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RELATIONSHIP BETWEEN RIVER BASIN CONDITIONS AND HYDRAULIC PARAMETERS AND WATER QUALITY COMPONENTS IN A RIVER IN A COLD, SNOWY REGION

By

Ken'ichi TAKADA
Kushiro Development and Construction Department,
Hokkaido Regional Development Bureau, MLIT of Japan,
Kushiro, Hokkaido, Japan

Makoto NAKATSUGAWA
Toyohashi Office of River,
Chubu Regional Development Bureau, MLIT of Japan,
Toyohashi, Aichi, Japan

Yasuhiro MURAKAMI
Civil Engineering Research Institute for Cold Region, PWRI,
Sapporo, Hokkaido, Japan

And

Shoji YAMASHITA
Civil Engineering Research Institute for Cold Region, PWRI,
Sapporo, Hokkaido, Japan

SYNOPSIS

Almost half of Japan is classified as cold and snowy in winter, and snowfall is thought to greatly affect the dynamics of water runoff and water quality. Although many researchers have clarified the relationships between such dynamics and physical conditions of a specific river basin, few studies have clarified the dynamics of water runoff and water quality and the physical conditions that basins in cold, snowy regions share with each other. This study uses quantification theory I and a multiple regression analysis to analyze the relationship between basin conditions (e.g., vegetation, geology, winter precipitation as a share of annual precipitation) and water runoff, and that between basin conditions and water quality. The focus of this study is Hokkaido, typifies which one of the cold, snowy regions of Japan, where snowfall accounts for nearly 20 to 40% of annual precipitation. The results show that the relationship between basin conditions and water runoff is consistent with past studies, and that snow accumulation contributes to flow regime stability to some extent. The relationship between basin conditions and water quality also shows that basin geology influences most of the water quality categories examined.

INTRODUCTION

Hydraulic parameters and water components in basins are important factors to consider in maintaining river channels, seacoasts, and riparian and coastal structures and ecosystems. Forests are known to play an important role in recharging water and thus smoothing the flow regime, and in mitigating flooding by reducing the discharge at times of floods. For these reasons, forests in Japan have been described as "green dams," and it has been suggested that forestry development could serve possible as a substitute for dams (1). However, forests are also known to be limited in these roles, and it has been suggested that forestry maintenance cannot fully substitute for dams (2). It has been pointed out that the presence of forests increases evapotranspiration, which can cause an imbalance in the water budget that is undesirable for water resource conservation (3). Numerical evaluations are necessary to examine the factors that affect flow regime, water quality and runoff characteristics.

Most river basins in Hokkaido are heavily forested, but each river basin has different hydraulic and water quality characteristics. Mushiake et al (4). revealed the relationship between flow regime and the climatic and geological conditions, mainly in regions on the Pacific Coast of Japan. Their study examined the relationship between basin conditions and hydraulic characteristics. They found that the low-water discharge is mainly influenced by geology, and that the drought specific discharge (obtained by dividing the 355^{th} greatest daily discharge in a year by the basin area to convert discharge into units of $m^3/s/100\ km^2$) is greatest in the case of Quaternary volcanic rock, followed by granite, Tertiary volcanic rock, Mesozoic formation, and Paleozoic formation. Shimizu et al (5) , (6). concluded that geology has greater influence on low-water discharge than does vegetation in dam basins throughout Japan. Kondo et al (7). suggested that in addition to basin geology, mountain volume affects the drought specific discharge. Many of these findings suggest that geology or topography has greater influence on low-water discharge than does vegetation. However, these studies have not yet clarified hydraulic and water quality characteristics in cold, snowy regions. One of the aim of this research is to clarify these characteristics.

Regarding the relationship between the conditions of a basin and the behavior of water quality components, Tachibana et al (8). pointed out that the water quality load is dependent on the discharge, and that the runoff of water quality load is determined by the constant in the equation used to express the relationship between water quality load and discharge (L-Q equation). Ohta et al (9). proposed a basic unit of water quality load for each land use. They worked out L-Q equations for the high-water and low-water discharge of the Ishikari River basin to find the relationship between water quality load and land use in the basin. Based on their research, Murakami et al (10). proposed a basic unit of water quality load that takes into account both geology and land use for river reaches upstream of dams, where there is less artificial influence.

This research investigates how basin conditions (vegetation and geology) influence runoff characteristics, while taking into account climatic factors in cold, snowy regions. The research also attempts to identify how these basin factors (i.e., basin conditions and climate factors) affect the forms of runoff of water quality load, and aims at using these factors as basic indices in river planning.

