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A Hydrological Study on Streamflow Characteristics of Small Forested Basins in Different Geological Conditions

By

Triyono Sudarmadji*, Tohru ARAYA* and Saburo HIGASHI**

地質条件の違いによる小流域河川流出特性の比較研究

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Abstract

To clarify the streamflow characteristics, a hydrologic analysis focusing on the input-output relationship between precipitation and streamflow was carried out. Streamflow characteristics and its processes were attempted to be clarified in reference to the input-output analysis and basin characteristics on different geological conditions.

During mid-winter and early summer, streamflow in the investigated basins was minimum. Heavy increases occurred in the early spring from melting snow and in the late summer following precipitation increases. Streamflow hydrographs showed that streamflow in Kiyokawa increased faster during and after precipitation than streamflow in Horonai.

Concerning the sources of streamflow, Kiyokawa was maintained by subsurface and groundwater, whereas Horonai was mostly fed by groundwater. Basin storage in Kiyokawa was poor due to impermeable or shallow soil layers, the steep slopes and high drainage density, while Horonai had an excellent storage properties and permeable soils.

Basin waterflow processes in releasing precipitation were faster in Kiyokawa Basin (Tertiary mudstone) than that in Horonai Basin (Quarternary volcanic). Consequently, the seasonal changes of streamflow in Kiyokawa fluctuated greatly, whereas those of Horonai were relatively steady under the changes of seasonal precipitation.

Key Words: Precipitation, Streamflow, Waterflow, Geological condition, Basin storage

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Introduction

The advance of civilization and the steadily increasing population have been resulting in competition for the use and control of available water resources. The large volume of domestic water consumption by municipalities, industries and agriculture necessitates the utilization of flowing river water from the upper reaches of the streams and the pumping of groundwater. In some regions, such conditions have been leading to rivalry over obtaining usable water, and this tendency is predicted to become more keen in the years to come.

Concerning water resource development planning, it is necessary to consider water availability and the requirements for its utilization, and how these can be reconciled. The main objective of water development, therefore, must be to make the most effective use of available water for meeting all foreseeable short and long term purposes.

Hydrologic studies on streamflow characteristics permit the assessment of the hydrological condition of headwaters by indicating the streamflow sources, the rate of the release of stored water and seasonal changes of streamflow over the period of a year. It is expected that these results will provide basic informations for hydrological research, environmental conservation, fish and ranching management, land development, urban planning and other fields.

I. Study Method and Investigated Areas

1. Study method

The aim of this study is mainly focused on analyzing the characteristics of streamflows and their waterflow processes under different geological conditions. The method being used in general is shown in Fig. 1. Due to the complexities of basin waterflow processes, this study was carried out based on the input-output hydrologic relationships between precipitation and streamflow. By combining input-output analysis with the analysis of the physical characteristics of basin, the streamflow characteristics and its waterflow processes were clarified.

The determination of the basin morphology was done by using some aerial photographs and topographic maps, identifying the orographic water divide, drainage networks and the elevation of contour lines. The results were confirmed through field surveys.

Geological conditions were ascertained from the geological maps of the Japan Geological Survey. Soil properties were examined through field surveys taking soil samples from the lower, middle and upper parts of a hill slope.

Soil analysis for mechanical and physical properties were carried out at the soil

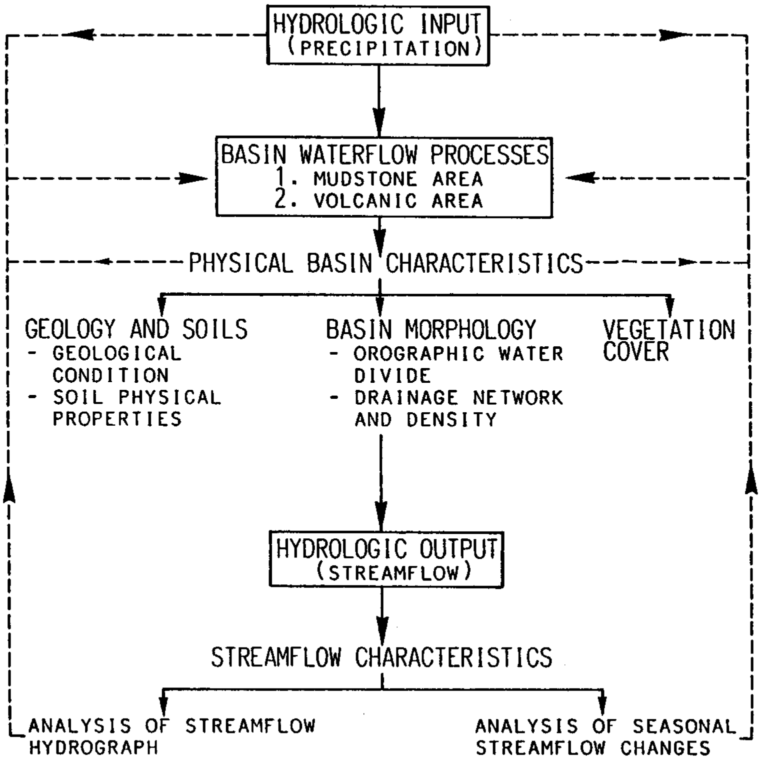


Fig. 1. Flow chart of the study.

laboratory. The infiltration rate was measured by using a double ring infiltrometer in the field. The hydraulic conductivity expressed as a coefficient of permeability was examined by using a simple test of soil permeability.

Historical records of climate factors including continuous hourly precipitation and air temperature of each investigated basins were used. Vegetational conditions such as dominant species, vegetation cover and forest floor were also examined.

Streamflow measurements using automatic water level recorder were carried out by both Teshio and Tomakomai Experiment Forests (1988-1989). In order to establish the total volume of flowing water passing the basin outlet, the discharge rate was measured periodically using a rotating current meter. By plotting the periodic discharge rates and water levels, a rating curve for predicting streamflow discharge was obtained.

2. Investigated areas

The recent progress in hydrological studies has clarified that geological conditions have a great influence on the soil physical properties and waterflow processes. As a general phenomena, this has been illustrated by representing annual streamflow hydrographs for several basins having different geological conditions (Fig. 2).

Tertiary mudstone and Quarternary volcanic areas are representative of the two major types of geological formations in Indonesia, such as in Kalimantan and Java. In some areas of these islands, the current problem is a rather unstable streamflow distribution, being very high during the rainy season which produces floods and very low during the dry season which causes droughts.

Especially in Kalimantan, because of the naturally fine textured soils, the fast movement of the falling precipitation redistribution without it being stored in the basin for a relatively long time is induced. Meanwhile in Java, there is the problem of a high population pressure and over-exploitation of the land, especially the alteration of forested areas.

In Indonesia, since hydrological studies based on the different such geological con-

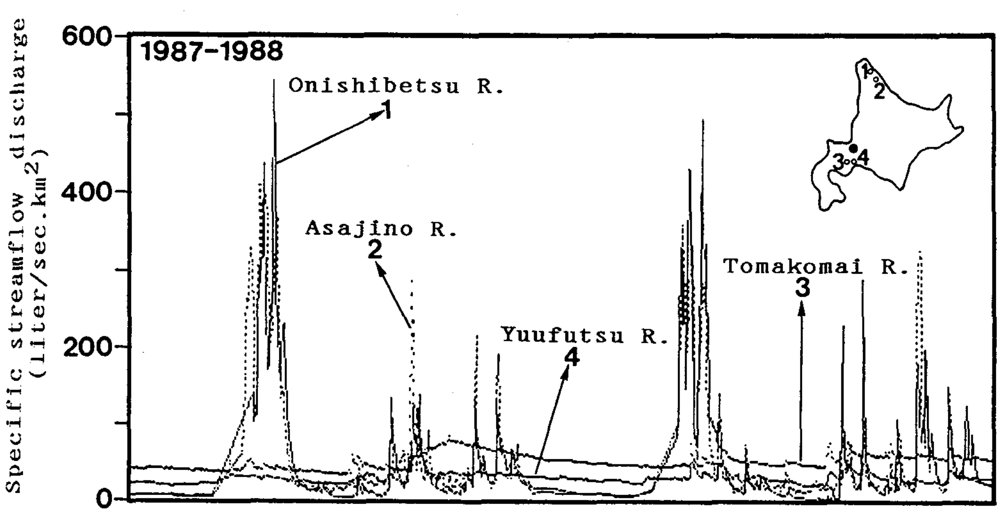


Fig. 2. Streamflow on different geological conditions.

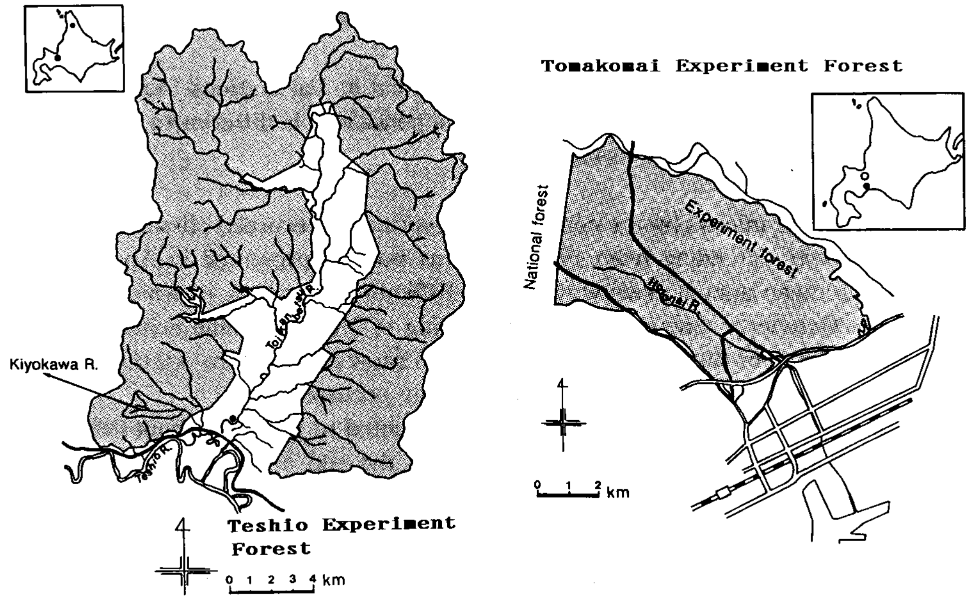


Fig. 3. Location map of study areas.

ditions mentioned have not been carried out intensively, this study was carried out in Kiyokawa and Horonai basins which are clearly different in their geological conditions, as similarly condition with Kalimantan and Java islands. Kiyokawa Basin is situated in the Teshio Experiment Forest, while the Horonai Basin is located in both Tomakomai Experiment Forest and a National Forest area (Fig. 3).

The Kiyokawa Basin, geographically, lies on the line of 45° North Latitude and 142° East Longitude. From the west part to the east, the Kiyokawa River flows passing numerous steep, forested and treeless slopes along the channel. It finally empties into the Teshio River. Several Sabo dams were constructed in the main channel for preventing probable landslide occurrences and debris flows from the upper part downstream through the channel. Another purpose of the dams is for improving the constancy of water supplies, through the small water plant station downstream of the basin.

The Horonai Basin lies at 42°36′ North Latitude and 141°36′ East Longitude, whereas Horonai River flowing from north-west part of the basin in a south-eastern direction through a flat forested area and finally emptying into the Pacific Ocean. Since the Horonai Basin has been designated as a headwater area, a small checkdam was constructed downstream for helping to supply water to Tomakomai City.

II. Climatical and Vegetational Conditions

Since climate factors are uncontrollable variables, it has been quite difficult to select the proper variable for determining the climatic condition in the investigated basins. Nevertheless, the precipitation and air temperature might be considered as the representative. Precipitation is the major input into the basin, whereas the air temperature is closely correlated with the form of precipitation and the process of water loss from the basin areas.

Furthermore, due to the climate factors recorded at the stations 2km far from the investigated basins, it should be noted there was a considerable differences with the actual condition inside of investigated basins.

1. Precipitation

To describe the micro climate conditions, a continuous recorded climatic data of both experiment forests extending from 1985-1989 was used as presented in Appendix 1. In Kiyokawa, the mean annual precipitation was 1076mm, about 50% of which occurred as rainfall (May-October). Snow fell in the beginning of November and completely melted by the end of March of the following year. Due to snow covers were relatively thick and sometimes reaching near 160cm, soil freezing rarely occurred.

The mean annual precipitation in Horonai amounted to 1197mm, about 70% of which was in rainfall (May-November). Snow began in the end of October or beginning of November, whereas the last snow melting occurred by the end of March. Snow cover was about 30 to 60cm, therefore, soil freezing frequently occurred from the beginning of winter until early spring.

