Influence of Changes in Vegetation upon the Runoff Characteristics of Mountainous Drainage Basins

By

SHIMIZU, Toshio[1], KIKUYA, Akio[2] and TSUBOYAMA, Yoshio[3]

Summary: In order to clarify the influence of changes in vegetation upon the runoff characteristics of mountainous drainage basins, we analyzed the changes over time of runoff in the Shozawa Basin. The area studied was that of the Takaragawa Forest Watershed Experiment Station of the Forestry and Forest Products Research Institute, where the forest tree species were changed from broad-leaved trees such as beech (*Fagus crenata* BL.) to coniferous trees such as Japanese cedar (*Cryptomeria japonica* D. DON) and larch (*Larix leptolepis* GORDON). By a process of clear cutting and also accurate hydrological and meteorological observations add over a long time period, we found that the degree of change in runoff due to the change in stand condition greatly varied between the no-snow season (August to October) and the snow cover and snowmelt season (March to May). It was clarified that the volume of runoff in a period, time of flood concentration and recession characteristics change in the no-snow season while the starting time of snowmelt runoff, period of snowmelt runoff and lag-time of freshet change respectively in the snow cover and snowmelt season. Moreover, the runoff characteristics temporarily fluctuated with tree cutting but it was recognized that there was a tendency for them to return to their original state as the forest recovered.

1. Introduction

When investigating in detail the characteristics of water runoff from the basin in conjunction with the forests, it is necessary to clarify the individual hydrological phenomena in forest land such as interception, evapo-transpiration and infiltration and then to integrate them. For this purpose, various researches are being carried out in many areas but the collection and analysis of data capable of totally explaining a hydrological cycle in forests is still not adequate.

Thus, in the present research, the authors have investigated the influence of the change in vegetation upon the runoff in a mountainous drainage basin by analyzing the change over time in the volume of runoff in the basin unit as the integrated results of individual hydrological phenomena within the basin in relation to the changes in forest vegetation for the target drainage basin. The authors have selected a drainage basin as a target, where the forest operations were performed and hydrological and meteorological observations have been accurately conducted over a long period of time.

2. Outline of the Basin and Observation Method

The basin analysed in the present research is the Shozawa Basin in which there is the Takaragawa Forest Watershed Experiment Station, Forestry and Forest Products Research Institute. The basin is one of the water source basins in the upstream area of

Received July 11, 1991 環境—11 Forest Environment—11

(1)(2)(3) Forest Environment Division

the Tone River. The main climatic station for meteorological observation at the downstream end of the basin is located at Long. 139° 01′ E. ; Lat. 36° 51′ N. ; elevation of 816 m. In the Shozawa Basin, the hydrological and meteorological observations for the forest watershed experiments have been continued from 1937 to the present in cooperation with Minakami District Forest Office, Maebashi Regional Forest Office. The Shozawa Basin is suitable for the purposes of the present research as described below. Fig. 1 shows the location and topographic map of the Takaragawa Forest Watershed Experiment Station.

The Shozawa Basin has an area of 117.90 ha, elevation of 800 to 1 370 m, mean slope of 24° 45′, and mean bearing of SSW. Geology mainly comprises granite rocks, a tertiary layer called the Misaka Layer, various small intrusive rocks penetrating these, and quarternary deposits formed by collapse transition (Tokyo Regional Forest Office, 1943). Also, the main soils appearing in this basin are brown forest soils and dry podzolic soils with exposed rock zones scattered locally.

This region is located on the Pacific Ocean side of the Japanese islands but is part of the main mountain ranges of the largest island at the furthest northwestern end of Kanto District. In the winter season, Japan Sea coast type mountainous weather occurs. Snow cover starts in late November and lasts until the end of April on average, though it may last until the first part of May in some years. The period of continuous snow cover is

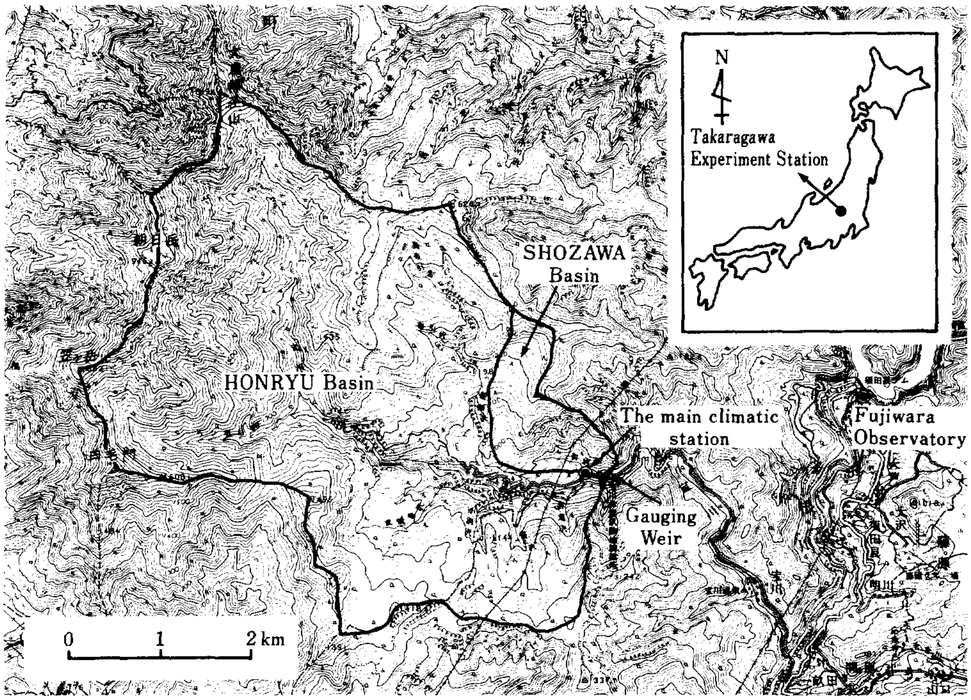


Fig. 1. The location and topographic map of the Takaragawa Forest Watershed Experiment Station.