CHARACTERISTICS OF THE STUDIED RIVER BASINS

Vegetation in the basins

Table 1 Studied river basins

River System	River	Observation	River System	River	Observation
Teshio River	Nisama River	Nisama	Shiribeshi Toshibetsu	Shiribeshi Toshibetsu River	Kami-toshibetsu
Teshio River	Teshio River	Moshiri	Shiribeshi Toshibetsu	Shiribeshi Toshibetsu River	Upper stream of Pirika River
Ishikari River	Biei River	Biei Midori Bridge	Saru River	Saru River	Horokeshi
Ishikari River	Chubetsu River	Higashikagura Bridge	Saru River	Nukabira River	Nukibetsu
Ishikari River	Ishikari River	Ishikaridaira	Tokachi River	Sarubetsu River	Yamuwakka Bridge
Ishikari River	Sorachi River	Ohira Bridge	Tokachi River	Toshibetsu River	Senju Bridge
Ishikari River	Sorachi River	Kisen Bridge	Tokachi River	Otofuke River	Otofuke Bridge
Ishikari River	Ikushunbetsu River	Okukatsura	Tokachi River	Satsunai River	Eirin #1 (Satsunai River Dam)
Ishikari River	Toyohira River	Otarunai	Tokachi River	Tokachi River	Inset (Tokachi dam)
Ishikari River	Toyohira River	Takinosawa	Tokoro River	Muka River	Tokiwa Bridge
Ishikari River	Toyohira River	Usubetsu Dam	Tokoro River	Tokoro River	Hoei
Ishikari River	Toyohira River	Main stream (Houheikyo Dam)	Tokoro River	Kami-horokatokoro River	Shikanoyu
Ishikari River	Izari River	Koryu	Abashiri River	Bihoro River	Bihoro Bridge
Rumoi River	Rumoi River	16-sen Bridge	Rumoi River	Rumoi River	Tachibana Bridge

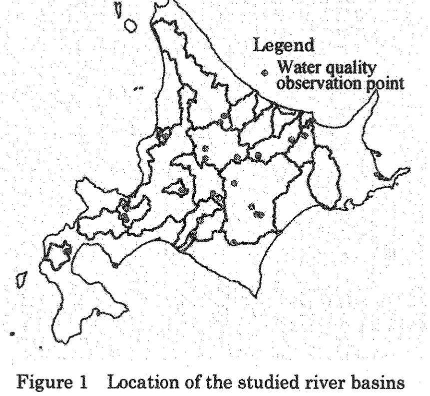

Figure 1 Location of the studied river basins

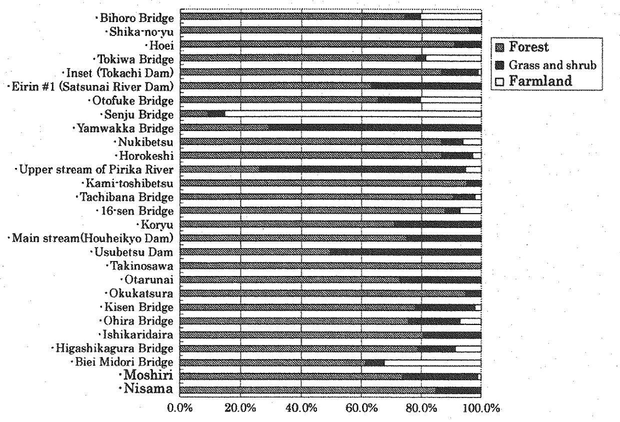

Figure 2 Composition of land use and vegetation

In this research, we chose 28 observation stations at locations where there is little or no artificial control of discharge such as from dams (Table 1, Figure 1). Geology and land use of areas around the observation stations were investigated based on the information on vegetation along rivers (The 3rd Vegetation Survey Mesh Data (11)) was downloaded from the Ministry of the Environment Web site. The data were separated according to the watershed boundaries of rivers and compiled according to the vegetation and land use categories (Figure 2.) Figure 2 shows the vegetation composition along each river: The plains tend to be composed of farmland and urbanized land, but the mountainous regions tend to be forested. Vegetation in mountainous basins can be subdivided into coniferous and broad-leaved forest, but here these are regarded together as forest. Most of the river basins in this research are forested. However, some of the areas which were studied, such as the upper stream of the Pirikabetsu River (Shiribeshi-Toshibetsu River) and of the Tokachi River (Senjyu Bridge area), are predominantly distributed with mixed grass and shrub vegetation or farmland.