For hydrograph analysis, daily precipitation (1988-1989) was used as the measure of hydrologic input into the basin (Appendixes 2 and 3). To describe the seasonal precipitation changes, monthly precipitation was expressed in Fig. 4, showing a similar seasonal pattern during the two years period of measurement.

Considering the possibility of surface flow occurrences, the precipitation intensity was observed (1988-1989), as shown in Fig. 5. The frequency of intensities from 0.5-1.0 mm/hr amounted to 50.7% in Kiyokawa and 33.2% in Horonai.

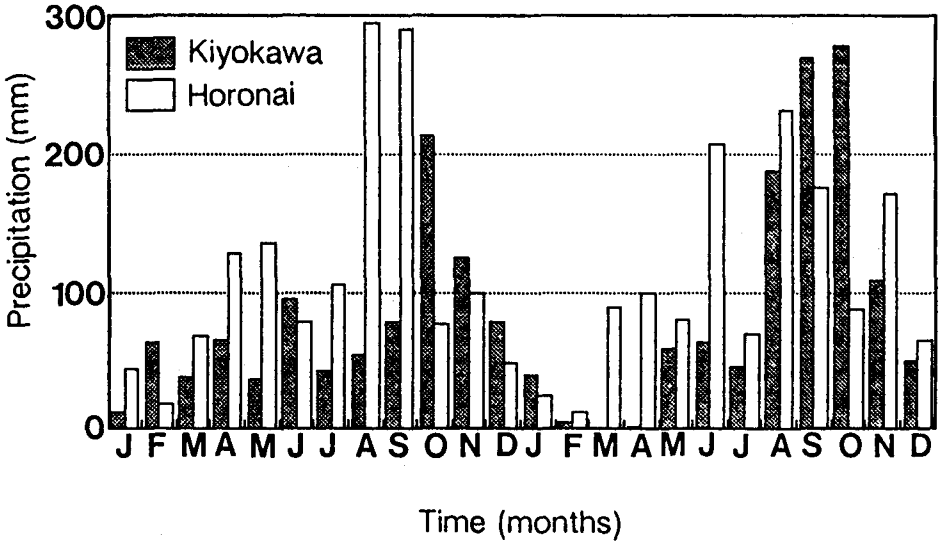


Fig. 4. Monthly precipitation (1988-1989).

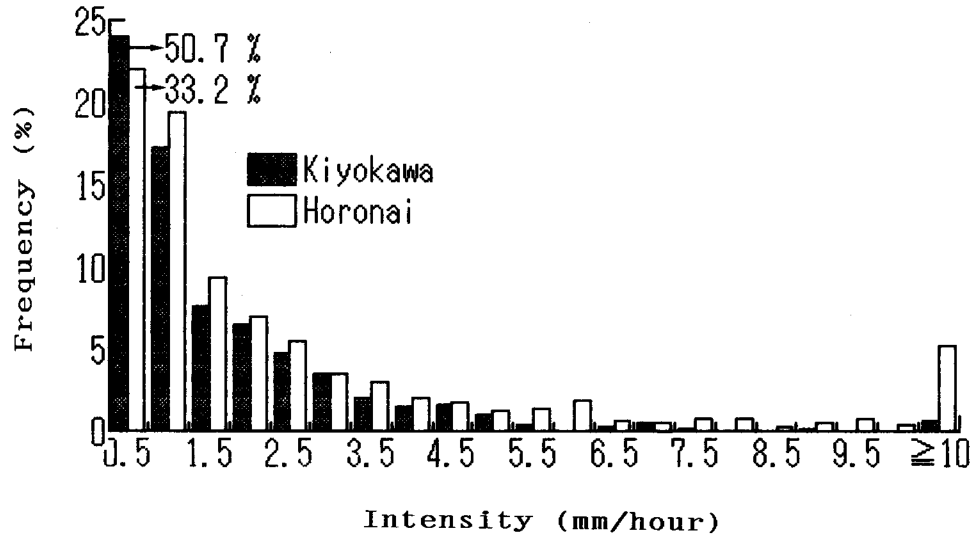


Fig. 5. Distribution of precipitation intensity.

2. Air temperature

From the view point of hydrologic process, air temperature is closely related with evapotranspiration, snow melting and soil freezing. In Kiyokawa, the air temperatures ranged from −23.7°C (January) to 30.8°C (August). The temperate would, decrease near to −30°C in winter, and increase nearly to 32°C in summer. In Horonai, temperatures ranged from −15.2°C (January) to 22.6°C (August). During winter, the low temperature would approach −17°C, whereas in summer it would approach 29°C.

3. Vegetational cover

The existing vegetation in any basin covers the surface soil and absorbs the force of falling precipitation before it reaches the soil surface. Vegetation cover may directly correlate with infiltration capacity, soil conditioning organic materials, bulk density and soil porosity, and also has a role in influencing the infiltration and evapotranspiration.

In Kiyokawa Basin, vegetation cover was mainly composed of mixed forests of broad leaved and coniferous trees such as *Abies sachalinensis*, *Picea jezoensis*,*Quercus mongolica* var. *grosseserrata*, *Kalopanax pictus*, *Ulmus davidiana* var. *japonica*, *Betula ermanii*, *Betula maximowicziana*. Moreover, most of the forest floor was densely covered with *Sasa kurilensis* or *Sasa senanensis*.

As in Kiyokawa Basin, the Horonai Basin was also primarily composed of mixed forests. *Betula maximowicziana*, *Betula ermanii*, *Betula platyphylla*, *Quercus mongolica* var. *grosseserrata*, *Quercus dentata*, *Acer mono*, *Acer palmatum* var. *matsumurae*, *Tilia japonica*, *Kalopanax pictus* and *Fraxinus mandshurica* var. *japonica* dominated among the broadleaved trees.

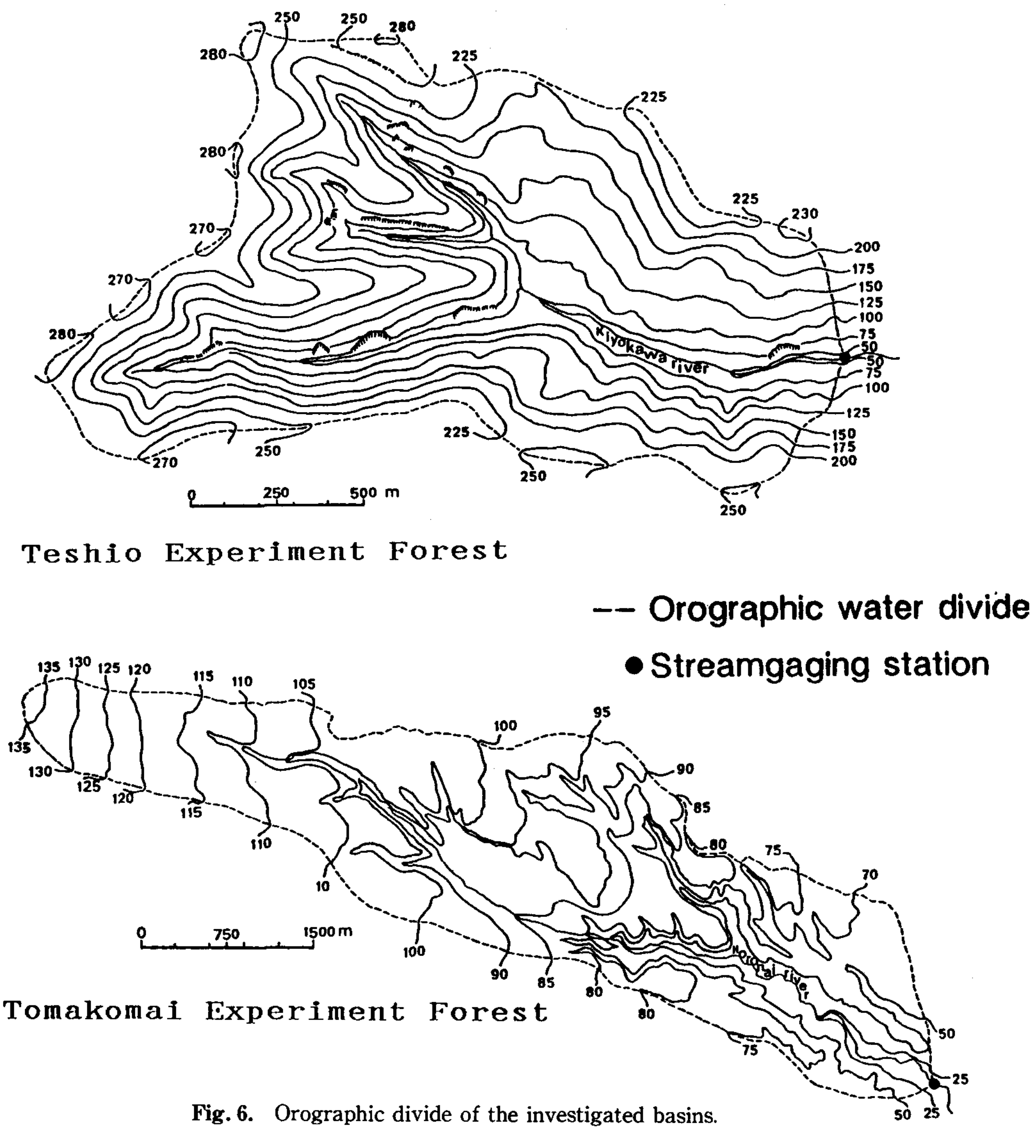
The coniferous trees were represented by *Picea jezoensis*, *Picea glehnii*, *Abies sachalinensis* and *Taxus cuspidata*. Artificial revegetation works by introducing young larch, *Larix kaempferi* were also widely distributed. Most of the forest floor was densely covered by shrubs and in some parts by Sasa.

The vegetational condition, as mentioned above, was considered to be not so extremely different as compared with geological condition. Therefore, vegetational cover in relation to the basin waterflow process was not examined and discussed comprehensively.

III. Physical Basin Characteristics

1. Basin morphology

A drainage basin is clearly an organized section of land surface. Morphologically, a basin form, shape, elevation relief and drainage network are of considerable importance as factors in hydrologic studies. To ascertain the morphological characteristics, some parameters of basin morphology were observed in both investigated basins.



Teshio Experiment Forest

Tomakomai Experiment Forest

Fig. 6. Orographic divide of the investigated basins.

1) Orographic water divide

Any basin drainage surface flow can be clearly defined by a topographic divide and cross section of the stream channel. However, a basin defined with respect to subsurface flow may often be different in area from the same basin defined according to the surface flow, due to basin areas being comprised of either permeable or impermeable soils and rock strata. The surface water divide (*orographic*) is often not identical with the subsurface (*hydrologic*) divide.

Many studies in similar areas have demonstrated that an anomalous distribution of streamflow occurred due to the fact that the surface divide and subsurface divide did not coincide which might have resulted from the groundwater divide being much farther apart than the orographic divide and having the greatest effect on the streamflow. In this study, it was presumed that these two divides coincided, although the actual difference might be considerable.

Orographic divide determination was performed by using topographic maps, as shown in Fig. 6. The orographic divide of Kiyokawa Basin could be determined easily because the topographic divide was clearly recognizable, while that of Horonai Basin could not be fully identified accurately. This was because Kiyokawa had steep slopes, whereas Horonai had gentle slopes. Kiyokawa Basin was found to be 182.4ha in area, while the Horonai Basin was 1037.6ha.

The values determined for basin area were used for expressing the streamflow discharge volume per unit area as well as for recording precipitation data. Hence, it might be possible that inaccurate determinations lead to misinterpretation of precipitation -streamflow correlation.

2) Drainage network and density

Drainage networks are comparatively simple in headwater regions of flat topography drawn by a single drainage course, where the path coincides with the axis of the basin area. In headwaters of steep slopes, several drainage courses may appear according to the developed topography (Riedl and Zachar, 1984).

The drainage network was ascertained from topographic maps and confirmed in the field. The planar view of the drainage network of Kiyokawa might be classified as a dendritic network of circular form with small tributaries feeding a larger channel, while Horonai was linear and palmate. The drainage density was found to be 1.85km/km^2 and 0.56km/km^2 respectively. This result indicated that Kiyokawa Basin had weak or impermeable subsurface materials and mountainous relief, while the low one figure for Horonai indicated the presence of more permeable subsoil materials and a topography of low relief.

An observation of stream channel segments from the outlet toward the upper part clarified that the Kiyokawa River was made up of three types of streams, a perennial stream flowing continuously over the year, intermittent streams (usually dry during parts of the year), and ephemeral streams flowing only in direct response to rainfall or melting snow. The first type was found in the downstream part, while the latter two were distributed from the middle to upstream part. The Horonai River, however, consisted of only a perennial type, along all segments, flowing continuously over the year.

2. Geology and soils

1) Geological condition

Kiyokawa is nearly entirely composed of the mudstone and sandy mudstone, belonging to a fold zone in a neogene system, whereas, Horonai is mostly composed of the volcanic materials from the Shikotsu, Eniwa and Tarumae volcanoes (Japan Geological Survey, 1987).