Photo 1. Gauging weir of SHOZAWA Basin.

thus from the first part of December to the last part of April on average. The rain to snow ratio of annual precipitation is about 6 : 4.

The river discharge in Shozawa Basin has been continuously measured from November 1937 by long-term automatic water gauges at the water gauging facilities in which seven Bazin type rectangular notches each being 1 m wide were installed at intervals of 0.8 m as shown in Photo 1.

From 1937-57 precipitation and snow depth were observed during the year including the winter season. However, from 1957, the precipitation occuring in the snow cover season (December to April) was observed only at the main climatic station using totalizer rain and snow gauges.

Therefore, for the daily precipitation and snow depth in that period, the values taken at the Fujiwara Observatory, Maebashi Regional Weather Bureau (the Sudagai Dam owned by Tokyo Electric Power Co., elevation of 700 m) about 3 km away from the target basin were used.

Air temperature was been observed throughout the year by long-term automatic temperature and humidity meters at the main climatic station. Also, the earth temperature was periodically measured by direct reading of thermometers embedded in the ground at depths of 0.3 m, 1.2 m and 2.6 m.

3. Changes in Forest Vegetation

The first total cruise in the Shozawa Basin, the site of the present research, was conducted in 1935. According to the survey, the relevant basin consisted of natural forests of mainly beech trees. The ratio of broad-leaved trees to coniferous trees was 8 : 2 ; with a proportion of 60% for beech, 18% for False arborvitae, 12% for Japanese oak and 10% for others. Also, the stand volume per ha was 191m^3 (Gov. For. Exp. Sta.,

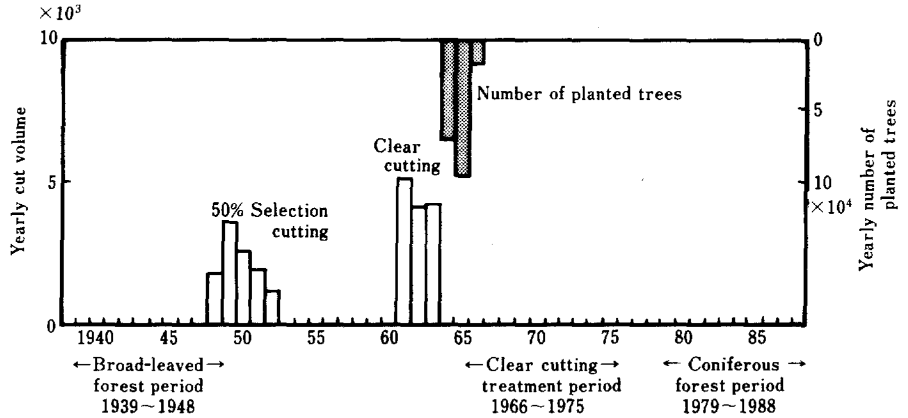


Fig. 2. Cut volume and number of planted trees by year on SHOZAWA Basin.

1961).

As shown in Fig. 2, in the said basin selected cutting of a volume of 50% of the tree total (cutting volume of 11 195 m^3) was carried out in the whole area from 1948 to 1952 and, thereafter, there was no additional work. However from 1961 to 1963, clear cutting (cutting volume of 13 730 m^3) was carried out in the whole area of the Shozawa Basin except for a few places. In successive years from 1964 to 1966, the planting of Japanese cedar and Japanese larch was carried out at the density of 3 580 trees/ha. The total number of trees planted was 188 400. And the proportion for each planted area was 80% Japanese cedar and 20% Japanese larch. In the forest survey conducted by the Minakami District Forest Office in 1986, the stand volume per ha was about 30 m^3 but the amount of growth was low in comparison to warmer regions.

In this paper the ten years from 1939 to 1948 before selection cutting of naturally grown broad-leaved trees, for which data are fully available, will be termed the broad-leaved forest period. The ten years from 1966 to 1975 after clear cutting will be termed the clear cutting treatment period. While the ten years from 1979 to 1988 (there is some missing data due to storm disasters) almost 20 years after the planting of Japanese cedar and larch will be termed the coniferous forest period, and the influence of changes in the forest upon runoff was analyzed by comparing the runoff characteristics of each period.

4. Results and Discussion

4.1 Outline of meteorological conditions and runoff characteristics

Comparing the influences upon runoff in forests, it is first necessary to clarify the meteorological conditions in the respective periods. Table 1 shows the meteorological conditions at the main climatic station in the survey period. When comparing the monthly mean precipitation of each period, there is on the whole no substantial difference though slight variations can be observed. The annual mean precipitation was

Table 1. Comparison of the meteorological conditions in target period (the main climatic station).

Precipitation (mm)

Month	1	2	3	4	5	6	7	8	9	10	11	12	Total
Broad-leaved forest period	260.5	200.2	146.1	121.0	118.2	156.1	225.9	138.5	194.5	182.1	151.6	258.0	2 152.7
Clear cutting treatment period	250.6	198.8	132.7	112.3	124.9	179.4	202.4	168.9	167.3	127.1	139.7	231.5	2 035.6
Coniferous forest period	254.8	205.4	137.3	137.2	150.1	200.8	204.3	170.4	240.4	148.3	149.0	142.0	2 160.1

Air temperature (°C)

Month	1	2	3	4	5	6	7	8	9	10	11	12	Mean
Broad-leaved forest period	−4.3	−4.1	−0.9	4.2	10.4	15.5	20.1	21.3	16.9	10.6	4.7	−1.3	7.7
Clear cutting treatment period	−4.3	−3.5	−1.1	5.7	11.4	15.8	20.2	21.5	16.5	10.0	4.5	−1.5	7.9
Coniferous forest period	−3.8	−3.6	0.5	6.1	12.2	15.8	19.5	21.4	16.6	9.6	3.9	−0.1	8.1

Earth temperature (°C)

Month	1	2	3	4	5	6	7	8	9	10	11	12	Mean
Broad-leaved forest period	4.9	3.9	3.3	2.9	6.2	11.6	16.1	18.9	19.1	16.1	12.0	7.5	10.2
Clear cutting treatment period	4.3	3.6	3.1	2.7	5.3	12.1	16.3	19.3	19.1	15.3	12.1	7.0	10.0
Coniferous forest period	5.2	4.4	4.0	3.0	6.9	10.8	14.5	17.2	17.8	15.1	11.1	7.3	9.8

Note : Earth temperature is the value at the depth of 1.2 m.