Geology in the river basins

Using geological information on Hokkaido (G01-56M)

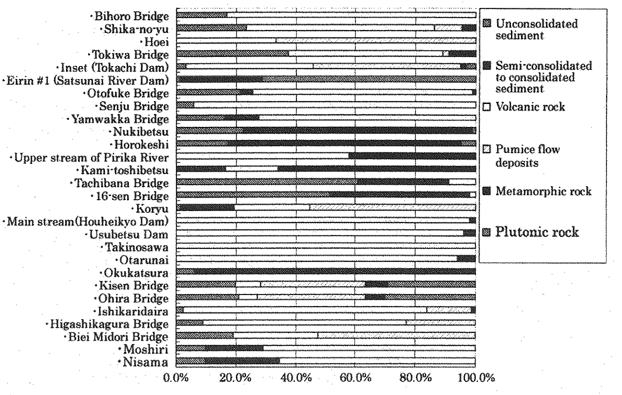

Figure 3 Composition of Geology

downloaded from the Geographical Survey Institute's Web site (12), the areas of each geology were calculated for the river basins (see Figure 3). Figure 3 shows areas that are characterized by a predominant distribution of volcanic rock or plutonic and metamorphic rock formations. However, most of the basins consist of multiple geological formations.

Distribution of drought specific discharge and precipitation

The drought specific discharge is used in this study as an index for stability of low-water discharge in Hokkaido. The annual daily discharge

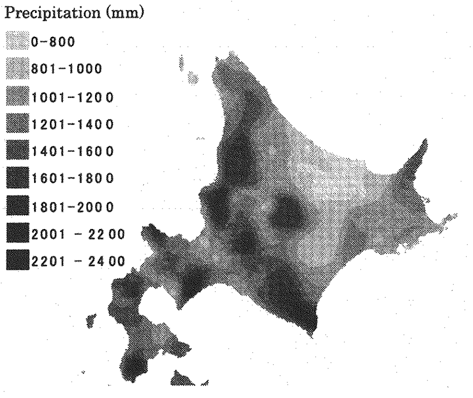

Figure 4 Precipitation distribution in Hokkaido

is grouped into the following four categories: 95-day discharge (the daily natural discharge that is likely to be equaled or exceed on 95 days in a given year), normal discharge (the daily natural discharge that is likely to equal or exceeded on 185 days in a given year), low-water discharge (the daily natural discharge that is likely to equal or exceed on 275 days in a given year), and drought discharge (or 355-day water level discharge; the daily natural discharge that is likely to be equal or exceed on 355 days in a given year). The drought discharge is divided by the area of each basin to determine the discharge per 100 km^2 ($m^3/sec/100km^2$). The greater the drought specific discharge, the more stable is the low-water discharge (4). To observe the distributions of flow regimes, the annual precipitation and daily discharge from the 321 hydrological stations in Hokkaido for the years 1996 through 2000 were collected. The daily discharge and the precipitation are ranked by dividing it by the area of the

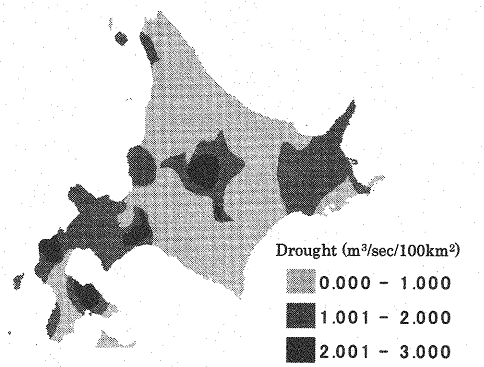

Figure 5 Distribution of drought specific discharge in Hokkaido

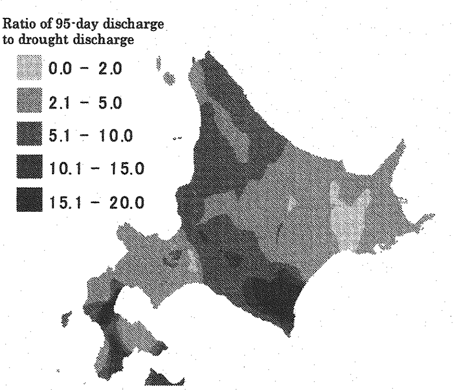

Figure 6 Distribution of ratio of 95-day discharge to drought discharge in Hokkaido