It was expected that differences in the hydrologic characteristics of the investigated basins would appear, due to the clear differences in geological lithology and structure. This geological differences was considerably influencing greatly on the physical properties of soils.

2) Physical properties of soils

Soil is a product of evolution consisting of genetically developed horizon layers (Foth, 1984). Additional materials such as dust, volcanic ash, pumice or eroded sediment from the higher parts also take place in developing surface soil of any landscape. Therefore, developed soils are composed of various mixtures of gravels, sands, silts, clays and organic matter.

Table 1. Characteristics of soil profiles under natural conditions

Sample sites	Depth (cm)	Hardness (mm)	Color identification	
			Munsell	Naked eye
Kiyokawa basin				
KL1	0- 8	5	7.5YR2/2	brownish black
KL2	8- 14	15	10 YR2/2	brownish black
KL3	14- 23	12	10 YR3/4	dark brown
KL4	23-100	14	10 YR4/4	brown
KM1	0- 15	6	7.5YR2/1	black
KM2	4- 18	5	10 YR2/2	brownish black
KM3	18- 24	15	10 YR3/4	dark brown
KM4	24-100	16	10 YR4/4	brown
KU1	0- 5	4	7.5YR2/2	brownish black
KU2	5- 30	20	10 YR2/2	brownish black
KU3	30- 45	22	10 YR3/4	dark brown
KU4	45-100	16	2.5YR4/4	olive brown
Horonai basin				
HL1	0- 10	4	7.5YR2/1	black
HL2	10- 40	8	7.5YR4/4	brown
HL3	40- 45	12	7.5YR3/2	brownish black
HL4	45-100	19	7.5YR3/3	grayish brown
HM1	0- 4	4	7.5YR2/1	black
HM2	4- 19	9	7.5YR4/4	brown
HM3	19- 29	6	10 YR3/4	dark brown
HM4	29-100	18	7.5YR4/4	grayish brown
HU1	0- 5	7	7.5YR2/1	black
HU2	5- 20	9	7.5YR4/4	brown
HU3	20- 25	10	10 YR3/4	dark brown
HU4	25-100	16	7.5YR5/2	grayish brown

Remark : L=lower part, M=middle part, U=upper part

The physical properties of soils should be clarified, considering the differences in parent materials and the soil evolution processes, and these soil properties should be related to the waterflow process occurring in a basin before the release of precipitation into the streamflow as a direct or delayed flow.

Soil profile examinations to an about 1m depth were performed at three sampling sites on a hill slope of the middle part at each investigated basins. The general characteristics of these profiles were classified based on the color and thickness of each layers as shown in Table 1.

Concerning to basin waterflow processes, the physical properties and depth of soils might be considered to be the most important controlling factors for filtrating the falling precipitation into the soils and subsurface flow production.

Table 2. Grain size distribution of soil materials

Sample sites	Depth (cm)	Soil materials distribution (%)		
		(<0.2mm)	(0.2−2mm)	(>2mm)
Kiyokawa basin				
KL1	0- 8	68.8	11.6	19.6
KL2	8- 14	50.1	30.6	19.3
KL3	14- 23	38.8	20.4	40.8
KL4	23-100	21.9	17.9	60.2
KM1	0- 15	36.6	59.0	4.4
KM2	4- 18	94.8	0.7	4.5
KM3	18- 24	93.0	0.7	6.3
KM4	24-100	55.9	5.9	38.2
KU1	0- 5	27.5	66.1	6.4
KU2	5- 30	81.1	7.3	11.6
KU3	30- 45	51.5	10.5	38.0
KU4	45-100	41.9	5.2	52.9
Horonai basin				
HL1	0- 10	5.8	57.9	57.9
HL2	10- 40	1.9	41.3	56.8
HL3	40- 45	0.6	41.9	57.5
HL4	45-100	1.7	24.8	73.5
HM1	0- 4	2.8	62.9	34.3
HM2	4- 19	1.0	49.9	49.1
HM3	19- 29	0.5	28.4	71.1
HM4	29-100	1.3	69.6	29.1
HU1	0- 5	3.0	56.1	40.9
HU2	5- 20	1.3	57.4	41.3
HU3	20- 25	1.7	55.7	42.6
HU4	25-100	2.2	31.2	66.6

Remark : L=lower part, M=middle part, U=upper part, (<0.2mm)=mixture of slit, clay and fined, sand, (0.2−2mm)=sand, (>2mm)=gravel

Grain size distribution of soil materials

Soil mechanical analysis was carried out by using several mesh of sieves. Particles separation was done by dry and wet method depend on the particles size. Soil materials were classified as gravels (>2mm), sands (0.2 to 2mm) and other fine particles (<0.2mm) which were largely composed of a mixture of silts and clays (Table 2). The amount of fine materials was abundant in Kiyokawa while the amount of coarser grains was relatively small. Conversely, in Horonai, the amount of coarse materials was abundant, whereas finer grain soils was relatively small.

Referring to the characteristics of soil texture, coarse textured soils predominantly of sands and gravels in Horonai considerably favored a vertical flow, whereas the fine textured soils in Kiyokawa inducing a resistance to vertical flow occurred swiftly.

Table 3. Soil moisture content and porosity

Sample sites	Depth (cm)	Soil moisture (%)	Three phases of soils (% Volume) Solid	Liquid	Gas	Porosity (% Vol.)
Kiyokawa basin						
KL1	0- 8	16.8	26.8	35.6	37.6	73.2
KL2	8- 14	16.2	28.2	22.7	49.2	71.8
KL3	14- 23	15.2	29.5	36.1	34.4	70.5
KL4	23-100	10.2	34.9	37.4	27.7	65.1
KM1	0- 15	23.3	14.8	29.1	56.1	85.2
KM2	4- 18	10.4	22.0	29.1	48.9	78.0
KM3	18- 24	12.8	31.1	32.5	36.4	68.9
KM4	24-100	15.5	31.9	33.1	35.1	68.1
KU1	0- 5	16.4	28.1	31.7	40.2	71.9
KU2	5- 30	14.1	38.5	34.0	27.5	61.5
KU3	30- 45	11.5	42.1	39.4	18.5	57.9
KU4	45-100	15.5	46.0	35.9	18.1	54.0
Horonai basin						
HL1	0- 10	3.8	14.0	30.7	55.3	86.0
HL2	10- 40	1.2	29.4	25.3	45.3	70.6
HL3	40- 45	0.7	32.9	17.4	49.7	67.1
HL4	45-100	0.2	33.6	25.6	40.7	66.4
HM1	0- 4	2.4	15.4	29.5	55.0	84.6
HM2	4- 19	0.5	32.6	21.3	46.1	67.4
HM3	19- 29	0.7	36.5	23.2	40.2	63.5
HM4	29-100	0.2	37.2	17.0	45.8	62.8
HU1	0- 5	2.1	17.6	29.2	53.3	82.4
HU2	5- 20	0.4	31.5	20.7	47.8	68.5
HU3	20- 25	1.2	31.9	22.7	45.4	68.1
HU4	25-100	0.4	35.2	22.3	42.5	64.8

Remark : L=lower part, M=middle part, U=upper part

Soil moisture and porosity

Soil substances consist of a mixtures of solid particles, air and water. Excluding the solid particles, the remainder is void or made up pores filled with air or water (Table 3). The soil moisture examination showed that the coarse soils in Horonai have a lower moisture content than the fine soils in Kiyokawa at any depth of layers. Soil moisture distribution in both areas showed a tendency to become smaller successively in the deeper layers.

Moreover, soil porosity in a coarse textured soils (Horonai) was slightly smaller than in a finer soil (Kiyokawa). Therefore, after smaller pore spaces are completely filled, water begins to fill the larger voids. Coarse textured soils have a larger pore size than fine textured soils, the pores being the passageways of water movements in the soils. Hence, a greater amount of water can move into the deeper layers in coarse soils, due to the larger pore spaces providing more possibilities much longer time for temporary water storages before percolating into the deeper layers.

Under any precipitation, fine soils would be saturated faster than coarse soils, where the infiltrated water moving slowly due to being tightly held in small pores interstices, forming impermeable layers. On the other hand, coarser soils would store infiltrated water in large pore interstices which would favor deep percolation. Due to the fine soils has a greater retention water, the conditions at Kiyokawa favored subsurface flow, while Horonai was largely favored deep percolation.

Infiltration and permeability

Infiltration rate estimations are presented in Table 4. They show a higher rate in the beginning and then decrease gradually over time with the entering of water. It can be noted that during the period of approximately one hour, the infiltration rate decreased from 3000mm to 900mm in Kiyokawa and 2070mm to 900 mm in Horonai. This might have been caused by the large pores becoming clogged with inwashed soil materials or as

Table 4. Average infiltration rate

No.	Inserted water (mm)	Cumulative time (minutes) Kiyokawa	Cumulative time (minutes) Horonai	Infiltration rate Kiyokawa (mm/min) (1)	Infiltration rate Kiyokawa (mm/hr) (2)	Infiltration rate Horonai (mm/min) (1)	Infiltration rate Horonai (mm/hr) (2)
1.	125	2.5	3.7	50.0	3000	34.5	2070
2.	250	7.1	9.1	35.5	2130	27.5	1650
3.	375	13.4	16.4	28.5	1710	23.0	1380
4.	500	21.3	25.4	23.5	1410	19.5	1170
5.	625	30.8	35.2	21.0	1260	18.0	1080
6.	750	41.2	46.3	18.5	1110	16.5	990
7.	875	53.7	58.7	16.5	990	15.0	900
8.	1000	67.8	72.8	15.0	900	14.0	840
9.	1125	84.1	87.9	13.5	810	13.0	780
10.	1250	101.6	103.4	12.5	750	12.7	762

Remark : (1)=measured, (2)=calculated

Table 5. Coefficients of soil permeability

Sample sites	Depth (cm)	Coef. of permeability (mm/sec)			
		(1)	(2)	(3)	Ave
Kiyokawa basin					
KL1	0- 8	0.75	0.81	0.61	0.72
KL2	8- 14	0.51	0.45	0.46	0.47
KL3	14- 23	0.39	0.31	0.30	0.33
KL4	23-100	0.44	0.25	0.14	0.28
KM1	0- 15	0.81	0.71	0.71	0.75
KM2	4- 18	0.27	0.31	0.35	0.31
KM3	18- 24	0.27	0.31	0.35	0.31
KM4	24-100	0.25	0.22	0.22	0.23
KU1	0- 5	0.37	0.39	0.41	0.39
KU2	5- 30	0.41	0.51	0.54	0.49
KU3	30- 45	0.13	0.42	0.85	0.46
KU4	45-100	0.05	0.06	0.05	0.05
Horonai basin					
HL1	0- 10	1.61	1.70	1.79	1.70
HL2	10- 40	0.78	0.71	0.75	0.75
HL3	40- 45	3.30	0.23	0.32	1.28
HL4	45-100	0.35	0.40	0.41	0.39
HM1	0- 4	1.67	1.57	1.65	1.63
HM2	4- 19	2.27	2.23	2.19	2.23
HM3	19- 29	1.36	1.33	1.39	1.36
HM4	29-100	0.20	0.37	0.37	0.31
HU1	0- 5	1.61	1.70	1.79	1.70
HU2	5- 20	1.27	1.23	1.22	1.24
HU3	20- 25	0.33	0.23	0.32	0.29
HU4	25-100	0.35	0.40	0.41	0.39

Remark : L=lower part, M=middle part, U=upper part, (1)...(3)=replication measurements

a result of soils becoming saturated with water.

Soil hydraulic conductivity was examined (Table 5), and the results showed that the permeability of coarse soils (Horonai) was comparatively greater than that of fine soils (Kiyokawa). This indicated that after precipitation had infiltrated into the soil surface, water moved vertically in the coarse grain soils faster than in fine grain soils.

As water moved in the soils, hydraulic conductivity would increase along with soil moisture content, because the larger pores would be filled. Therefore, it could be surmised that majority of waterflow occurred in the larger connecting pores. Consequently, coarser soils might carry a large amount of flowing water from the upper layers which were or nearly were saturated to be stored in the deeper soil layers, while the fine grain soils with no larger pores stored a lesser amount of water.

IV. Streamflow Characteristics

The paths followed by precipitation, from the time it strikes the land surface until it appears as a streamflow, have been of great interest to research hydrologists. Such information is very important for predicting the timing, magnitude and distribution of streamflows throughout the year (Kennedy, 1986).