2 152.7 mm for the broad-leaved forest period, 2 035.6 mm for the clear cutting treatment period, and 2 160.1 mm for the coniferous forest period, and therefore these values are very similar. Annual mean air temperature was 7.7, 7.9 and 8.1°C, and annual mean earth temperature was 10.2, 10.0 and 9.8°C respectively and again there are no great differences between the periods. Thus, the meteorological conditions in each period are considered on average to be almost identical.

Therefore, the element that greatly changed in the basin surveyed is the forest vegetation, so the difference in runoff characteristics for each period are considered to be greatly affected by the changes in forest vegetation.

In order to know approximately how the volume of runoff has changed over time as a result of changes in forest vegetation, the mean values of the monthly volume of runoff over ten years were determined for the broad-leaved forest period, the clear cutting treatment period and the coniferous forest period, and these values were compared with each other. The results are shown in Fig. 3. From this figure, it can be seen approximately that the characteristics of monthly volume are altered by forest cutting and forest recovery by planting. Also, the annual mean volume of runoff is 1 765.6 mm for broad-leaved forest period, 1 807.7 mm for clear cutting treatment period and 1 843.6 mm for coniferous forest period, thereby indicating that there are only slight differences between the periods.

However as shown in Fig. 3, a great difference can be recognized in the degree of runoff change due to the variation in the stand condition between the no-snow season (August to October) and the snow cover and snowmelt season (March to May). This occurs because the characteristics of runoff through forest vegetation varies according to whether the input precipitation in to the basin is snow or rain. Moreover, the seasonal changes in the forest such as leaf shedding or leaf settling in the forest also seem to be correlated with the runoff.

It is also difficult to evaluate the precipitation input in the season when both snow and rain occur, and this makes for difficulty in detecting the influence of vegetation upon

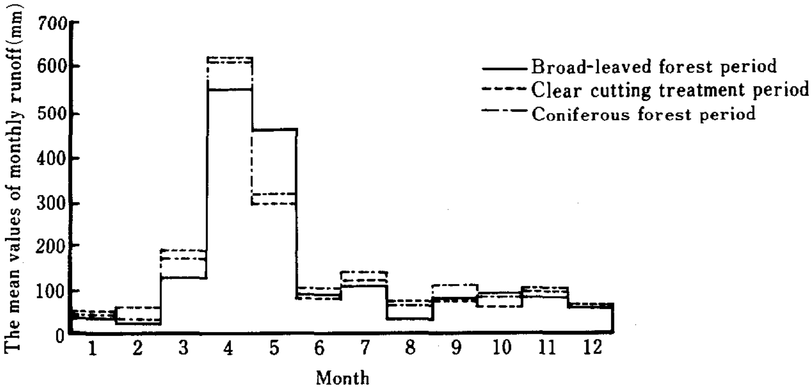


Fig. 3. Changes of the mean values of monthly runoff (average in ten years).

runoff. Thus, the influence of the forest upon runoff was investigated separately for the no-snow season and snow cover and snowmelt season.

4.2 Runoff characteristics in the no-snow season

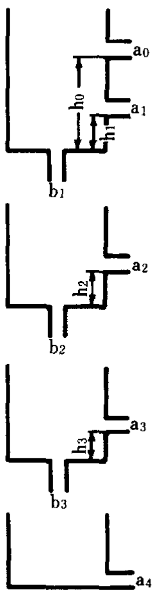
When cutting is performed in a forest, the volume of runoff increases. This has been verified by many studies made at various places over long periods of time (BOSCH and HEWLETT, 1982; NAKANO, 1976; YOSHINO and KIKUYA, 1985). This is considered to occur due to water volume loss, that is, the quantity of tree crown interception and evapotranspiration by the forest are reduced by the cutting (SUZUKI, 1983).

Here in order to check the variation in runoff accompanied by changes in the forest, the relation between precipitation and volume of runoff was determined.

4.2.1 Comparison by runoff models

In order to find the difference in rainfall-runoff characteristics due to change in forest vegetation, an investigation was made by using Tank models (SUGAWARA, 1972) that are generally utilized in rainfall-runoff analysis.

In the broad-leaved forest period under initial conditions, optimum Tank models for a daily runoff hydrograph were produced (Fig. 4) and utilizing this for reference, the runoff in the clear cutting treatment period and coniferous forest period was compared with the measured values and the calculated one, and the results are shown in Fig. 5. Here, the thick line shows the measured value in respective periods. The estimates using the optimum Tank models are for the broad-leaved forest period are shown by the thin line. Also, for the clear cutting treatment period and coniferous forest period, forecast values were determined by inputting the precipitation of the survey years of these periods in the Tank models which were determined by the broad-leaved forest



Tank model parameters for Broad-leaved forest period

(mm/day)	(mm/day)	(mm)
$a_0=0.29$	$b_1=0.14$	$h_0=73.5$
$a_1=0.11$	$b_2=0.069$	$h_1=23.4$
$a_2=0.018$	$b_3=0.010$	$h_2=13.3$
$a_3=0.077$		$h_3=8.1$
$a_4=0.0004$		

Fig. 4. Tank model (series storage type).