basin to calculate the individual specific discharge. The distribution of precipitation obtained from these data is shown in Figure 4. The distribution of drought specific discharge is shown in Figure 5. The distribution of the ratio of discharge over a period of 95-days to drought discharge, which is the 95-day discharge divided by drought discharge, is shown in Figure 6. Each discharge is the mean value for the 5 years from 1996 through 2000 in Figure 6. A comparison of Figures 4, 5 and 6 reveals that the trends for distribution of annual precipitation in Figure 4 differ from those for distribution of drought specific discharge in Figure 5. The trends differ greatly between Figures 5 and 6. Areas with high ratios of 95-day discharge to drought discharge have low drought discharge, which indicates that the flow regimes are relatively unstable. Therefore, figures 4,5 and 6 indicates that the areas of high precipitation are not necessarily the same as the areas of high drought specific discharge, and the areas of low precipitation are not necessarily the same as the areas of high drought specific discharge. When the distribution of drought specific discharge in Figure 5 and the geology map in Figure 7 are compared, the areas with volcanic pumice flow deposit and the areas with higher drought specific discharge generally coincide, as can be seen from the figures.

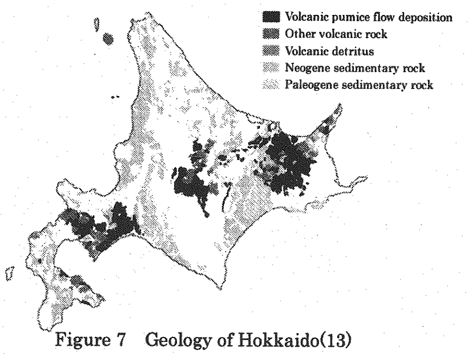

Figure 7 Geology of Hokkaido(13)

This information has led to us the surmise that geology has greater influence on drought specific discharge than any other parameters.

QUANTITATIVE ANALYSIS USING HAYASHI'S QUANTIFICATION THEORY- I

Method for analyzing runoff characteristics and water quality

Table 2 List of factors

River basin characteristics	Number of factors	Factors
Land use	3	Forest, Grass and shrub, Farmland
Geology	6	Unconsolidated sediment, Semi-consolidated to consolidated sediment, Volcanic rock, Pumice flow deposits, Metamorphic rock, Plutonic rock
Climate	2	Climate on Japan Sea side, Climate on Pacific side

Based on a method used by Mushiake et al (4), Hayashi's quantification theory-I was used to obtain a comprehensive understanding of parameters affecting runoff and water quality. The values for discharge and water quality from the various rivers in this study are known. Using these criterion variables, regression analyses were performed and the discharge and water quality values were associated with the basin factors. Specific factors related to the basin factors, such as geology, were assigned to a value of 1 if their distribution is greater than average for the basin, and a value of 0 if their distribution is less than average for the basin. Such factors as land use, geological, and climatic categories and the individual items are listed in Table 2.

The predominant item in land use and that in geology are determined by the ratio of area that the item occupies. An item is determined to be predominant if it accounts for more than 50% of the total basin area. Even if its area does not account for more than 50%, it is regarded as predominant if it accounts for a conspicuously large share of the total basin area. The climatic categories are classified by determining whether the winter precipitation ratio (the ratio of precipitation from December through March to the total precipitation) is greater than 20% or less than 20%. The winter precipitation ratio shows clear differences according to each region (Figure 8): Regions where precipitation it exceeds 20% tend to be on the Japan Sea side and those where it is less than 20% tend to be on the Pacific side (including regions on the Sea of Okhotsk).

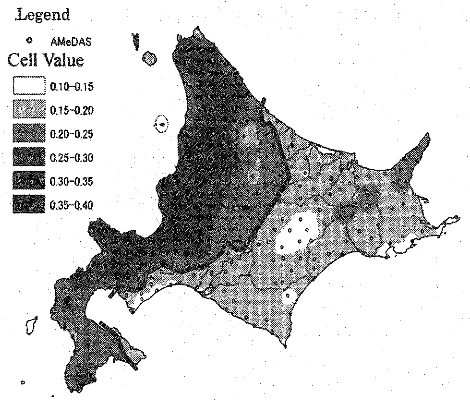

Figure 8 Distribution of winter precipitation in Hokkaido
(ratio of winter precipitation to annual precipitation)
The line is the boundary between winter precipitation ratio of 0.2 or less and 0.2 or more

In Hayashi's quantification theory I, a multiple correlation analysis is performed using a group each variable (dummy variables) from which each is excluded in turn. In this way, it is possible to calculate the weight of each items/ (category weight) and to evaluate the results.