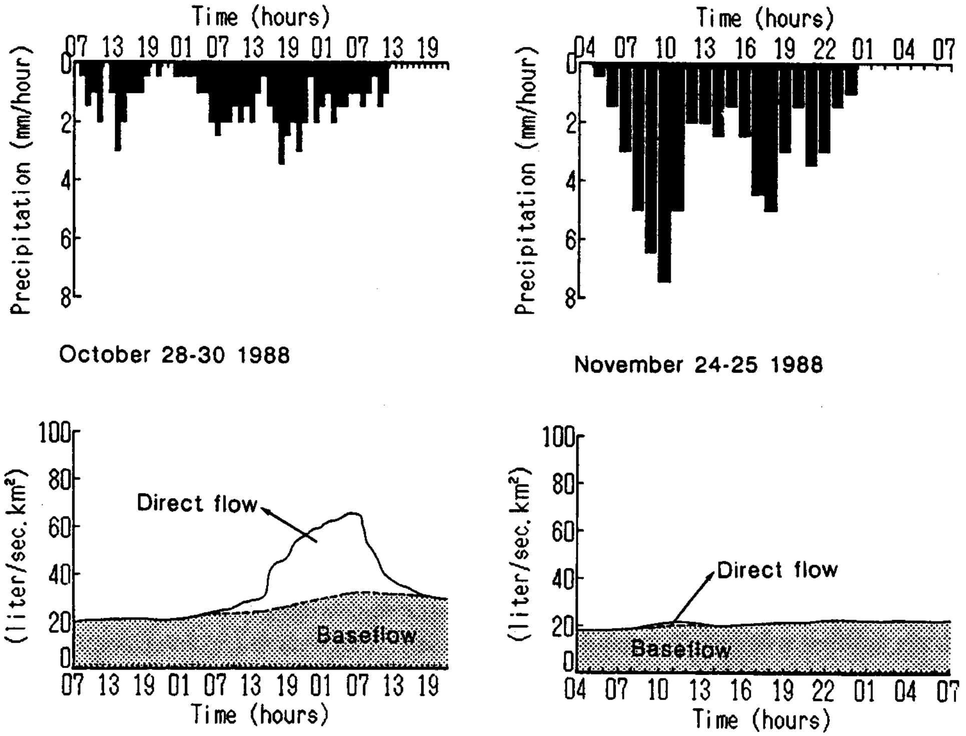
In this study, to assess the streamflow characteristics, continuous streamflow measurements (1988-1989) as the hydrologic output of both investigated basins were used (Appendixes 4 and 5).

1. Hydrograph analysis

Streamflow hydrograph can be regarded as an integral expression of the basin characteristics and its climatic environments, representing the input-output relationship between precipitation and streamflow. Therefore, hydrograph analysis was used to analyze the streamflow characteristics.

1) Streamflow hydrograph of individual precipitation

Streamflow components, conceptually, may be considered as the surface, subsurface and groundwater flow. For practical purposes, surface and subsurface flows were treated as direct or quick flows, whereas groundwater flows were described as base or delayed flows. Quantitative distinctions were arbitrarily decided based on the arrival time of



October 28-30 1988

November 24-25 1988

Streamflow hydrograph in response to 71 mm precipitation

Streamflow hydrograph in response to 62.5 mm precipitation

Fig. 7. Streamflow hydrographs of the observed rivers.

water into the stream channel inferred from its appearance on the streamflow hydrographs.

Analysis of individual precipitation occurances was performed under the following seasonal precipitation changes. The first step was done by selecting clusters of consecutive precipitation occurrances which might produce direct flows. Subsequently, the corresponding precipitation data was plotted against the streamflow data. Due to the fact that both of the investigated basins were different in area, streamflow discharge data was expressed as specific discharge volume per unit area for comparative purposes.

A typical streamflow hydrograph, expressing how precipitation traveled into stream channels was shown in Fig. 7. Peak flow represents the highest concentration of streamflow, whereas a falling limb indicates the withdrawal of direct inflows. The increases in direct flows in Kiyokawa River were greater compared with Horonai River. To estimate each source of streamflow, the direct and base flows were separated by a dashed segment even though it is impossible to draw an exact hydrograph separation line on any hydrograph.

Separation of the streamflow components was done by extending the antecedent flow rate to a point directly below, or a little beyond the peak flow, and then connecting this point to an arbitrary point on the recession limb. This procedure was applied since the base flow could not be precisely determined. The initial base flow was assumed to be equal to the total discharge. Afterward, the values for the later base flow were estimated until reaching an arbitrary end point of direct flow.

2) Hydrologic response and direct flow ratio

Hydrologic response expresses an increase in streamflow following the occurrence of precipitation. It was used to indicate how the basin characteristics influence the transmission of precipitation into direct or delayed flows. To estimate the composition of streamflow source contributions, the proportion of direct flow to total streamflow was expressed as direct flow ratio.

Fig. 8 shows the distribution of hydrologic response and the direct flow ratio. Hydrologic response ranged from 0.2 to 5.2% for Kiyokawa, and 0.03 to 0.9% for Horonai. The average was found to be 1.3% and 0.13% respectively. These results confirmed that most of the precipitation infiltrated into the soils due to precipitation intensity almost never exceeded the infiltration rate.

The average proportion of direct flow to total streamflow was 7.6% and 2.0%, while the ranges were found to be 1.3-30.2% and 0.4-8.5% for Kiyokawa and Horonai respectively. Accordingly, it could be drawn as an inference that the direct flow contribution in the Kiyokawa River was greater, due to a larger amount of direct flow contribution into the streamflow.

2. Seasonal changes of streamflow

Annual hydrographs (Fig. 9) showed that in the mid-winter and early summer of each year streamflow was nearly minimum. Conversely, heavy increases in streamflows from melting snow occurred in early spring, though precipitation was light and in the late summer as precipitation increased and basin storage was recharged.

Kiyokawa River showed a high level of response to precipitation and snowmelt, revealing poor storage caused by impermeable or shallow soil layers, steep slopes and high drainage density. Meanwhile, Horonai River varied little over the year, indicating ex-

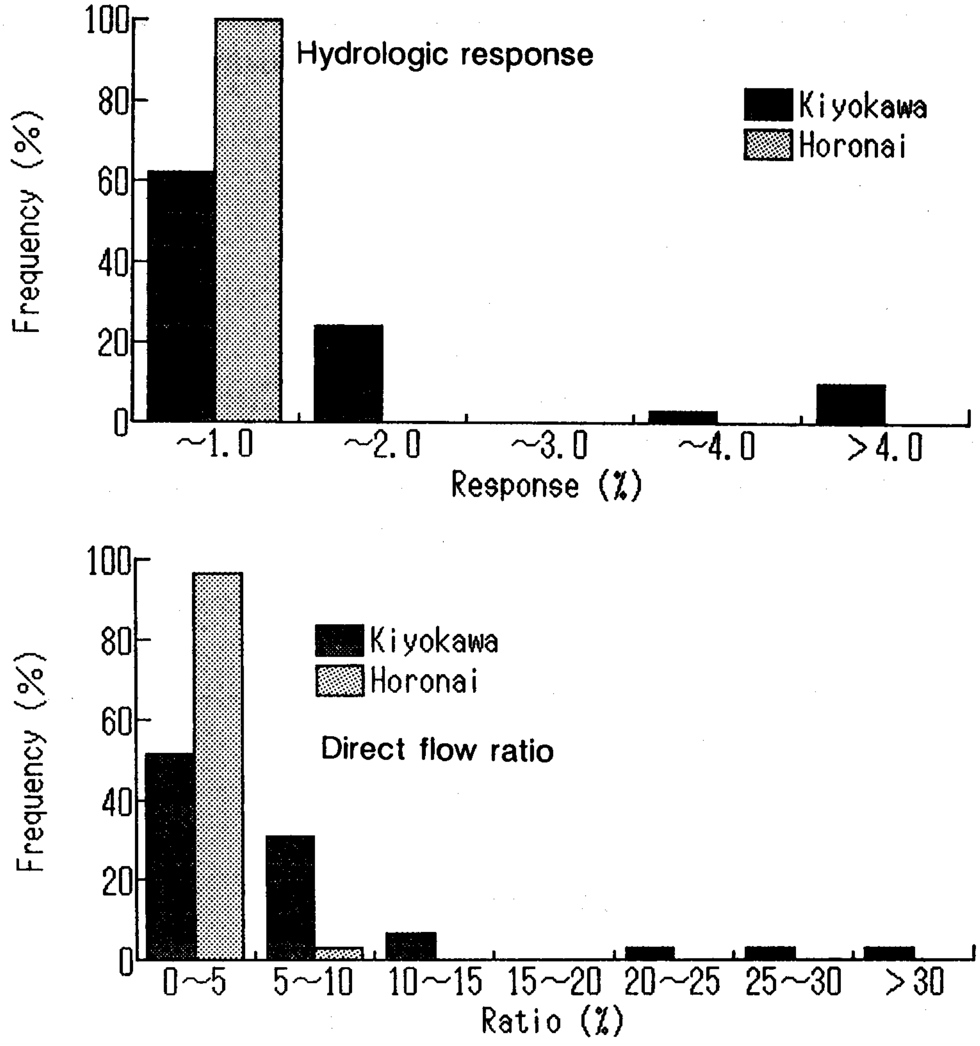


Fig. 8. Distribution of hydrologic response and direct flow ratio.

cellent storage in deep, permeable soils with superb downward percolation.

The range of annual streamflow of Kiyokawa in 1988 was 4.4 to 72.2 ℓ /sec·km^2 and in 1989 was 5.4 to 85.6 ℓ /sec· km^2 . In Horonai it was 16.0 to 32.6 ℓ /sec·km^2 (1988) and 15.7 to 42.8 ℓ /sec·km^2 (1989) respectively. Furthermore, Kiyokawa River showed annual changes on dominant streamflow discharge, while Horonai was relatively steady as shown in Fig. 10.

Kiyokawa River predominantly in the 5.0 to 10.0 ℓ /sec·km^2 range in 1988, whereas in 1989 both the 5.0 to 10.0 ℓ /sec·km^2 and 10.0 to 15.0 ℓ /sec·km^2 ranges were dominant. This change in dominant streamflow range was largely caused by seasonal precipitation changes in terms of the amount of precipitation and its distribution. The dominant streamflow discharge in Horonai ranged from 15.0 to 20.0 ℓ /sec·km^2 (1988-1989) under the seasonal changes of precipitation.

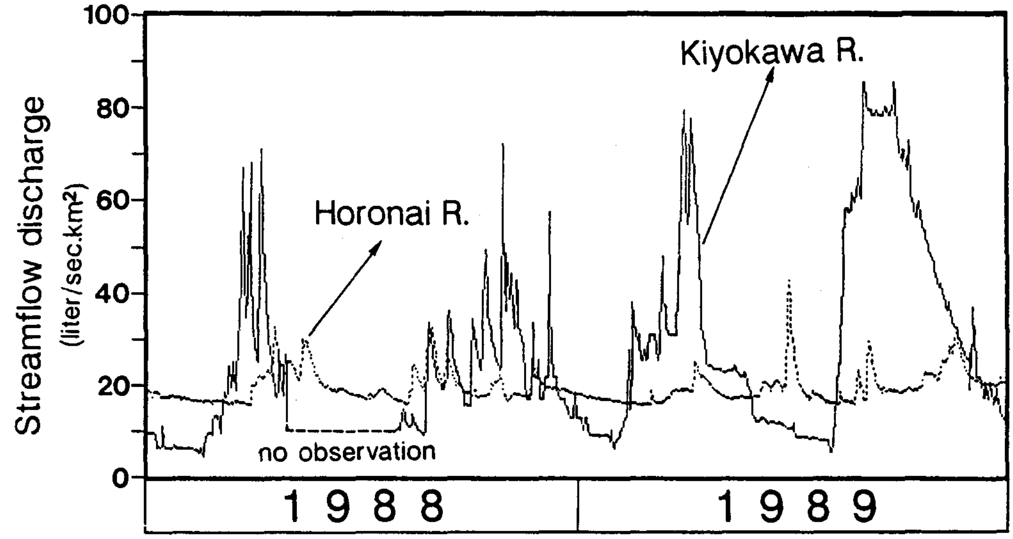


Fig. 9. Annual streamflow hydrograph of the investigated basins.

