Forest-Watershed Experiments in Japan

By TOSHIO SHIMIZU

Forest Influences Division, Forestry and Forest Products Research Institute
(Kukizaki, Inashiki, Ibaraki, 305 Japan)

Forest workings such as logging, planting, herbicide spraying, fertilizing, and forest road construction, as well as forest recreation activities exert influences on streamflow and water quality of rivers.

Since old time, relations of forests to flood flow and water yield have been a matter of keen concern in Japan, and research on this aspect has been undertaken mainly by watershed experiments. The first watershed experiment was started in 1906 at 8 forest experimental watersheds located in Ōta, Kasama, and Ashio national forests, distributed in Ibaraki and Tochigi prefectures. In this experiment, outflow was compared between forest lands and bare lands. By the way, watershed experiment was initiated in 1899 at Emmental of Switzerland, and in 1910 at Wagon Wheel Gap in the U.S.A..

After the first watershed experiment, experimental watersheds on the forest-water yield relation have been set up at various places throughout Japan. Effects of forests on river streamflow have been examined, and much information has been obtained. Measuring methods have been developed and actual measurements have been made on individual hydrologic phenomena such as rain interception, evapotranspiration, infiltration capacity, surface and subsurface runoff, etc.. As a result, the role of forests in water balance has come to be understood quantitatively to a certain extent.

On the other hand, a recent increasing trend is that forest lands are used for other purposes, such as construction of golf courses and houses in suburban areas, development of tourist resorts and grazing lands at piedments of volcanic mountains, etc.. It causes problems against appropriate land utilization and environmental conservation of forests, as well as prevention of floods and water quality deterioration. These problems have come to be discussed as the subject of technology assessment.

In relation to water shortage occurring frequently in summer seasons, the actual status of low flow from mountainous watersheds is being studied, including the problem that "Is it possible to expect forest's function for maintaining and enhancing the base flow?"

Research results so far obtained

Out of the forest hydrologic experiments so far conducted by the Forestry and Forest Products Research Institute at the experimental watersheds on the forest-water yield relation shown in Fig. 1 and Table 1, results of experiments[1-9], mainly on changes of streamflow caused by forest cutting and recovery of vegetation will be presented briefly.

1) Forest cutting and annual runoff

In case of Japan, annual runoff is apparently increased by clear cutting. This fact is recognized without exception, irrespective of different watershed characteristics such as kinds of forest, rainfall conditions etc..

Increase of annual runoff by clear cutting is about 190–270 mm, equivalent to about 10–50% of the total annual runoff and 8–19% of the annual precipitation. The largest increase of annual runoff occurs in the year when the clear cutting is completed or in the next year, with a few exceptions.

The effect of cutting, showing the greatest effect by clear cutting, decreases with the decrease of cutting rate in selective cuttings and no effect is observed by a low cutting

Fig. 1. Location map of experimental watersheds under the control of For. & For. Prod. Res. Inst.

rate. With the recovery and increasing growth of vegetation in a cut-over area, the increment of annual runoff is recognized to decrease.

2) Forest cutting and flood flow

Flood flow (direct runoff · peak discharge) caused by a heavy rain showing a total storm precipitation of more than 150–200 mm and maximum 1 hr precipitation of more than 25–40 mm is apparently increased by clear cutting, as compared with that before the clear cutting.

The direct runoff becomes 1.2–2.0 times larger, and peak discharge 1.1–1.9 times larger than the expected values for the case when the forest was not removed. But, selective cuttings at low cutting rate hardly effect the flood flow.

However, the direct runoff caused by heavy rain is not always increased by clear cutting. It is sure that the direct runoff is increased by cutting in many cases of freshet caused by a storm, but there are cases which show decreased direct runoff, depending upon whether the surface soil of watershed is dry or wet, and also upon the total storm precipitation and its intensity. Namely, when the watershed area is very dry before the freshet, a considerable portion of rainfall is consumed to moisten the soil, i.e. initial losses at the time of freshet become large, resulting in a reduced flood flow as compared to that before the clear cutting. With the rain heavier than a certain level, however, the initial losses become relatively less and not

Table 1. List of experimental watersheds on the forest—water yield relation under the control of For. & For. Prod. Res. Inst.