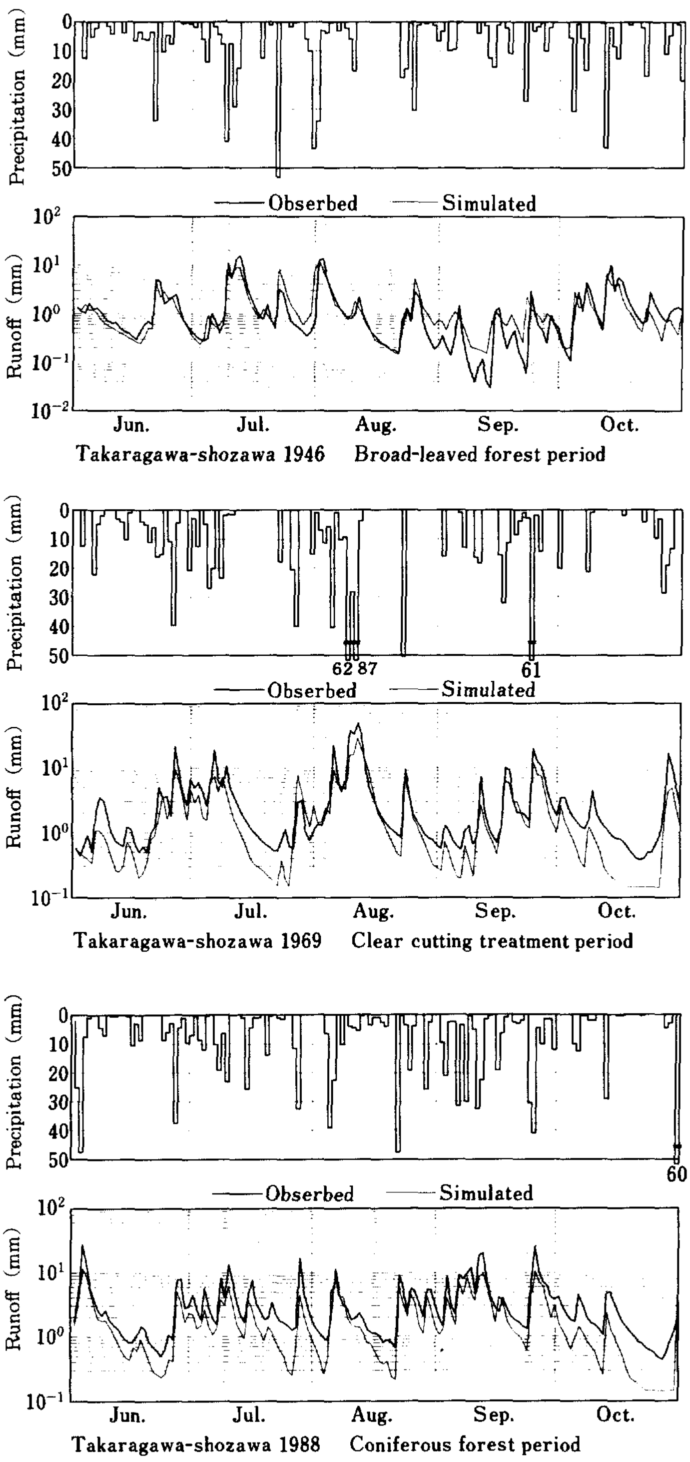


Fig. 5.　Comparison of hydrographs in each period by the optimum Tank models for the broad-leaved forest period.

period as a comparative reference. This corresponds to the value when the vegetation was assumed to be unchanged.

From Fig. 5, it can be recognized that the measured values of the peak and low flow discharge in the clear cutting treatment period are all larger than the calculated values based on the broad-leaved forest period as reference. That is, the volume of runoff increases generally as a result of forest cutting. By considering the scale of the height of runoff as a logarithmic scale, it can be shown that the peak discharge will be considerably increased by forest cutting. Also in the coniferous forest period, the volume of runoff is larger compared to the broad-leaved forest period. This probably occurs because the stand volume (stand structure) in the coniferous forest period is smaller than that of the broad-leaved forest period and also the evapo-transpiration is low. Also in the comparison between the clear cutting treatment period and coniferous forest period, no great difference was recognized between the fluctuation of runoff characteristics for the broad-leaved forest period in both periods, but the runoff in the coniferous forest period tends to become slightly similar to the runoff in the initial broad-leaved forest period compared to the clear cutting treatment period.

4.2.2 Period volume of runoff

In the analysis by Tank model, the overall runoff fluctuation due to change in forest in the no-snow season was compared ; here the difference in the period volume of runoff was investigated. The season August to October when there is absolutely no influence from snow was selected as the now-snow season since the first snow fall and thaw may vary yearly.

Fig. 6 shows the plot of the relation between period precipitation and period volume of runoff from August to October. And the following regression formulas were obtained for each period :

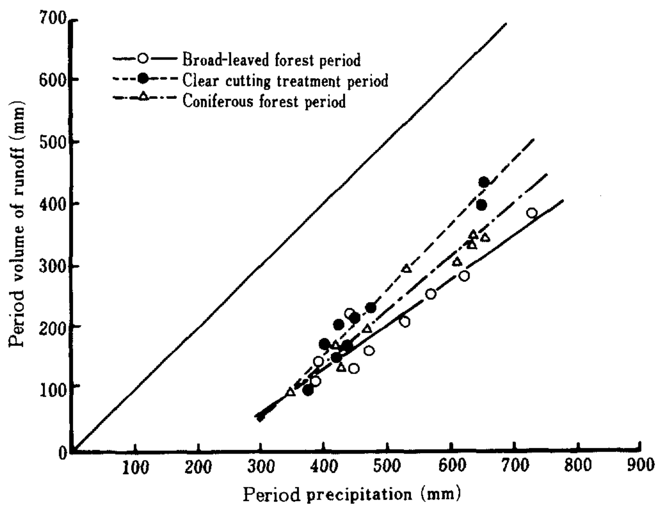


Fig. 6. The relation between period precipitation and period volume of runoff from August to October.