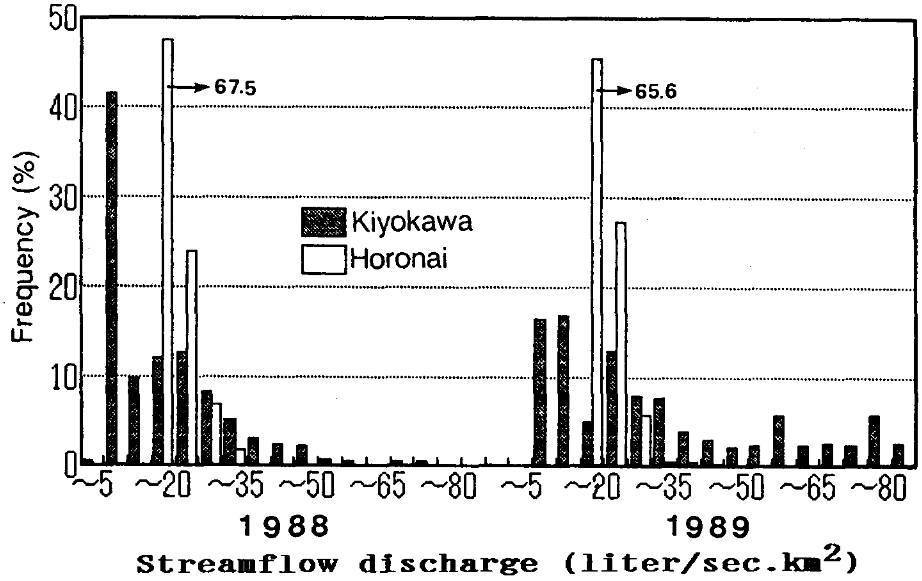


Fig. 10. Annual changes of specific streamflow discharge distribution.

1) Index of basin regime

Seasonal streamflow variation was expressed by representing the maximum and minimum of daily discharge rates and their maximum/minimum ratios (Cr) of each month as shown in Table 6 and Fig. 11. The maximum and minimum were 85.6 ℓ/sec·km^2 (September) and 4.4 ℓ/sec·km^2 (February) in the Kiyokawa River, while in the Horonai

Table 6. Monthly changes on maximum and minimum of mean daily streamflow discharge rates (liter/sec·km²)-(1988-1989)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Kiyokawa basin												
Ma	10.9	13.1	68.3	71.1	—	—	—	33.6	36.1	72.2	48.	57.4
	12.7	38.1	73.1	79.7	24.3	12.7	12.0	65.0	85.6	74.0	46.5	36.8
Av	7.5	7.4	29.4	30.1	—	—	—	14.9	22.3	31.7	29.3	19.6
	10.2	19.9	37.3	43.7	21.6	12.1	9.0	37.3	79.6	60.5	35.4	19.9
Mi	6.4	4.4	9.5	12.4	—	—	—	9.2	15.6	15.6	16.9	12.7
	7.6	6.4	25.4	23.7	12.7	10.9	8.2	5.4	60.7	47.3	25.4	12.0
Cr	1.7	3.0	7.2	5.7	—	—	—	3.7	2.3	4.6	2.9	4.5
	1.7	6.0	2.9	3.4	1.9	1.2	1.5	12.0	1.4	1.6	1.8	3.1
Horonai basin												
Ma	19.7	17.3	19.9	32.6	29.7	19.8	19.1	32.5	28.8	22.0	24.2	20.7
	18.0	16.6	19.1	25.0	18.4	42.8	37.3	23.1	29.6	22.8	31.1	21.8
Av	17.9	16.7	16.3	23.6	24.1	18.6	17.8	21.5	21.9	18.9	19.0	19.2
	17.4	16.1	17.5	20.7	17.5	21.1	20.5	17.0	20.5	20.0	25.3	20.7
Mi	17.1	15.9	15.7	19.8	19.6	17.5	16.8	16.0	18.2	17.3	16.6	18.0
	16.8	15.7	15.7	18.6	17.0	17.7	16.3	15.7	17.0	18.4	21.2	20.1
Cr	1.2	1.1	1.3	1.6	1.5	1.1	1.1	2.0	1.3	1.3	1.5	1.2
	1.1	1.1	1.2	1.3	1.1	2.4	2.3	1.5	1.7	1.2	1.5	1.1

Remark: *Ma*=maximum, *Av*=average, *Mi*=minimum, *Cr*=maximum/minimum ratio

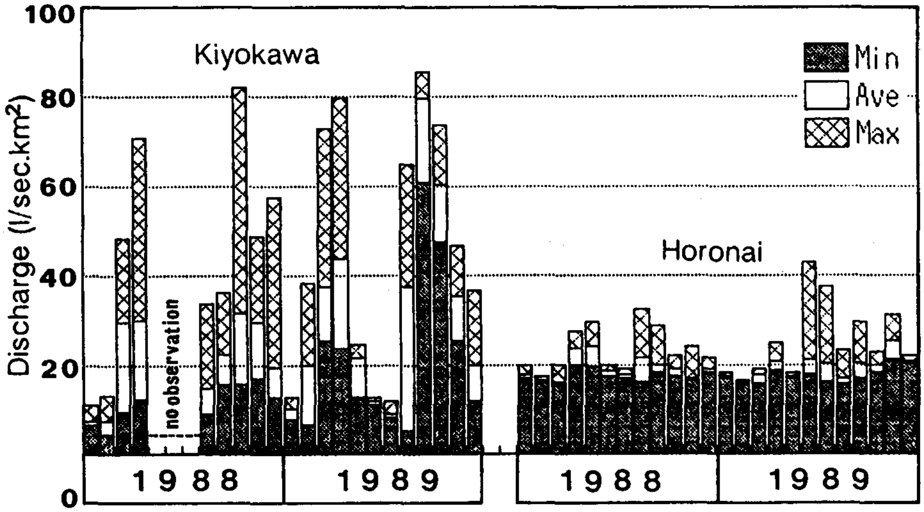


Fig. 11. Monthly changes of specific streamflow discharge rates.

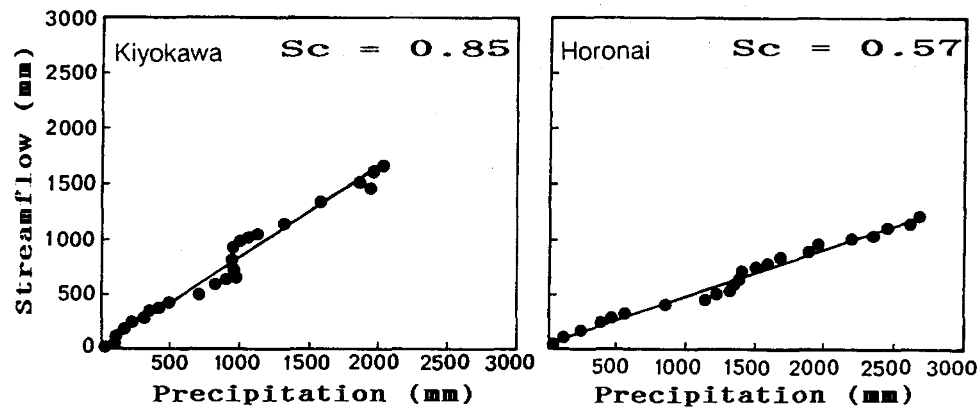


Fig. 12. Precipitation-streamflow correlation (1988-1989).

River the values were found to be 42.8 ℓ /sec·km^2 (June) and 15.7 ℓ /sec·km^2 (February).

The range of the Cr was found to be 1.2-12.0 and 1.1-2.3 for Kiyokawa and Horonai, respectively. It could be shown that the range of Cr in Kiyokawa was almost ten times as great as in Horonai. Moreover, the average Cr for the two rivers was 3.5 and 1.4, with the value for Cr in Kiyokawa being almost three times as great as that in Horonai.

From these results, it might be surmised that the streamflow in the Kiyokawa River was somewhat erratic compared with the Horonai River, due to the waterflow processes for releasing infiltrated and percolated precipitation in the Kiyokawa Basin was faster than in the Horonai Basin.

2) Streamflow coefficient and basin storage

As previously discussed, streamflow considerably varies corresponding to the seasonal precipitation changes. By plotting the streamflow against the precipitation, a specific correlation was obtained shown in Fig. 12. This streamflow coefficient (Sc), is a parameter to express the proportion of occurring precipitation to the streamflow.

The Sc for Kiyokawa was greater than that for Horonai, indicating a higher release of precipitation to the streamflow during 1988-1989. Consequently, it could be assumed that the releasing process of basin storage in Kiyokawa was faster than in Horonai. In other word, the basin storage capability was significantly different in the two basins.

The precipitation-streamflow correlation naturally differs according to the seasonal changes of precipitation and basin characteristics. However, due to the lack occasionally of streamflow records, this correlation seems possible to be used for determining streamflow changes according to the seasonal precipitation in any unmeasured basin having similar physical characteristics to basins already calibrated for their Sc.

Concerning basin storage capacity, it can be derived by estimating the difference between precipitation and streamflow as shown in Fig. 13. Although it is only a very rough estimation, it can be used easily to show the potential recharge of precipitation into basin storages and the potential basin water losses through evapotranspiration.

Furthermore, considering the magnitude of basin water loss in the investigated basins is not exceedingly different, it might be accepted that potential recharge into basin storage in Kiyokawa was lower compared with in Horonai, due to the faster discharge of water

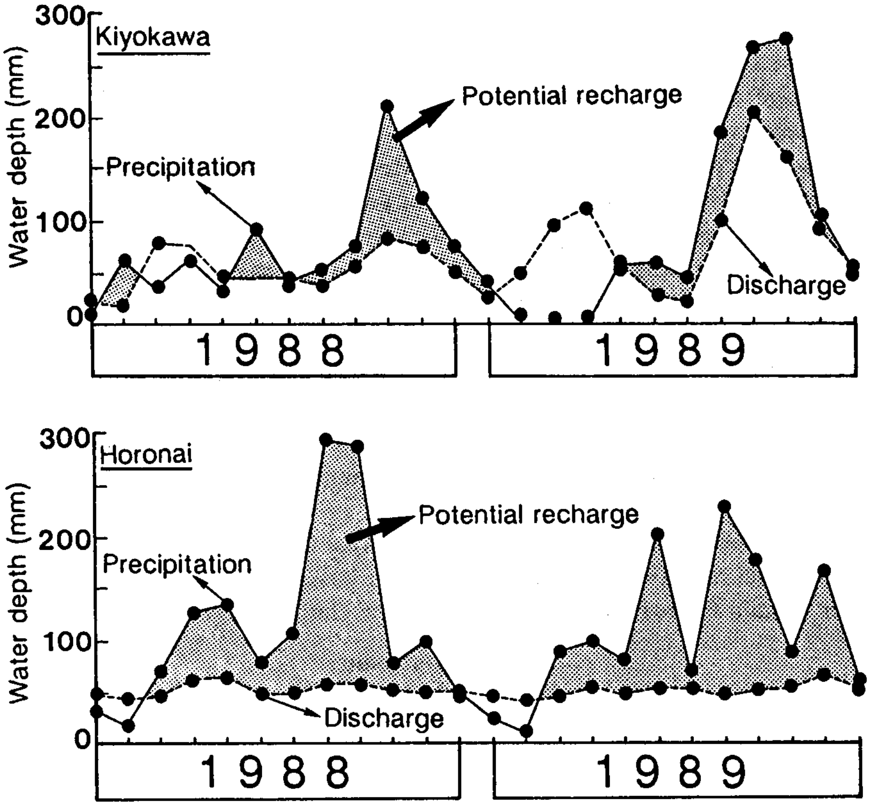


Fig. 13. Potential recharge for basin storage.

from basin storage into the streamflow.

Conclusively, it was confirmed that the streamflow source of Kiyokawa River was eagerly considerably maintained by both subsurface flow and groundwater proportionally, whereas Horonai River was mostly fed by groundwater. Consequently, the streamflow in the Kiyokawa River fluctuated greatly according to the seasonal changes of precipitation, while the Horonai River was relatively steady.

Conclusion

Streamflow characteristics are determined largely by the climate of the areas and are influenced by basin characteristics, especially in terms of geological conditions. The soils formed in the Tertiary mudstone and Volcanic areas have different physical properties which influence greatly the filtration of precipitation, water storage and movement in the soil, and the processes of the release of storage water into the streamflow.

A higher drainage density in Kiyokawa indicated the basin impermeability in subsoil materials and a mountainous relief, whereas the lower one in Horonai represented a higher occurs of permeable subsoil materials and a low relief. This difference generated different stream types of intermittent streams primarily fed by quick flow and perennial streams mainly maintained by delayed flows, as indicated by each hydrologic responses.

A lack of surface flow indicated that most of quick flows were generated from subsurface flow. A greater hydrologic response and direct flow ratio in Kiyokawa revealed a poor basin storage capacity, whereas the lower one in Horonai indicated an excellent storage capacity, showing the basin storage capability of volcanic areas was greater compared with mudstone areas.

The seasonal streamflow changes was greater for Kiyokawa than Horonai indicated by a higher Sc, denoting a faster redistribution of precipitation to the stream channel. The lower one for volcanic areas represents streamflow retardation through basin storage. Referring to streamflow distribution over time, this evidence revealed that the quick flow contribution in mudstone areas was greater than in volcanic areas.

To develop a data base system for assessing the hydrological condition, the input-input analysis is proposed to be applied, since it can be easily used for both short and long-term purposes. The hydrologic response and direct flow ratio derived from hydrograph analysis is suggested for indicating the streamflow sources, while the index of basin regime and streamflow coefficient seem possible for ascertaining the seasonal changes of streamflow.