Analyzing the runoff characteristics and basin conditions

First, the relationship between discharge (drought specific discharge, and the ratio of discharge over a period of 95-days to drought discharge) and basin conditions was analyzed. If the drought specific discharge (m^3/sec/100km^2) is high, the flow regime is stable, which indicates ample discharge even during the so-called drought period. Furthermore, when the ratio of discharge over a period of 95-days to drought discharge is high, the flow fluctuates greatly, and when the ratio is low, the flow is generally stable. The data used here were averaged values of data gathered over a period of 5 years from 1996 through 2000.

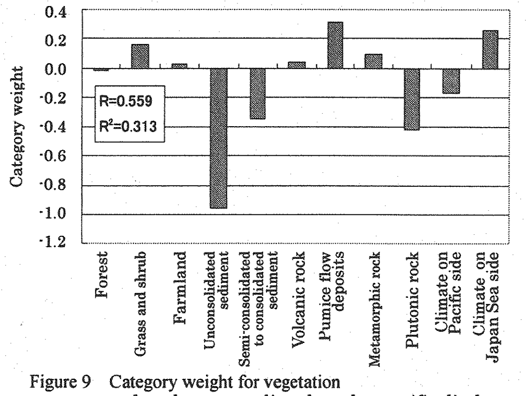

Figure 9 Category weight for vegetation and geology regarding drought specific discharge

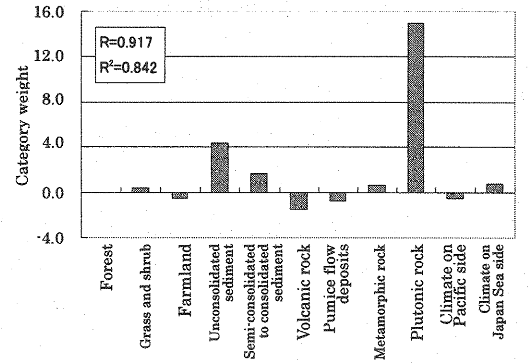

Figure 10 Category weight for vegetation and geology regarding ratio of 95-day discharge to drought discharge

The category weights of drought specific discharge and those of the ratio of 95-day water discharge to drought discharge are shown in Figures 9 and 10, respectively. The ratio of water discharge over a period of 95-days to drought discharge indicates the stability of the flow, and an overall good correlation between the ratio and the stability of the flow is recognized. It can also be observed from Figures 9 and 10 that there is an almost opposite relationship. For example, for drought specific discharge (shown in Figure 9) the category weight is positive for pumice flow deposit; however, for ratio of drought discharge (shown in Figure 10) to 95-day discharge the category weight is negative for pumice flow deposits. The reverse is true for plutonic rock and for unconsolidated sediment.

However, no clear trends were found for land use (e.g., forest, grass and shrub, and farmland). For climate, the flow tends to be more stable on the Japan Sea side, where influence of snow is great shown in Figure 9. Although we can say climatic factors have an influence on the flow regime, such an influence is not as great as geology. Geological conditions have a greater influence on flow regime than land use or climate do. This is consistent is with the findings of Mushiake et al., Shimizu, and Kondo et al., and it is verified by this study in Hokkaido, which is a cold, snowy region.

As mentioned before, the flow tends to be more stable on the Japan Sea side, as a result of the heavy snowfall there. Kondo et al (7). points out that river basins with high drought specific discharge coincide with areas with deciduous broadleaf trees, but that such river basins tend to be on Japan Sea side, which there is heavy snowfall and is covered with beech forests. He concludes that vegetation and climate factors may not be independent. The findings of this study show that the influence of vegetation and climatic factors on the ratio of 95-day water discharge to drought discharge is small compared to the influence of geology. These results support the findings of Mushiake et al (4). that geology is the major factor in the stability of flow regimes.