Broad-leaved forest period :

$$R = 0.72\,P - 156.2 \quad (r = 0.95) \qquad (1)$$

Clear cutting treatment period :

$$R = 1.04\,P - 267.8 \quad (r = 0.98) \qquad (2)$$

Coniferous forest period :

$$R = 0.86\,P - 207.5 \quad (r = 0.98) \qquad (3)$$

where, R : Period volume of runoff (mm)

P : Period precipitation (mm)

Each formula was statistically reviewed and a significant difference of 5% level was recognized.

From this Figure and regression formulas, it can be recognized that if clear cutting of forest is performed, then the discharge increases but thereafter the discharge recovers to the original state as the forest grows again by planting.

The difference in runoff volume among the broad-leaved forest period, the coniferous forest period and the clear cutting treatment period is considered to be affected by forest interception and evapo-transpiration. Moreover, the difference in volume of runoff between broad-leaved forest period and coniferous forest period is considered to be related to the difference in stand volume, that is, the difference in stand structure such as the amount of leaves.

4.2.3 Time of flood concentration

The time of flood concentration can express the degree of freshet in mountainous rivers. This is also correlated to the relation between rainfall and peak discharge and thus it greatly changes depending on the difference in the form of land use. As a practical estimate formula for the time of flood concentration in the rivers in hilly mountainous basins, the following equation has been proposed (KADOYA and FUKUSHIMA, 1976) :

$$t_p = C \cdot A^{0.22} \cdot r_e^{-0.35} \qquad (4)$$

where, t_p : time of flood concentration (min)

A : Catchment area (km^2)

r_e : Effective rainfall intensity (mm/h)

C : coefficient determined by basin conditions

In the present research, the degree of variation over time of flood concentration between the broad-leaved forest period, the clear cutting treatment period and the coniferous forest period was investigated. The results are shown in Fig. 7. This figure indicates that the time of flood concentration greatly varies as a result of the change in forest vegetation. That is, the time of flood concentration becomes very short after clear cutting of forest, but it tends to return to the original value after the forest recovers. The value of C in equation (4) in each period was as follows :

Broad-leaved forest period	C : 239.2
Clear cutting treatment period	C : 177.9
Coniferous forest period	C : 221.4

From the above, it can be understood that the mature forest especcially has the effect of delaying the time of flood concentration as compared to other conditions.

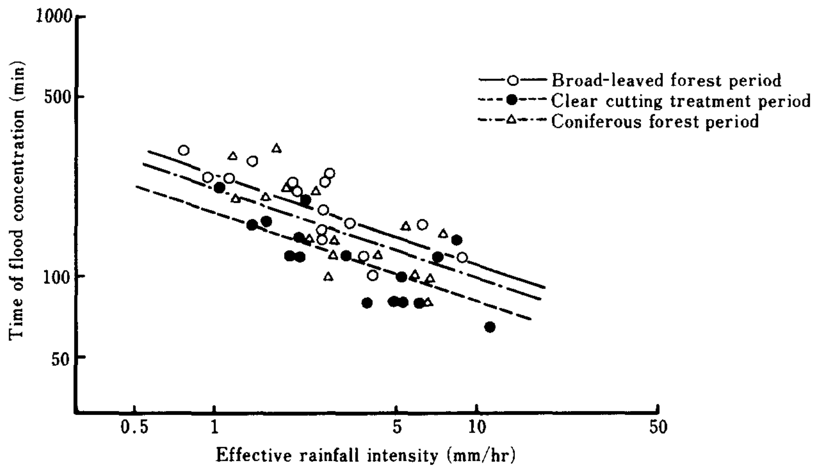


Fig. 7. The relation between the time of flood concentration and effective rainfall intensity.

Also, in conjunction with the investigation of time of flood concentration, we analyzed the peak discharge in each period ; that is, the relation between peak discharge and maximum one-hour precipitation before peak and total precipitation until the peak were analyzed, and no difference was recognized in peak discharge between the periods analyzed. There were no statistically significant differences in the short-term runoff characteristics, probably because the dispersion in the measurement of precipitation such as rainfall intensity and precipitation distribution in basin was large.

4.2.4 Recession characteristics

Discharge on days without rain generally tends to decrease with time. And, as its well known, its recession trend greatly varies depending on the topography, geological structure and soils in the basin (TAKAHASHI, 1978).

On the other hand, the forest consumes moisture in soils by evapo-transpiration as the basis of its living activities. In consequence, even the forest seems to have some kind of influence upon the runoff.

In the case of this same basin, the topographic, geological and soil conditions will not change. Thus the influence of the forest upon the moisture in soils and even upon the runoff is expected to vary according to the conditions of forest vegetation.

The average recession curve was determined from the data of the volume of runoff on a day without rain in each period for the broad-leaved forest, the clear cutting treatment and the coniferous forest periods as shown in Fig. 8. Respective regression formulas obtained are :

Broad-leaved forest period :

$$Q = 5.49\, e^{-0.31t} \quad (r = 0.98) \qquad \cdots\cdots (5)$$

Clear cutting treatment period :

$$Q = 5.26\, e^{-0.24t} \quad (r = 0.98) \qquad \cdots\cdots (6)$$

Coniferous forest period :

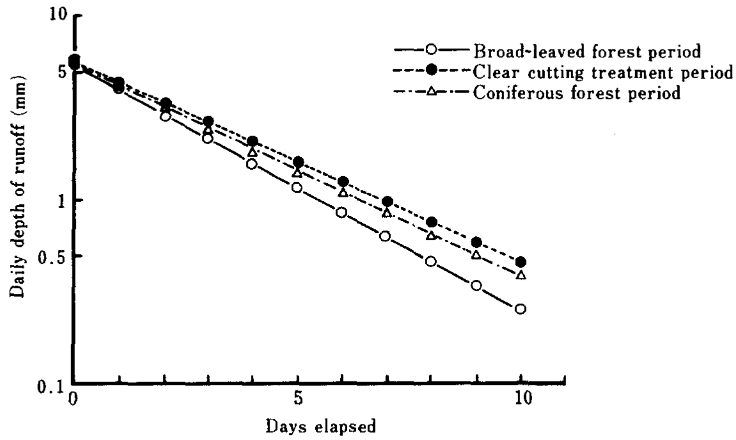


Fig. 8.　Average recession curves in each period.