Considering these results, more studies of streamflow characteristics under many different geological conditions associated with other basin characteristics should be carried out in order to gain further insight into streamflow characteristics.

Acknowledgements

We wish to thank Prof. Koichiro FUJIWARA, Dr. Kaichiro SASA, Dr. Yumiko TANAKA, Mr. Tomoyuki NANRI and all members of the Laboratory of Erosion Control Engineering, Hokkaido University, for their kind help and useful suggestions.

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要約

水資源を開発する場合，その河川流域での水需要量と可給水量との関係が最も重要となる。本研究は水を供給する河川の流出特性と流域内での流出過程を，地質条件の異なる2流域でのinput（降水量）とoutput（流出）との関係に着目し，このinput-outputの関係と流域特性との関連から比較検討を行った。調査地は第三紀泥岩地域（清川）と第四紀火山性地域（幌内川）で，流域特性調査と降水量および気温の観測を行った。

1）清川観測流域（面積182.4 ha，流域平均勾配43％）では細砂，シルト，粘土が多くを占めるが，一方の幌内川観測流域（1037.6 ha，10％）は粗粒砂で構成されていた。浸透能は両流域とも1000 mm/hr以上と大きな値であったが，透水性は幌内川流域の方がより大きかった。

2）年間の流量ハイドログラフから，両流域とも流量は初夏の渇水期と厳冬期に小さく，融雪期と晩夏の多雨時期に大きいかった。また，一連続降雨による流量ハイドログラフから，清川の流量が幌内川に比べ早く増加していた。

3）直接流出量/降水量を求めると，清川では0.2～5.2（平均1.3％），幌内川では0.03～0.9（平均0.13％）であった。また直接流出量/全流出量は，清川では1.3～30.2％（平均7.6％），そして幌内川では0.4％～8.5％（平均2.0％）であった。

4）清川における'88年（降水量900 mm）の流量変動幅〈ならびに流量頻度分布〉は，4.4～72.2 ℓ/sec・km²：40％〈5～10 ℓ/sec・km²：40％〉，'89年（1107 mm）が5.4～85.6 ℓ/sec・km²〈5～10 ℓ/sec・km²：16％，10～15 ℓ/sec・km²：16％〉であった。また幌内川では，'88年（1374 mm）が15.7～42.8 ℓ/sec・km²〈15～20 ℓ/sec・km²：67％〉，そして'89年（1313 mm）は16.0～32.6 ℓ/sec・km²〈15～20 ℓ/sec・km²：65％〉であった。

5）'88～'89の両年で各月の最大流量/最小流量を求めると，清川で1.2～12（平均3.5），幌内川で1.1～2.3（平均1.4）となった。

6）Streamflow coefficient（Sc）は，清川で0.85、幌内川で0.57となった。

7）表面流出は両流域とも見られなかった。これは1)より，浸透能が降雨強度よりかなり大きな値を示したことから説明できる。このことに3)を考え合わせると，両流域とも中間流出

と地下水流出がほとんどで，清川は中間流出と地下水流出が幌内川では地下水流出が大部分を占めると考えられた。

8)　1)と2)より，清川流域は透水性が低く浅い土壌層と急斜面のため貯留性が低く，また幌内川流域は透水性のよい土層のためすぐれた貯留性を持っていると考えられた。

9)　降水の季節的変動に伴う流量の変動は，5)より第三紀泥岩地域で大きく，第四紀火山性地域では相対的に安定していることが，さらに6)より降水が浸透・透水して河道に流出するまでの時間は，第三紀泥岩地域の方が第四紀火山性地域に比べより速い事が明らかとなった。

Photo 1. Scanty water level in Kiyokawa River.

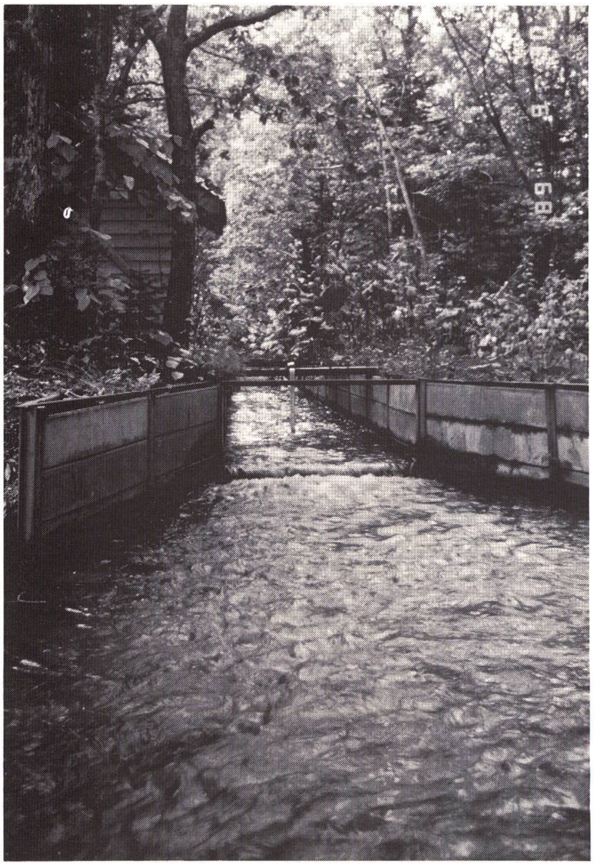

Photo 2. Streamflow of Kiyokawa River on peak discharge.

Photo 3. Scanty water level in Horonai River.

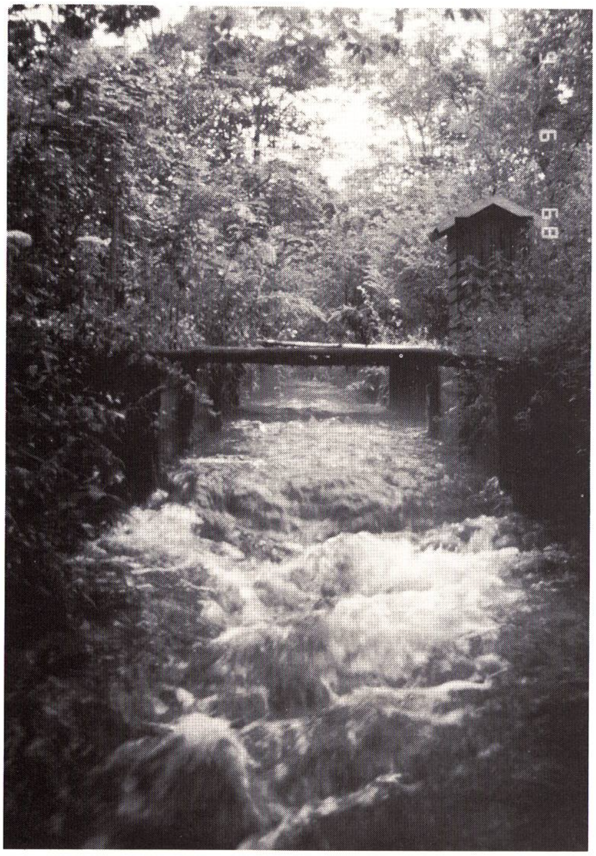

Photo 4. Streamflow of Horonai River on peak discharge.

Appendix 1. Average and range of monthly mean for climatic variables of both investigated basins (1985-1989)

No.	Climatic variables (unit)	Period (year)	Range	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Kiyokawa basin															
1.	Precipitation	1985-1989	Avg.	56.5	43.5	36.5	49.0	61.0	59.0	71.0	106.0	172.0	187.0	145.0	89.0
	(mm)		Max.	99.5	63.0	55.5	79.5	82.0	94.5	111.5	188.0	269.0	278.0	182.0	138.5
	(1076mm/yr)		Min.	13.0	4.5	0.0	2.0	36.5	39.5	42.0	50.0	78.5	108.5	108.5	50.0
2.	Air temperature	1985-1989	Avg.	−6.4	−7.6	−0.8	5.8	11.3	15.4	20.0	22.8	17.0	10.3	4.1	−2.6
	(°C)		Max.	3.8	3.7	8.5	17.9	22.4	25.8	29.3	30.8	26.5	21.8	14.9	7.5
			Min.	−23.7	−23.0	−14.7	−5.3	0.9	4.9	10.5	15.4	6.1	0.8	−5.5	−14.0
3.	Relative humidity	1985-1989	Avg.	77.3	77.5	75.6	73.3	70.3	74.7	77.7	78.5	78.3	76.9	78.4	79.0
	(%)		Max.	89.1	90.3	89.3	91.3	87.2	89.2	89.6	88.2	88.8	88.9	90.0	90.6
			Min.	43.9	38.7	36.4	20.6	16.2	20.8	20.6	17.7	20.3	23.4	32.2	39.2
4.	Wind speed	1985-1989	Avg.	2.9	2.5	3.0	2.9	3.3	2.8	2.5	2.3	2.2	2.5	2.7	2.4
	(m/sec)		Max.	9.7	11.4	12.3	10.7	11.2	9.5	7.9	8.1	8.9	9.9	12.4	11.1
			Dir.	WSW	NNE	WRW	WSW	WSW	NE	NNE	WSW	SW	NNE	NNE	WSW
Horonai basin															
1.	Precipitation	1985-1989	Avg.	23.0	15.5	69.0	121.0	81.0	76.0	155.0	228.0	179.0	93.0	116.0	40.5
	(mm)		Max.	31.5	18.0	88.5	179.0	135.5	207.0	246.5	405.0	289.5	171.5	172.0	65.0
	(1197mm/yr)		Min.	12.5	13.0	50.5	37.0	26.0	12.5	69.0	90.0	60.0	64.0	67.0	10.0
2.	Air temperature	1985-1989	Avg.	−8.2	−6.9	−2.0	3.8	8.2	12.6	16.2	19.5	15.1	7.7	1.2	−2.2
	(%)		Max.	−2.2	−0.4	2.3	9.2	13.3	17.3	19.6	22.6	19.9	14.4	9.3	2.8
			Min.	−15.2	−13.3	−7.9	−1.3	2.1	8.1	12.7	16.4	9.6	1.4	−5.5	−6.7
3.	Relative humidity	1977-1981	Avg.	83.5	79.5	80.8	83.3	82.0	90.0	94.3	95.5	89.3	87.3	80.5	83.5
	(%)		Max.	98.8	96.3	96.3	99.5	99.0	99.9	99.9	99.7	99.5	99.8	98.5	98.8
			Min.	57.3	54.3	58.5	58.3	59.3	75.8	84.8	85.3	70.8	63.0	53.5	56.5
4.	Wind speed	1985-1989	Avg.	2.3	2.5	2.6	2.7	2.8	2.2	2.2	2.4	4.5	2.5	2.5	2.7
	(m/sec)		Max.	5.3	5.1	5.5	5.7	5.7	4.4	4.4	5.1	8.3	5.2	6.7	6.1
			Dir.	NW	WNW	WNW	SSW	SSE	SSW	SSW	SSW	SE	NNW	SSW	WNW

Appendix 2. Daily precipitation (mm) in Kiyokawa basin (1988-1989)