Relationship between water quality and river basin characteristics

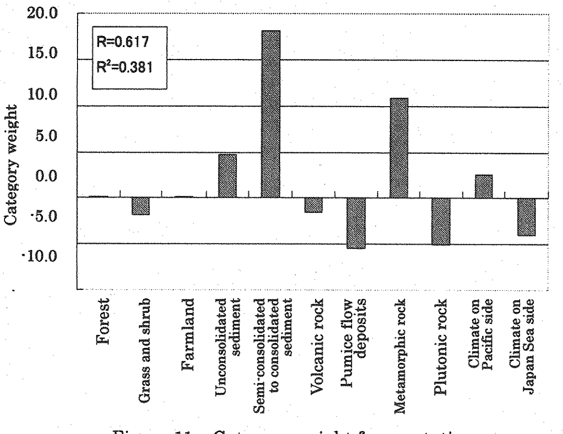

Figure 11 Category weight for vegetation and geology regarding SS

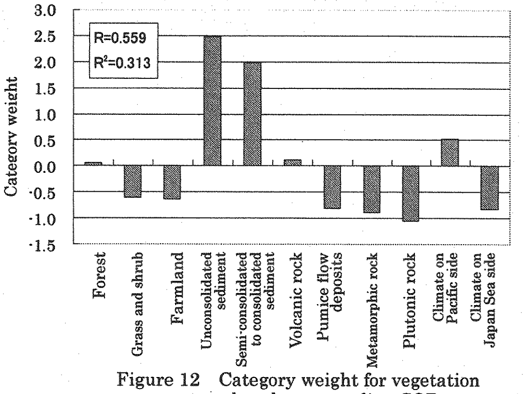

Figure 12 Category weight for vegetation and geology regarding COD

Hayashi's quantification theory I was used to analyze the relationship between water quality and river basin characteristics in the same manner as in the previous section. All data are average values for the years 1996 through 2000. The water quality used in the analysis was the average value for concentrations of water quality components recorded in routine surveys performed at observation stations by Ministry of Land, Infrastructure and Transport Government of Japan, mainly during periods of normal discharge.

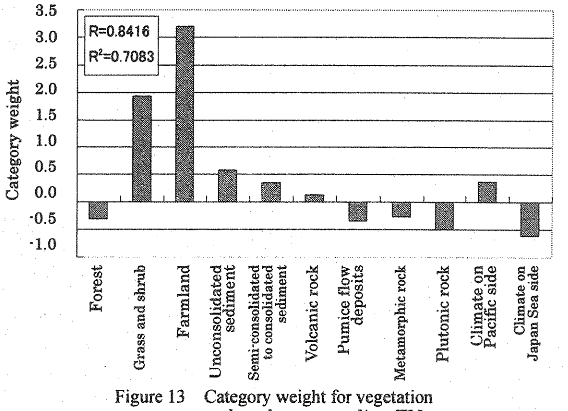

Figure 13 Category weight for vegetation and geology regarding TN

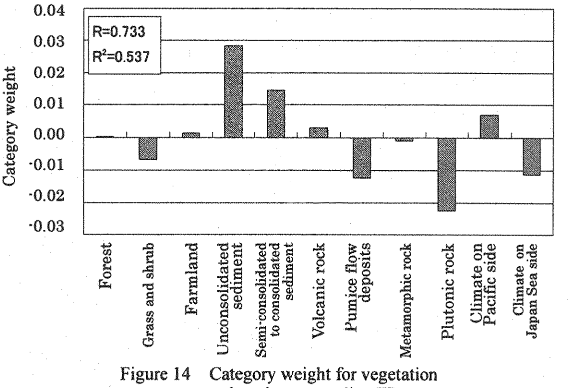

Figure 14 Category weight for vegetation and geology regarding TP

The items for analysis are suspended solids (SS), chemical oxygen demand (COD), total nitrogen (TN) and total phosphorus (TP), and the results are shown in Figures 11 to 14. The distribution of category weights for SS, COD, and TP are mutually similar in Figure 11, 12 and 14. Figure 11, 12 and 14 show evidence that geological conditions such as the types of unconsolidated sediment (gravel, sand, clay and clastics) and semi-consolidated to consolidated sediment (conglomerates, sandstone, mudstone and slate) influence the runoff of SS. Metamorphic rock also shows a large positive category weight regarding SS. For climate, the Pacific side has a positive category weight in all water quality elements.