$$Q = 5.21\, e^{-0.26t} \quad (r = 0.98) \qquad \cdots\cdots(7)$$

where, Q : Daily depth of runoff (mm)

t : Number of days passed

From this figure, it can be shown that the recession occurs more quickly in the period where the forest is present than the recession in the period after cutting. Particularly, the recession tendency is stronger in the broad-leaved forest period which had a larger stand volume compared to the coniferous forest period. This indicates that the influence of evapo-transpiration by the forest is substantial. However, the total volume of runoff during the recession is not greatly affected by the presence or absence of tree cover. If the daily discharge of 5 mm in the first day of calculation is used for calculating the total volume of runoff in ten days during recession for each period, then it is 14.3 mm for broad-leaved forest period, 17.2 mm for clear cutting treatment period and 16.1 mm for coniferous forest period.

4.3 Runoff characteristics in the snow cover and snowmelt season

The forest is considered generally to have the effect of delaying the snowmelt and lengthening the runoff period of the water from the melting snow (Kittrege, 1949). Also according to the survey results (Anderson, 1956) on the forest and snow cover, it is known that the presence of forest greatly affects the conditions of snow cover.

It was observed that the forest has two contradictory actions (Shidei, 1955) ; decreasing snow cover by the tree crown which blocks snow and by capturing it increases snow cover. Generally, the former is believed to be more related to coniferous trees and the latter to the deciduous broad-leaved trees. Moreover, it is recognized that the daily amount of snowmelt per 1°C of daily mean air temperature increases as a result of the cutting of forest (Enjyu, 1954).

For clarifying the relation between forest conditions and volume of snowmelt runoff from the basin, it is necessary to accurately measure and analyze the micro meteorological elements such as snow depth, amount of snowmelt, insolation and wind velocity inside and outside the forest. However, although this may be possible for specific points, it is difficult to extend the results of analysis to a stand or basin unit having a plane extension (SHIMIZU, 1990).

Therefore in the present research, the influence of forest upon snowmelt runoff was examined using the highly accurate observation data for discharge.

4.3.1 Comparison of daily discharge hydrograph

Snowmelt runoff in the snowmelt season in the Shozawa Basin starts in the beginning to the middle of March, though there is a yearly seasonal variation, and the hydrograph rises though with daily changes. The snowmelt runoff is completed between the end of May and the beginning of June; thereafter the hydrograph shows increased water discharge produced by rainfall but as a whole shows an attenuating tendency.

Here, in order to see how the snowmelt runoff varies over time depending on changes in the forest, the mean values of the daily volume of runoff over every ten years were determined respectively for the broad-leaved forest period, the clear cutting treatment period and the coniferous forest period. The mean hydrograph of the snow cover-snowmelt seasons is shown in Fig. 9.

From this figure, snowmelting and accompanied runoff are increased after cutting of forest compared to the situation before cutting and additionally the snow disappears

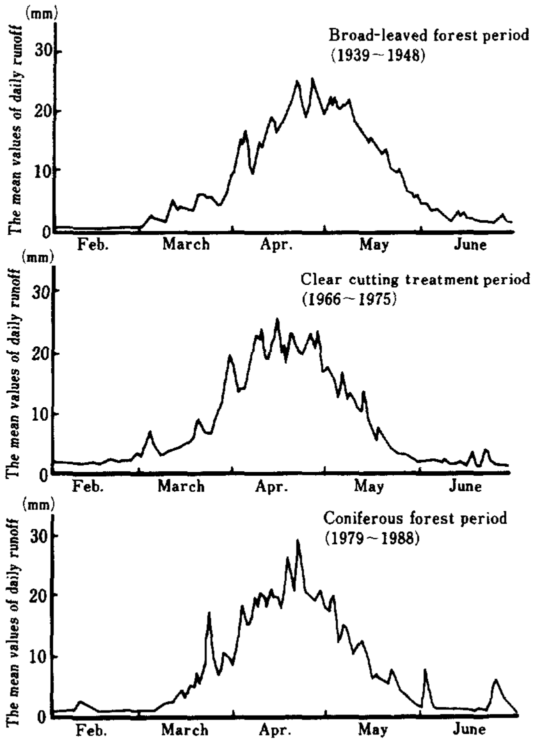


Fig. 9. The mean hydrograph of snow cover-snowmelt seasons in each period.

quicker and the snowmelt runoff is terminated quicker. However, as the forest recovers, the snowmelt runoff tends to be delayed, thereby gradually returning to the conditions before cutting. Therefore, it is apparent that the forest has the effect of delaying the snowmelt runoff due to its covering function.

The forest blocks the solar radiation with the tree crowns. However if cutting is performed, then the snow cover is left exposed without the cover of the tree crown so that the absorption of solar radiation increases and snowmelting is accelerated. Because of this, the runoff from the snowmelt increases in early spring (beginning of snowmelt) and also the snowmelt runoff is ended earlier (disappearance of snow).

Also, it was found an examining each tree species, that the coniferous forest blocks the snowfall with the tree crown. While in contrast snow cover easily occurs in the deciduous broad-leaved forest since the tree crown layer is irregular, and in spring time new leaves cover the snow on the forest floor and block solar radiation (Shidei, 1955). In consequence, there is more snow cover in the broad-leaved forest compared to the coniferous forest, and the snowmelt runoff is easily delayed. However, as explained earlier in the discussion concerning change in forest vegetation, the dates here are different according to forest age, stand structure and growing stock per ha between the broad-leaved forest and the coniferous forest periods. Thus, the strict comparison of tree species by the same scale of stand may not be always possible here. However, it is possible to observe the runoff change over the various periods with the loss of vegetation in the broad-leaved forest→ clear cutting→ coniferous forest and thereafter the recovery of the forest.