Date	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1.	0.0	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	3.5	0.5	0.0	0.0	1.0	0.0	0.0	0.5	3.5	0.0	3.0	1.0
2.	0.0	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.0	24.5	0.5	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	40.5	0.5	0.0	0.5
3.	0.0	10.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	32.5	1.5	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	34.5	0.0	0.0	0.5
4.	0.0	2.5	0.0	1.5	3.0	31.0	0.0	0.0	0.0	4.5	4.0	6.5	0.0	0.0	0.0	0.0	2.5	1.0	0.0	0.0	16.0	0.0	0.0	1.0
5.	0.0	0.5	2.5	0.5	1.0	12.5	0.0	0.0	0.0	7.5	12.0	6.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.5	22.0	0.0	5.0
6.	0.0	3.0	6.5	0.0	0.0	1.5	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	14.0	0.0	0.0	0.5	34.0	6.5	0.0
7.	0.0	10.5	2.0	0.0	0.0	2.0	0.0	0.0	0.0	0.5	0.0	7.0	21.5	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	1.5	37.0	1.0
8.	0.0	2.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.5	1.5	1.5	0.0	0.0	0.0	0.0	0.0	1.0	11.5	0.0	12.0	0.0	0.0
9.	0.0	0.0	1.5	0.0	0.0	0.0	4.0	0.0	22.0	0.0	12.5	30.0	0.0	0.0	0.0	0.0	8.0	0.0	0.0	3.0	0.5	21.0	7.5	0.5
10.	0.0	0.5	1.0	0.0	0.0	0.0	22.5	0.0	3.5	7.0	3.5	0.0	1.5	0.0	0.0	0.0	0.5	0.0	1.0	29.0	0.0	0.0	0.0	1.0
11.	0.0	1.5	0.5	0.0	0.0	0.0	15.5	0.0	0.0	13.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.5	13.5	2.5	0.5	8.0
12.	0.0	0.5	1.5	0.5	0.0	0.0	0.0	0.0	34.0	20.0	0.5	0.0	0.0	0.0	0.0	0.0	0.5	0.0	9.5	0.0	8.0	0.0	8.5	10.5
13.	0.0	0.5	2.0	3.0	23.0	14.0	0.0	0.0	2.0	10.5	17.5	0.0	0.0	0.0	0.0	0.0	2.5	0.0	0.0	5.5	16.5	0.0	25.5	1.5
14.	0.0	0.0	4.0	0.5	0.0	17.5	0.0	0.0	0.5	14.5	3.0	20.0	0.0	0.0	0.0	0.0	12.5	0.0	0.0	0.0	0.0	0.0	7.5	0.5
15.	0.0	0.0	0.5	9.0	0.0	0.0	0.0	0.0	0.0	2.5	0.0	1.5	0.0	0.0	0.0	0.0	17.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16.	0.0	0.0	3.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0	0.0	0.0	0.0	0.0	22.0	0.0	0.0	0.0	19.5	3.0	0.0
17.	0.0	0.0	0.5	0.5	0.0	13.0	0.0	0.0	0.0	0.5	1.0	0.5	0.5	0.0	0.0	0.0	0.5	0.5	0.0	0.0	1.5	9.0	1.5	0.0
18.	0.0	0.0	0.0	0.0	3.5	0.5	0.0	0.0	0.0	4.5	4.5	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.5	1.5	0.0	7.5
19.	0.0	4.5	0.0	3.5	0.5	1.0	0.0	0.0	0.0	2.5	1.5	0.0	2.0	0.0	0.0	0.0	0.0	0.0	1.5	0.0	0.0	55.0	3.5	3.0
20.	0.0	0.5	0.5	8.0	5.0	1.5	0.0	0.0	7.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	8.5	0.0	18.0	0.0	47.5	8.0	0.0	8.0
21.	0.0	0.5	1.5	0.0	0.5	0.0	0.0	0.0	0.0	5.5	2.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	1.0	0.5	0.0	0.5
22.	0.0	0.5	0.5	6.0	0.0	0.0	0.0	0.0	2.0	1.0	2.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	2.5	21.0	0.0	17.0	0.0	0.0
23.	0.0	6.5	6.0	13.5	0.0	0.0	0.0	0.0	7.5	0.0	4.0	0.0	0.0	0.0	0.0	0.0	2.0	11.5	0.0	49.5	0.0	7.5	0.0	0.0
24.	0.0	1.5	0.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0	9.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.5	0.5	0.0	26.5	0.0	0.0
25.	0.0	1.0	0.0	2.0	0.0	0.0	0.0	35.5	0.0	0.0	13.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.0	0.0	0.0	0.0
26.	0.0	1.5	0.0	7.0	0.0	0.0	0.0	15.5	0.0	5.0	2.5	0.0	0.5	0.0	0.0	0.0	0.0	5.5	0.0	0.0	20.0	15.0	0.0	0.0
27.	0.0	8.0	0.0	5.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.5	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.5	1.5	0.0	0.0
28.	0.0	2.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	16.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	57.	29.0	12.5	0.0	0.0
29.	6.0	1.5	0.0	0.0	0.0	0.0	0.0	3.0	0.0	39.5	0.0	0.0	0.0	0.0	0.0	1.0	0.0	8.0	0.0	1.0	7.0	0.0	2.0	0.0
30.	3.0		0.0	0.0	0.0	0.0	0.0	0.0	0.0	15.0	0.0	0.0	1.5		0.0	0.0	0.0	0.0	0.0	0.0	9.0	0.0	2.5	0.0
31.	4.0		0.0		0.0		0.0	0.0		0.0		0.5	2.5		0.0		0.0		10.5	8.5		11.0		0.0
Total	13	63	38	65	37	95	42	54	79	213	125	79	40	5	0	2	59	64	45	188	269	278	109	50

Appendix 3. Daily precipitation (mm) in Horonai basin (1988-1989)

Date	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1.	9.5	0.0	0.5	0.0	1.0	0.5	0.0	0.0	2.0	2.0	0.0	0.0	4.5	0.0	0.5	1.5	0.0	0.0	0.0	1.0	0.0	0.0	5.0	0.0
2.	0.5	2.0	1.0	0.0	0.0	0.0	0.0	0.0	0.5	11.0	3.5	0.0	0.5	0.0	0.0	0.5	0.0	0.0	0.0	0.0	17.5	0.0	0.0	1.5
3.	0.0	1.0	2.5	0.0	0.0	8.0	0.0	0.0	0.0	0.0	0.5	0.0	2.5	1.0	2.5	0.0	0.0	0.0	0.0	0.0	54.0	0.0	0.0	0.0
4.	0.0	0.0	2.0	0.0	8.0	6.0	0.0	0.0	4.0	0.0	21.0	0.0	0.0	0.0	39.5	0.0	0.5	0.0	1.5	0.0	16.5	10.5	0.0	1.0
5.	0.0	0.0	0.5	0.0	0.0	1.0	0.0	3.0	0.0	0.0	4.0	0.0	0.0	0.0	0.5	1.5	0.0	0.0	0.0	0.5	0.0	16.5	0.0	0.0
6.	0.0	0.0	0.5	8.0	0.0	0.0	0.0	10.5	1.0	1.5	1.5	0.0	0.0	0.0	0.0	0.0	0.0	30.5	0.0	0.0	5.5	0.5	15.0	0.0
7.	0.0	0.0	0.0	1.0	0.0	9.5	8.5	0.0	0.0	8.0	1.0	15.5	0.0	0.0	0.5	0.5	0.0	1.0	0.5	1.5	0.0	0.0	28.0	3.5
8.	0.0	0.0	0.5	0.5	0.0	0.0	37.5	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.5	6.5	0.0	0.0	0.0	2.5	0.0	0.0	3.5	14.5
9.	1.5	1.0	0.5	0.0	0.0	23.5	20.5	0.0	18.5	0.0	0.5	0.0	0.0	0.0	0.5	45.0	7.0	0.0	3.0	0.5	0.0	0.0	18.5	5.5
10.	0.5	1.0	0.0	0.0	0.0	7.5	1.5	0.0	0.5	1.0	3.5	0.0	0.5	0.0	2.0	0.5	0.0	0.0	3.5	6.0	0.0	0.0	0.0	1.5
11.	0.0	0.0	0.0	0.0	0.5	0.0	19.5	0.0	1.0	0.5	0.0	0.0	1.0	0.0	9.5	0.0	0.0	0.0	1.0	0.5	5.0	0.0	0.0	0.5
12.	0.0	0.5	13.0	0.0	50.5	0.5	1.5	29.0	79.0	6.5	0.0	0.0	0.0	0.0	0.5	0.0	2.5	0.0	2.5	0.0	0.0	0.0	11.0	0.0
13.	0.0	0.0	1.0	7.0	25.5	14.0	0.0	17.0	0.0	0.0	0.5	9.0	0.0	0.0	4.0	0.0	14.0	0.0	0.0	15.5	0.0	0.0	26.5	0.0
14.	6.0	0.0	0.0	0.5	0.0	4.5	0.0	20.0	0.0	0.0	0.0	6.5	2.5	0.5	2.0	0.0	12.0	0.0	0.0	54.0	0.5	0.0	0.5	0.0
15.	1.0	0.0	0.0	0.5	0.5	0.5	10.5	0.0	0.0	0.0	0.5	1.0	0.0	0.0	4.0	0.0	0.0	1.5	0.0	0.0	2.5	13.5	0.0	0.0
16.	0.5	0.0	3.5	0.0	25.0	0.5	5.5	0.0	0.0	0.0	0.0	8.5	0.0	0.0	0.0	28.0	0.0	29.5	10.0	0.0	0.0	3.5	13.0	0.0
17.	0.0	0.5	0.5	0.0	0.5	3.5	0.0	0.0	0.0	1.0	0.5	6.0	0.0	0.0	0.0	7.0	0.0	6.0	4.0	0.0	1.5	0.0	0.5	0.0
18.	0.0	0.0	1.5	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.5	0.5	0.0	0.5	0.0	0.0	17.0	7.5	33.5	0.0
19.	12.5	0.0	5.5	58.5	0.0	0.0	0.0	0.0	1.0	0.5	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	23.5	0.0	0.0	2.5	7.5	0.0
20.	3.5	0.0	1.0	3.0	0.0	0.5	0.0	3.0	0.5	0.0	0.0	1.5	2.0	5.0	0.0	0.0	3.0	1.0	14.0	0.0	22.5	0.5	0.5	0.0
21.	1.0	0.0	0.0	0.0	0.0	0.0	0.0	8.0	0.0	9.0	0.0	0.0	0.5	2.0	0.0	0.0	8.0	0.0	0.0	0.5	0.0	24.5	0.0	0.0
22.	3.5	0.0	12.0	10.0	0.0	0.0	0.0	0.5	0.0	0.0	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	4.0	2.0	0.0	0.0	0.0
23.	3.5	9.5	20.5	2.0	0.0	0.0	0.0	5.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	23.0	0.5	0.5	0.0	0.5
24.	0.5	0.5	1.0	0.0	0.0	0.0	0.0	9.5	0.0	0.0	62.5	0.5	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0
25.	0.0	1.0	0.5	0.0	0.0	0.0	0.0	6.0	0.0	0.0	0.0	0.0	0.0	0.0	13.0	0.0	0.0	7.5	0.5	0.0	8.5	1.0	0.0	0.0
26.	0.0	0.5	0.0	3.0	21.5	0.0	0.0	40.5	0.0	0.5	0.0	0.0	1.0	0.0	1.0	0.0	0.0	28.5	1.5	0.0	0.0	0.5	0.0	4.5
27.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.5	0.0	0.0	4.5	0.0	0.0	7.0	3.0	0.0	0.5	4.5	0.0	0.0	3.5	31.5
28.	0.0	0.0	0.0	0.0	1.0	0.0	0.0	10.0	1.5	21.5	0.0	0.0	1.5	4.5	0.0	0.5	5.5	21.0	0.0	99.0	22.0	0.0	5.0	0.5
29.	0.0	0.5	0.0	11.5	0.5	0.0	0.0	30.0	0.0	1.0	0.0	0.0	0.0	0.0	2.0	0.0	3.5	79.0	0.0	2.5	0.5	0.0	0.5	0.0
30.	0.0		0.0	19.0	0.0	0.0	0.0	13.0	0.0	6.5	0.0	0.0	0.0		0.0	0.0	0.5	1.0	0.5	0.5	0.0	0.0	0.0	0.0
31.	0.0		0.0		0.0		0.0	0.5		0.5		0.0	0.0		4.0		21.0		2.5	15.5		0.0		0.0
Total	44	18	68	125	136	80	105	206	112	77	100	49	24	13	89	99	81	207	69	232	176	82	172	65

Appendix 4. Mean daily specific streamflow discharge (liter/sec·km²) in Kiyokawa basin (1988-1989)