Table 3 Volume of deposition at major dams in Hokkaido[10]

Dam	Year of completion	River basin a km²	Elapsed Year b years	Deposition Volume c 1000 m³	Deposition volume/ area/year c/a/b 1000m³/km²/years
Nibutani Dam	1997	1,215.0	4	4,730.0	973
Satsunaigawa Dam	1997	117.7	5.6	563.0	854
Katsurazawa Dam	1956	151.2	45	2,630.6	387
Izarigawa Dam	1980	113.3	21	912.9	384
Tokachi Dam	1984	592.0	17	3,669.0	365
Takisato Dam	1998	1,661.9	4	2,085.6	314
Pirika Dam	1989	115.0	12	420.2	304
Hoheikyo Dam	1972	134.0	30	1,042.2	259
Ashibetsu Dam	1956	126.0	45	1,288.9	227
Taisetsu Dam	1974	291.6	28	1,846.0	226
Jozankei Dam	1989	104.0	13	260.7	193
Iwaonai Dam	1970	331.4	32	1,869.0	176
Kanoko Dam	1983	124.0	18	262.0	117
Kanayama Dam	1967	470.0	35	1,124.0	68

Some data, including deposition volume, are reference values.
(Source: Hokkaido Regional Development Bureau)

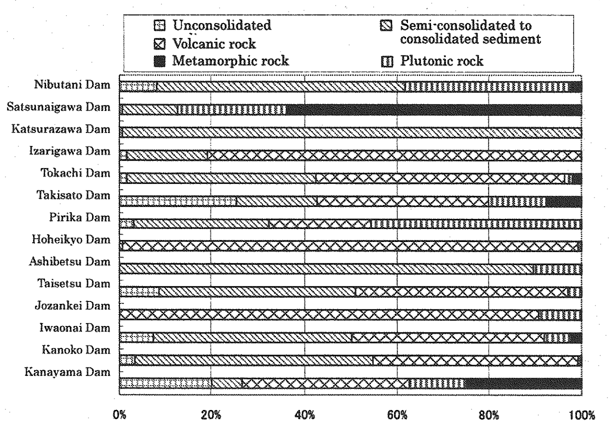

Figure 15 Breakdown of dam catchment geology (area ratio) in Hokkaido[10]

Regions on the Pacific side are subjected to high sediment runoff, such as the Hidaka region, are pluvial regions that are widely distributed with unconsolidated sediment or metamorphic rock, which is consistent with the trends shown for SS, COD and TN.

The findings indicate that category weights for SS and COD, and TP are affected by the existence of brittle materials, such as unconsolidated sediment, Table 3 and Figure 15 support this conclusion. They show evidence of the amount of sediment deposited at major dams in Hokkaido and geological compositions of the dam basins. Table 3 shows that Nibutani Dam has the highest specific sedimentation rate per unit area, followed by Satsunaigawa Dam and Katsurazawa Dam. Figure 15 is the figure which showed a ratio of a geological feature area in a dam basin of Hokkaido. The dams with high specific sedimentation rate are classified according to geological formations with high ratios of semi-consolidated to consolidated sediments and metamorphic rocks in their basin (Figure 15).

The category weights for TN (Figure 13), however, show different trends from those for SS, COD and T-P. The category weights for land use items are greater than those of geology. For land use items, Figure 13 provides evidence that runoff of TN is slightly reduced in forests but is increased in grass and shrub as well as in farmland. After this, it is necessary to examine nitrogen fixation or physicochemical changes in the forest and in the soil to quantify these trends. There is however, also concern that a large number of forested river basins in this study may have resulted in statistical bias. Nevertheless, the determination coefficients and correlation coefficients strongly support the conclusions.

RELATIONSHIP BETWEEN BASIN CHARACTERISTICS (LAND USE, GEOLOGY) AND HYDRAULIC PARAMETERS/WATER QUALITY

Relationships between runoff characteristics and geology

The characteristics of geology and land use were studied with regard to their relationships to hydraulic parameters and water quality. First, in Section of *Quantitative analysis using HAYASHI'S quantification Theory-I*, using Hayashi's quantification theory I, geology was found to strongly correlate with drought specific discharge, and with ratio of 95-day discharge to drought discharge. With that in mind, Multiple-regression analysis was performed to analyze these relationships.

The term "Geology" here is the ratio of each surface geological category of each river basin, obtained from the Digital National Land Information of the Geographical Survey Institute, mentioned in Section of Geology in river basins. The geological categories in this surface geology data include some that do not exist in Hokkaido and some categories that are not predominant. Therefore, the categories are grouped into unconsolidated sediments, semi-consolidated to consolidated sediments, volcanic rock, pumice flow deposit, metamorphic rock, and plutonic rock, as the Section entitled *Quantitative analysis using HAYASHI's quantification Theory-I*, and their area ratios are obtained. The multiple-regression coefficients for drought specific discharge, according to geological categories, are shown in Figure 16. Multiple-regression coefficients for the ratio of 95-day discharge to drought discharge,

