also suggests that the degree of increase in the runoff is a difference in the geological characteristics of the catchments.

It is difficult to compare the hydrological characteristics of catchments which have different sizes. But considering the hydrological characteristics in one geological region as a pattern that changes from upstream to downstream, it may be considered that the groups in Figure 5 are in major regions with catchments which have identical characteristics in regard to river runoff patterns. As a result, the three groups can be characterized hydrologically as (1) a moderate specific runoff region, (2) a high specific runoff region and (3) a low specific runoff region.

(4) *Runoff characteristics of the Mt. Usu region*

Classifying into 3 major regions as in Fig. 5, it can be understood that the Mt. Usu region as a low specific runoff. This is also clear from Fig. 6 with the distribution of specific runoff in the Lake Toya basin. The low specific runoff in this region appears to be due to the water permeability and the water retentivity

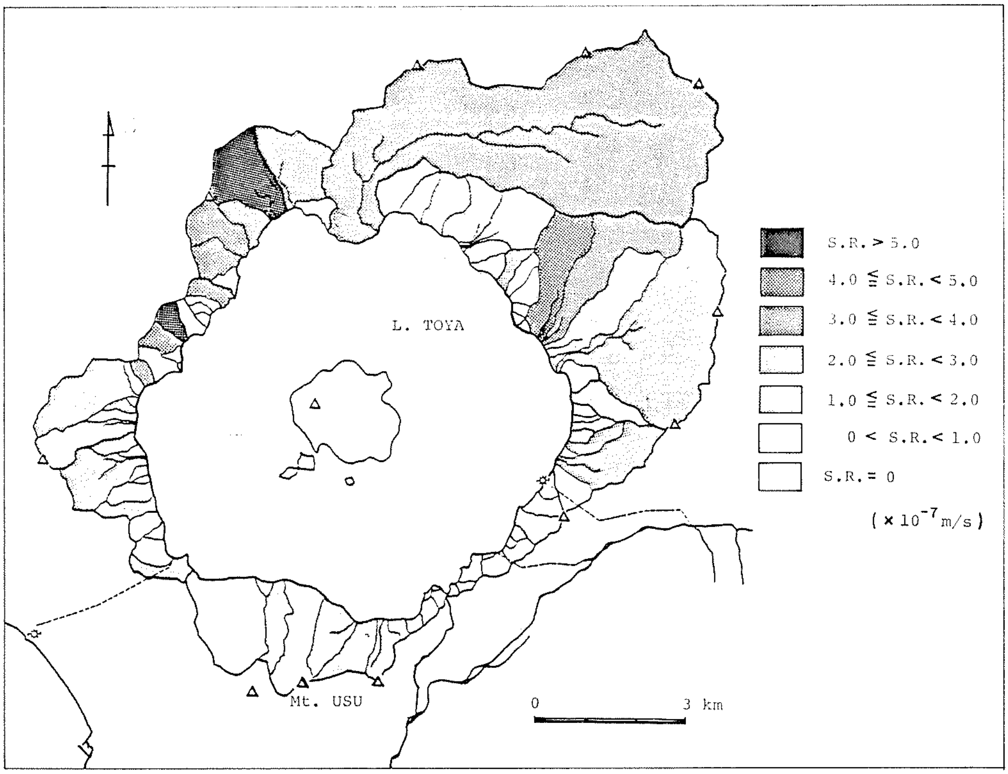

Figure 6. Distribution of specific runoff in the Lake Toya basin.

of the surface materials, the Quaternary volcanic rocks and ash. At the lake side of this region, many alluvial fans are present, and alluvial sediments of secondary sediments of the Quaternary volcanic rocks are widely distribution. These sediments are unconsolidated and have high hydraulic conductivity (i. e. Doi, 1960), and the surface water on the fan permeates easily into the subsurface. On Nov. 29–30, 1983 at measuring, river runoff was observed at point P in Figure 1, but its water flow did not reach the lake. From these results, it is considered that alluvial fan sediments characterized by high hydraulic conductivity is an important reason why the river runoff was relatively small in this region.

5. Conclusion

The Lake Toya basin can be classified into three major geological regions : (1) a region composed of the Neogene andesites (Takarada, Iwaya, Nakatoya, Higashikohan, Tsukiuraminami), (2)a region composed the Neogene andesites overlaying the Toya Pumice Flow sediments (Toya village, Asahiura), (3)a region composed of the Quaternary volcanic rocks from the Usu volcano. They are hydrologically characterized by (1)a moderate specific runoff region, (2)a high specific runoff region and (3)a low specific runoff region. The Mt. Usu region, the (3) region, is a relatively small runoff area in the Lake Toya basin. The low specific runoff in the Mt.

Usu region appears to be due to surface materials which have high hydraulic conductivity.

The runoff characteristics of the Lake Toya basin were detailed in this study. The data of river discharge can be used as basic data for estimating the water balance of the lake. The problem of the annual value and the time changes in the river runoff from the basin still remaines to be determined. Hereafter, it is necessary to study these problems to control lake water.

Acknowledgments

I would like to thank Director Takashi Kurohagi and Mr. Hiroyuki Haruna, Toya Limnological Station, Faculty of Fisheries, Hokkaido University for their help and support in this study. I also thank Mr. Hiroto Ishida and Mr. Fumiaki Sugiyama, Laboratory of Fundamental Research, Graduate School of Environmental Science, Hokkaido university for their help with the field survey in the Lake Toya basin.

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(*Recived 31 August 1987*)