4.3.2 Snowmelt runoff period

Normally, the snowmelt is quickened by the cutting of forest, and the snowmelt runoff period is considered to be shorter in comparison with the period before cutting though it also depends upon meteorological factors such as air temperature and rainfall in that year (Troendle and Leaf, 1981).

Therefore, it is defined here that the start of the snowmelt runoff occured when increased water was first recognized on the hydrograph (daily change in discharge), that the completion of the snowmelt runoff was that day when the daily change disappeared from the hydrograph, and that the number of days between the start and completion is the snowmelt runoff period.

The relationship between the snowmelt runoff period and the snow depth at the main climatic station immediately before the start of snowmelt runoff was plotted in Fig. 10 for each period for the broad-leaved forest period, the clear cutting treatment period and the coniferous forest period. Respective regression lines are indicated in this Figure, and a significant difference was recognized statistically with a level of significance of 5% between respective equations.

Broad-leaved forest period :

$$T = 0.10\,D + 74.1 \quad (r = 0.65) \qquad \cdots\cdots (8)$$

Clear cutting treatment period :

$$T = 0.18\,D + 47.9 \quad (r = 0.74) \qquad \cdots\cdots (9)$$

Coniferous forest period :

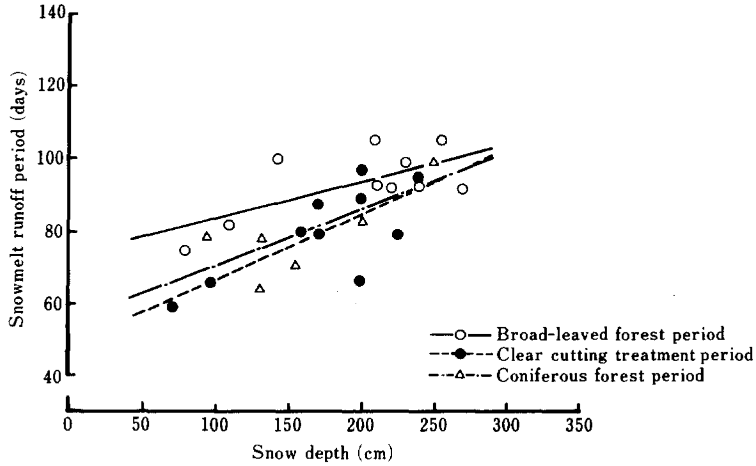


Fig. 10. The relation between snowmelt runoff period and snow depth immediately before the start of snowmelt runoff.

$$T = 0.15\,D + 54.3 \quad (r = 0.77) \qquad \cdots\cdots (10)$$

Where, T : Snowmelt runoff period (days)

D : Snow depth (cm) at the main climatic station immediately before the start of snowmelt runoff

From this figure, it can be shown that the snowmelt runoff period as a whole is shortened by the cutting of forest and lengthens as the forest recovery progresses. In the year when the snow depth is large, a great difference is not seen in the snowmelt runoff period before and after the cutting of forest, but the difference in the snowmelt runoff period is great in the year when the snow depth is small. By observing throughout the snowmelt season, the snowmelt runoff period is shortened about half a month by the cutting of forest, but it can also be shown that the snowmelt runoff period is slightly lengthened by the recovery of forest and returns to the original period. This occurs due to changes in micro meteorological elements such as an increase in insolation on to the snow surface, wind velocity, temperature and other factors due to the cutting of forest.

4.3.3 Lag-time in freshet

The hydrograph of freshet from snow cover region has a unique curve of an asymmetrical type between right and left and, in response to the daily change in air temperature, shows the same daily change. In order to find the degree of change in the time delay between air temperature peak and snowmelt freshet peak due to changes in the forest, the days with temporarily irregular freshets due to rainfall and subsequent recession portions were excluded; only the days having saw-toothed daily changes unique to snowmelt freshets were selected. Also the time difference between the time of daily maximum air temperature and the time of peak discharge in that day was defined as the lag-time in freshet; and the relation between the lag-time and snow depth at the main climatic station in that day was determined with the results, as shown in Fig. 11.

The regression formula for the relation between them both is as indicated below, and

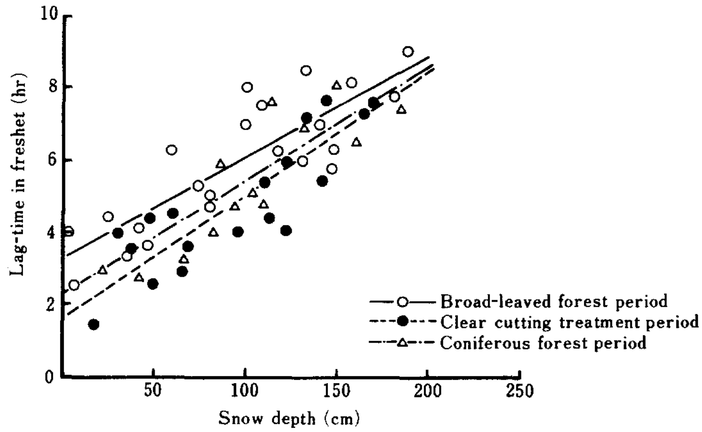


Fig. 11. The relation between Lag-time in freshet and snow depth in that day.

a significant difference with the level of significance of 5% was recognized between respective formulas.