Date	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1.	9.5	6.4	13.1	32.7	—	—	—	10.5	24.3	15.6	36.1	16.9	12.7	6.7	28.2	79.7	23.7	12.7	10.9	8.2	60.7	74.0	46.5	27.0
2.	9.5	6.4	13.1	27.6	—	—	—	10.9	23.2	15.6	48.8	16.9	12.7	6.4	31.1	69.4	23.7	12.4	10.9	8.2	81.6	73.1	45.1	19.2
3.	9.5	6.4	11.3	27.6	—	—	—	10.9	22.2	25.4	44.3	16.9	12.7	7.0	31.1	59.9	23.2	12.4	10.9	8.2	85.6	71.2	43.6	28.7
4.	9.5	6.4	9.5	25.6	—	—	—	10.5	21.2	34.2	38.8	20.2	12.7	8.2	31.1	55.0	22.7	12.4	12.0	8.2	85.6	69.4	42.9	28.7
5.	9.5	6.4	11.2	25.2	—	—	—	13.5	20.7	31.1	44.3	21.7	12.7	8.5	31.1	58.2	22.7	12.4	10.5	5.4	81.6	68.5	42.2	36.8
6.	9.5	6.4	16.4	48.7	—	—	—	14.8	20.2	29.3	42.9	21.7	10.5	9.2	31.1	67.7	22.7	12.7	8.8	5.4	80.6	71.2	41.5	29.3
7.	9.5	6.4	8.3	52.6	—	—	—	13.1	19.2	28.2	36.1	21.7	12.7	9.8	31.1	77.8	22.7	12.7	8.8	5.4	79.7	70.3	42.2	25.4
8.	9.5	6.4	17.7	71.1	—	—	—	12.4	19.2	26.5	32.3	57.4	12.7	10.5	28.2	71.2	23.2	12.7	8.8	7.9	79.7	67.7	42.2	21.7
9.	9.0	6.4	17.4	54.8	—	—	—	11.6	20.2	24.3	32.3	38.1	12.7	11.6	25.4	65.0	23.2	12.7	8.8	13.9	79.7	67.7	40.1	21.7
10.	7.0	6.4	18.4	49.9	—	—	—	11.2	21.2	24.3	42.9	27.0	10.2	12.4	28.2	63.3	23.2	12.4	8.8	17.8	78.7	66.8	38.8	21.7
11.	6.4	5.8	24.1	47.0	—	—	—	11.2	20.7	23.2	38.8	21.7	10.5	12.7	31.1	59.9	23.2	12.4	8.8	19.7	78.7	73.1	38.1	20.7
12.	6.5	6.0	24.2	37.4	—	—	—	11.2	22.2	28.2	32.9	21.7	9.2	13.5	40.8	58.2	23.2	12.0	8.8	24.8	78.7	62.4	37.4	21.2
13.	6.4	5.6	19.5	32.7	—	—	—	11.6	34.2	37.4	31.7	21.7	9.2	14.8	48.0	56.6	23.2	12.0	8.8	24.8	78.7	61.6	36.1	17.4
14.	6.9	5.7	25.0	29.6	—	—	—	13.5	36.1	44.3	29.9	21.7	9.2	27.6	38.1	49.5	24.3	12.4	8.8	29.9	79.7	59.9	38.1	17.4
15.	10.9	5.3	20.9	27.5	—	—	—	12.4	32.3	49.5	29.9	19.2	9.2	14.8	37.4	36.1	23.7	12.4	8.8	36.1	78.7	59.1	36.8	20.7
16.	7.2	6.1	22.2	25.4	—	—	—	11.6	29.9	38.1	28.7	17.8	9.2	24.8	37.4	32.9	23.2	12.4	8.8	42.8	78.7	58.2	35.5	18.3
17.	6.4	5.9	18.7	23.8	—	—	—	10.9	26.5	35.5	21.0	16.9	9.2	38.1	32.3	31.1	22.7	12.4	8.5	50.3	78.7	56.6	34.2	16.9
18.	6.4	4.7	19.7	20.9	—	—	—	10.5	24.3	33.6	16.9	16.9	9.2	34.2	31.1	28.7	22.2	12.4	8.5	58.2	78.7	56.6	33.6	17.8
19.	6.4	4.4	31.1	19.4	—	—	—	10.2	23.7	32.3	16.9	16.9	9.2	31.1	31.1	26.5	22.2	12.0	8.5	58.2	78.7	59.1	32.9	20.7
20.	6.4	6.4	32.9	17.7	—	—	—	9.8	22.7	29.9	16.9	16.9	8.8	31.1	31.1	24.8	21.7	12.0	8.8	58.2	78.7	59.9	32.3	17.8
21.	6.5	8.8	37.6	17.2	—	—	—	9.8	22.7	28.7	16.9	16.9	9.2	29.9	31.1	24.3	22.2	12.0	8.5	57.4	80.6	56.6	32.3	16.9
22.	6.4	9.5	40.6	19.2	—	—	—	9.5	21.2	27.6	16.9	16.5	9.2	31.1	31.1	24.3	21.7	12.4	8.5	57.4	79.7	55.0	30.5	16.0
23.	6.4	9.5	67.0	27.6	—	—	—	9.5	20.7	26.5	18.7	14.8	9.2	29.3	31.1	24.3	22.7	12.0	8.5	58.2	79.7	54.2	29.9	16.9
24.	6.5	9.5	48.2	22.2	—	—	—	9.2	20.2	25.4	33.6	15.2	9.2	25.4	31.1	24.3	22.2	12.0	8.5	61.6	78.7	53.4	29.3	19.2
25.	7.0	9.5	44.1	19.0	—	—	—	10.9	19.2	24.3	23.2	3.9	9.2	25.4	31.1	23.7	21.2	11.6	8.5	60.7	78.7	53.4	28.7	16.9
26.	6.4	9.3	34.8	17.7	—	—	—	31.1	17.4	23.7	21.7	12.7	9.2	25.4	40.8	23.7	20.2	11.6	8.2	59.9	78.7	51.8	27.6	16.9
27.	6.4	12.5	40.1	22.6	—	—	—	33.6	15.6	23.2	21.7	12.7	9.2	27.6	47.3	23.7	19.2	11.2	8.2	59.9	80.6	51.1	27.0	13.9
28.	6.4	13.1	52.4	26.5	—	—	—	32.3	16.0	24.3	21.7	12.7	9.2	25.4	44.3	23.7	18.3	11.2	8.2	61.6	81.6	50.3	26.5	14.3
29.	6.4	13.1	46.7	22.2	—	—	—	29.9	16.0	72.2	25.4	12.7	7.6	25.9	66.8	23.7	16.0	10.9	8.2	65.0	85.6	49.5	25.9	13.1
30.	6.4		68.3	12.4	—	—	—	28.2	15.6	58.2	16.9	18.3	10.5		73.1	23.7	13.9	10.9	8.2	61.6	82.6	48.0	25.4	12.7
31.	6.4		45.4		—		—	26.5		42.9		12.7	8.8		72.2		12.7		8.2	61.6		47.3		12.0

Appendix 5. Mean daily specific streamflow discharge (liter/sec·km²) in Horonai basin (1988-1989)

Date	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1.	19.7	17.1	16.6	20.0	24.9	19.6	17.3	16.8	28.4	18.5	17.8	20.7	18.0	16.6	16.1	19.3	18.4	17.7	37.3	16.4	20.1	18.8	22.2	21.6
2.	19.3	17.3	16.6	19.8	25.0	19.6	17.3	16.8	26.4	18.0	16.9	20.5	18.0	16.6	15.7	19.1	18.2	17.7	32.7	16.4	18.4	18.6	21.8	21.4
3.	18.9	17.1	16.6	20.3	25.0	19.8	17.3	16.6	25.0	17.9	16.6	20.3	18.0	16.6	15.7	19.1	18.0	17.7	29.4	16.4	17.1	18.6	22.0	21.6
4.	18.4	17.0	16.4	20.5	24.2	19.3	17.1	16.7	23.6	17.8	16.9	20.5	18.0	16.4	18.9	9.1	17.9	17.9	27.4	16.3	17.0	18.4	21.6	21.6
5.	18.4	17.0	16.4	21.7	23.6	18.9	16.9	16.7	22.5	18.7	17.3	20.0	18.0	16.4	17.0	18.9	17.7	17.9	25.4	16.3	17.0	18.6	21.2	21.4
6.	17.5	17.0	16.3	22.0	23.1	19.3	16.9	16.3	21.5	18.8	17.7	19.7	17.9	16.4	16.4	18.8	17.7	19.3	23.9	16.3	23.9	18.9	21.6	21.2
7.	18.4	17.0	16.3	22.0	22.4	18.8	17.7	16.1	20.4	17.6	17.9	19.6	17.7	16.4	16.4	18.8	17.5	19.7	22.6	16.3	29.6	18.8	24.1	21.0
8.	18.4	16.6	16.4	21.8	21.9	19.3	17.9	16.0	20.2	17.3	18.0	19.6	17.7	16.3	16.3	18.8	17.3	20.6	21.4	16.3	27.6	18.8	24.1	21.2
9..	18.4	16.6	16.3	21.6	21.5	18.9	17.1	16.0	9.1	17.4	8.3	19.5	17.5	16.3	16.1	23.1	17.5	20.8	20.4	16.3	26.4	18.9	25.4	21.0
10.	18.4	16.6	15.9	21.9	21.1	18.5	17.7	16.4	19.4	17.5	18.1	19.3	17.5	16.3	16.1	25.0	17.3	20.8	19.9	16.3	24.5	19.3	25.0	20.6
11.	18.4	16.6	16.1	21.8	22.8	18.7	17.3	18.4	27.8	17.6	18.1	19.2	17.5	16.1	16.3	24.7	17.1	20.4	19.1	16.1	23.5	19.5	25.0	20.4
12.	18.0	16.6	5.9	23.0	28.0	19.2	17.4	17.8	28.8	17.6	18.2	19.4	17.7	16.1	16.3	23.9	17.0	20.2	18.9	15.9	22.2	19.3	25.4	20.4
13.	17.5	16.6	16.3	23.2	29.7	19.1	17.6	20.6	26.7	17.7	18.0	19.5	17.5	16.1	16.3	23.1	17.5	19.9	18.4	16.3	21.0	19.1	25.8	20.2
14.	17.5	16.6	16.3	22.8	28.5	19.2	18.2	24.0	25.1	17.7	17.8	19.3	17.5	16.3	16.6	22.4	17.5	19.5	18.2	18.6	20.4	18.9	27.9	20.2
15.	17.5	16.6	15.9	22.4	29.4	19.1	18.4	24.2	23.9	17.8	17.6	19.3	17.3	16.1	16.8	21.8	17.3	18.9	17.9	17.0	20.1	18.8	28.3	20.2
16.	17.5	16.6	16.4	22.2	29.0	19.2	18.8	23.7	23.0	18.0	17.8	19.1	17.3	16.1	17.0	22.0	17.3	19.9	17.9	16.6	19.5	19.3	28.1	20.4
17.	17.5	16.6	16.4	22.0	28.3	19.0	19.0	22.7	22.0	18.2	17.9	18.9	17.1	16.1	17.3	22.0	17.5	20.2	17.7	16.8	19.3	19.1	26.8	20.4
18.	17.5	16.3	16.3	25.7	27.4	18.8	19.1	21.9	21.3	18.2	17.7	19.0	17.1	16.1	17.5	21.8	17.5	20.8	17.1	16.6	19.1	18.9	27.4	20.2
19.	17.5	16.3	16.4	32.6	26.6	18.5	19.1	21.2	20.7	19.2	17.8	19.1	17.3	16.1	17.5	21.6	17.7	21.0	17.5	16.4	18.6	19.1	30.2	20.2
20.	17.5	16.6	16.3	30.3	5.8	18.4	19.1	20.8	20.0	20.2	17.8	19.1	17.3	16.1	18.0	21.4	17.7	21.0	18.8	16.6	19.5	19.5	31.5	20.2
21.	17.7	16.6	16.3	28.6	24.8	18.2	18.8	19.9	20.4	20.0	18.0	19.1	17.1	15.9	18.6	21.0	17.9	20.8	18.2	16.6	18.9	19.5	30.2	20.2
22.	17.9	16.6	16.1	27.2	24.0	18.1	18.5	19.5	20.1	20.7	18.1	18.9	17.1	15.7	18.9	20.8	17.5	20.6	18.2	16.3	18.9	20.1	29.1	20.2
23.	17.7	16.6	16.1	26.1	22.8	18.1	18.2	19.0	19.9	20.5	20.8	18.9	17.0	15.7	18.9	20.4	17.5	20.1	18.0	16.4	18.9	21.2	28.1	20.1
24.	17.5	16.6	16.1	25.0	22.2	18.0	18.1	18.7	19.5	20.5	23.6	18.8	17.1	15.7	18.9	20.2	17.5	19.5	18.0	16.1	19.1	22.4	27.0	20.1
25.	17.5	16.3	16.1	24.3	22.3	17.7	17.8	26.1	19.1	21.0	24.2	18.5	17.0	15.9	19.1	19.7	17.5	18.9	18.0	16.1	19.3	22.8	26.2	20.1
26.	17.5	15.9	15.9	23.5	21.3	17.7	17.7	30.8	18.7	21.4	23.5	18.3	17.0	15.7	18.9	19.5	17.3	20.4	17.9	15.7	18.9	22.6	25.6	20.2
27.	17.3	16.6	15.9	22.7	20.7	17.6	17.4	29.4	18.5	22.0	22.9	18.3	17.1	15.7	18.9	19.3	17.3	20.1	17.9	15.7	18.8	22.6	25.0	21.8
28.	17.3	16.6	15.7	22.4	20.6	17.8	17.1	28.7	18.5	21.3	22.4	18.1	17.0	15.9	18.9	18.9	17.5	20.4	17.5	19.9	19.3	22.4	24.1	20.6
29.	17.5	16.6	15.7	24.8	20.3	17.5	16.9	32.2	18.	20.2	21.9	18.0	17.0	15.9	19.1	18.8	17.3	37.3	17.5	23.1	18.8	22.4	23.3	20.6
30.	17.3		15.9	25.0	19.9	17.5	16.9	32.5	18.2	9.2	21.3	18.0	16.8		18.9	18.6	17.1	42.8	17.0	20.2	18.8	22.6	22.6	20.6
31.	17.1		19.9		19.6		16.8	30.6		17.8		18.1	16.8		19.1		17.9		16.3	19.5		22.6		20.6