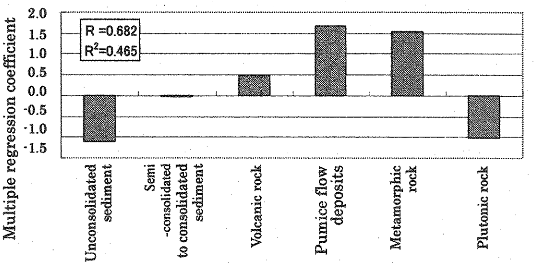

Figure 16 Multiple regression coefficients for geology regarding drought specific discharge

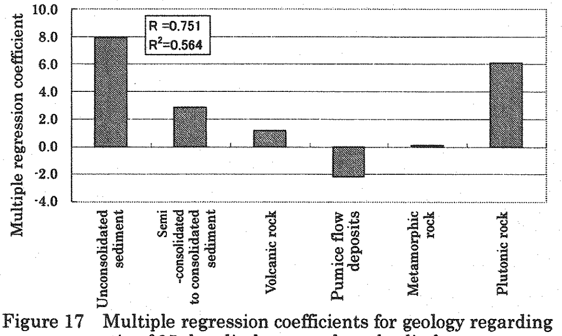

Figure 17 Multiple regression coefficients for geology regarding ratio of 95-day discharge to drought discharge

according to geological categories, are shown in Figure 17. Both results show higher multiple-regression coefficients between runoff characteristics and geology than in the results of the analysis in the Figures 9 and 10. This proves that there is a close relationship between runoff characteristics and geology.

Relationship between Water Quality and Geology, and between Water Quality and Land use

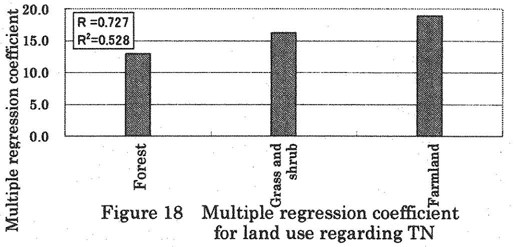

Figure 18 Multiple regression coefficient for land use regarding TN

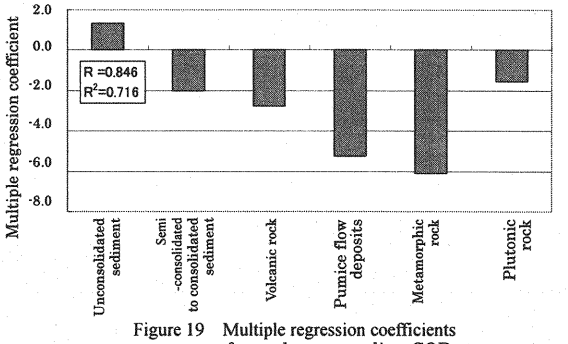

Figure 19 Multiple regression coefficients for geology regarding COD

For water quality, the multiple-regression coefficients for COD are obtained according to geological area ratios. Because of the high correlations (Section of *Relationship between water quality and river basin characteristics*), by using the same method used in section of Relationships between runoff characteristics and geology , this shown in Figure 18 and 19. The multiple-regression coefficients for TN are obtained according to the land use area ratios. These findings (Figures 18 and 19) show higher correlations than those obtained from the analysis that was used in Hayashi's quantification theory I (shown in Figure 12 and 13). Figures 18 and 19 evidence that COD is influenced by geology, that TN is influenced by land use, and that both are strongly influenced by the river basin characteristics.

CONCLUSION

The results of this research are as follows:

1) The relationship between river basin characteristics and runoff characteristics was found by using Hayashi's quantification theory-I. Among the relationships, it was revealed that the runoff characteristics are more strongly influenced by geology than by land use.
2) Analysis performed by means of Hayashi's quantification theory-I indicates that there are strong correlations between water quality and geology. These findings are supported by the fact that in river basins, notably in dam catchments where semi-consolidated to consolidated sediment predominate, the volumes of SS and sediment deposition are large, and materials such as soil and sand are actively transported in these river basins. However, the results show that land use has more influence on TN than geology does.
3) Multiple-regression analyses were performed to determine the relationship between geological area ratio and runoff characteristics and to determine the relationship between land use area ratio and water quality components. The trends were similar to the analysis that used Hayashi's quantification theory-I.

The findings obtained of this study demonstrate that river basin conditions correlate to some degree with hydraulic parameters and with water quality. Therefore, it will be possible to perform similar analysis on other river basins.

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