Broad-leaved forest period :

$$L_g = 0.028\,D' + 3.3 \quad (r = 0.84) \qquad \cdots\cdots (11)$$

Clear cutting treatment period :

$$L_g = 0.034\,D' + 1.7 \quad (r = 0.89) \qquad \cdots\cdots (12)$$

Coniferous forest period :

$$L_g = 0.031\,D' + 2.3 \quad (r = 0.84) \qquad \cdots\cdots (13)$$

where, L_g : Lag-time in freshet (hours)

D' : Snow depth (cm) at the main climatic station

For instance, if the snow depth is 100 cm, then the lag-time in freshet is 6 hours for broad-leaved forest period, 5 hours for clear cutting treatment period and 5.5 hours for coniferous forest period ; and it can be known that the peak of snowmelt freshet is accelerated by about one hour by the cutting of forest but the peak of snowmelt freshet tends to be delayed by the recovery of the forest. The lag-time in freshet decreases as the snow depth decreases in any period. After the cutting of forest, it is recognized that the lag-time in freshet tends to greatly decrease compared to the forest conditions.

Felling site absorbed sun light considerably and its snowmelt started earlier and was a larger amount (Ono and Kawaguchi, 1978) during the day compared to forest land, so that snow quality tended to change easily after cutting and, in consequence, snowmelt runoff seems to have started earlier.

In the present research, we have investigated the influence of types of forest vegetation upon the runoff in a mountainous basin during the no-snow season and snow cover-snowmelt season at the Takaragawa Forest Watershed Experiment Station.

We found that the volume of runoff fluctuates in the direction of a temporary increase in runoff due to cutting of forest and then gradually returns to the original state as forest recovery progresses.

In the future, it is important to continuously investigate and compare the volume of runoff of the coniferous forest period, where the Japanese cedar and larch are growing in the Shozawa Basin, with the volume of runoff of the broad-leaved forest period with original beech trees. This means that the comparison of runoff volumes in the basin unit between broad-leaved forest and coniferous forest under strict survey conditions must be made; and the results obtained will become important basic data for comparing long-term forest recovery and changes in runoff.

Acknowledgment

The hydrological materials used as the basis for the present research have been made available through the many efforts of those who engaged in observation at the Takaragawa Experiment Station. The authors gratefully appreciate their efforts and cooperation in arranging the data offered by Mr. Shoichi YOSHINO, former Director of the Takaragawa Experiment Station.

Literature cited

ANDERSON, A.W. : Forest-cover effect on snowpack accumulation and melt, Central Sierra Snow Laboratory, Trans. Amer. Geoph. Union., **37**, 307-312 (1956)

BOSCH, J.M. and HEWLETT, J.D. : A review of catchment experiments to determine the effect of vegetation changes on water yield and evapotranspiration, J. Hydrol., **55**, 3-23 (1982)

ENJYU, K. : The amount of discharge and the thawing of snow, J. Jpn. Soc. Snow and Ice, **15** (6), 12-18 (1954) (in Japanese with English summary)

Gov. For. Exp. Sta. : A Observation report of forest and water experiment stations, 120-128 (1961) (in Japanese)

KADOYA, M. and FUKUSHIMA, A. : Concentration time of flood in small or medium river basin, Bull. Disas. Prev. Res. Inst., Kyoto Univ., No. 19 B, 143-152 (1976) (in Japanese with English summary)

KITTREDGE, J. : Forest Influences, McGraw-Hill, 394 pp. (1949)

NAKANO, H : Effect on streamflow of forest cutting and change in regrowth on cut-over area, Bull. Gov. For. Exp. Sta., 240, 1-251 (1971) (in Japanese with English summary)

ONO, S. and KAWAGUCHI,T. : Influences of forest cutting on snowmelt process —A case of Kamabuchi forest and water experiment station—, J. Tohoku Branch Jpn. For. Soc., **29**, 163-164 (1978) (in Japanese)

SHIDEI, T. : Influences of forest on snow, Res. Snow and Ice, No. 2, 195-201 (1955) (in Japanese)

SHIMIZU, T. : Influences of deforestation on snowmelt runoff, J. Jpn. Soc. Snow and Ice, **52** (1), 29-34 (1990) (in Japanese)

SUGAWARA, M. : Runoff analysis method, Kyoritu Publications, 257 pp. (1972) (in Japanese)

SUZUKI, M. : Forest-influences on rainfall-runoff process, J. Jpn. Assoc. Hydol. Sci., **13**, 1-10 (1983) (in Japanese)

TAKAHASHI, Y. ed.: River Hydrology, Kyoritu Publications, 218 pp. (1978) (in Japanese)

Tokyo Regional Forest Office: A report of Takaragawa forest and water experiments, 33-39 (1943) (in Japanese)

TROENDLE, C.A. and LEAF,C.F.: Effects of timber harvest in the snow zone on volume and timing of water yield, Interior West Watershed Management (Symposium, Spokane, Wash., 1980), 231-243 (1981)

YOSHINO, S. and KIKUYA, A.: Effect of removal of forest vegetation on stream flow for warm season in high-elevation watershed (I). The Honryu basin in the Takaragawa experimental watershed, Bull. For. and For. Prod. Res. Inst., 331, 127-145 (1985) (in Japanese with English summary)

* The title in parentheses is tentative translation from the original Japanese title by the authors of this paper.

植生変化が山地流域の流出特性に及ぼす影響

志水俊夫[1], 菊谷昭雄[2], 坪山良夫[3]

摘　　要

植生の変化が山地流域の流出特性に及ぼす影響を明らかにするため，ブナなどの広葉樹林→皆伐→スギ・カラマツの針葉樹林と林種転換が行われ，しかも長期間にわたり正確に水文・気象観測が実施されている森林総合研究所宝川試験地の初沢流域を対象にして，流出の経時的変化について解析を行った。その結果，林況変化による流出変化は，流域への入力としての降水量が雪であるか，あるいは雨であるかにより，森林植生が流出特性に関係する機構が異なるため，無雪期（8～10月）と積雪・融雪期（3～5月）とで大きな差が認められた。無雪期では期間流出量，洪水到達時間，減水特性が，積雪・融雪期では融雪流出の開始時期，融雪流出期間，出水の遅れ時間がそれぞれ変化することが明らかになった。さらに流出特性は森林の伐採により一時的に変動するが，森林の回復とともにやがてもとの状態にもどる傾向が認められた。

1991年7月11日受理
(1)(2)(3)　森林環境部