Location & watershed	Area (ha)	Mean elevation (m)	Mean gradient (°)	Aspect	Geology	Mean annual precipitation (mm)	Mean annual runoff (mm)	Forest vegetation at the beginning of experiment	Observation period and treatment
KAMIKAWA (Hokkaido)									
Minamitani	572.9	600	17	W	Rhyolite Andesite debris	1,388	699	Natural mixed forest of hardwood and softwood	1938–1954 Selective cutting
Kitatani	645.4	600	17	W	Rhyolite Andesite debris	1,453	808	Natural mixed forest of hardwood and softwood	1942–1958 Clear cutting
Ichinosawa	8.9	520	——	N	Rhyolite Granite	1,116	523	Natural mixed forest of hardwood and softwood	1942–1953 Clear cutting, planting
Ninosawa	73.3	640	——	NW	Rhyolite Andesite debris	1,271	711	Natural mixed forest of hardwood and softwood	1942–1953 Selective cutting
KAMABUCHI (Yamagata)									
No. 1	3.06	200	34	SE	Tuff Shaletic tuff	2,641	2,016	Natural hardwood forest dotted with artificial forest of Japanese cedar and cypress	1939–Continued
No. 2	2.48	200	36	SE	Tuff Shaletic tuff	2,641	2,075	Natural hardwood forest dotted with artificial forest of Japanese cedar and cypress	1939–Continued Clear cutting Burning and terracing
No. 3	1.53	210	34	E	Tuff Shaletic tuff	2,361	2,232	Natural hardwood forest	1961–Continued Partial clear cutting
No. 4	1.12	210	34	W	Tuff Shaletic tuff	2,361	1,780	Artificial forest of Japanese cedar	1961–Continued Partial clear cutting
TAKARAGAWA (Gunma)									
Honryu	1905.7	1,390	24	SE	Tuff Diorite Granite	3,673	3,117	Natural mixed forest of hardwood and softwood	1937–Continued Partial clear cutting
Shozawa	117.9	1,070	25	SE	Tuff Serpentine Granite	2,153	1,783	Natural mixed forest of hardwood and softwood	1937–Continued Selective and partial clear cutting, planting
No. 1	6.48	940	36	S	Tuff	2,168	915	Natural mixed forest of hardwood and softwood	1957–Continued
No. 2	4.42	980	38	SSW	Tuff	2,168	1,518	Natural mixed forest of hardwood and softwood	1957–Continued Selective and clear cutting
No. 3	5.17	1,060	37	SSE	Tuff	2,168	1,398	Natural mixed forest of hardwood and softwood	1957–Continued Selective and clear cutting

Location & watershed	Area (ha)	Mean elevation (m)	Mean gradient (°)	Aspect	Geology	Mean annual precipitation (mm)	Mean annual runoff (mm)	Forest vegetation at the beginning of experiment	Observation period and treatment
ŌTA (Ibaraki)									
Kōyōjurinku	15.7	350	——	SSW	Amphibolite	1,567	916	Natural hardwood forest	1906–1919 Clear cutting, planting 1980–Continued
Shinyōjurinku	36.6	340	——	SSW	Amphibolite	1,654	752	Artificial forest of Japanese cedar	1906–1912
Yōreirinku	21.1	250	——	W	Amphibolite	1,666	905	Young-growth forest of Japanese cedar	1906–1912
KASAMA (Ibaraki)									
Kōyōjurinku	5.9	210	——	E	Clay-slate Palaeozoic strata	1,646	504	Natural hardwood forest	1906–1912
Shinyōjurinku	7.3	230	——	E	Clay-slate Palaeozoic strata	1,674	574	Artificial forest of Japanese cedar	1906–1912
Muryubokuchiku	5.2	230	——	NE	Clay-slate Palaeozoic strata	1,526	394	Cut-over area	1910–1912
ASHIO (Tochigi)									
Kōyōjurinku	298.5	1,080	——	W	Liparite Quartz-porphyrite Granite	2,363	1,148	Natural hardwood forest	1908–1912
Muryubokuchiku	259.9	950	——	E	Quartzite Palaeozoic strata	2,229	——	Bare land by smoke damage	1908–1912
TATSUNOKUCHIYAMA (Okayama)									
Minamitani	22.6	160	26	NW	Graywacke Clay-slate Quartz-porphyry	1,153	293	Natural forest of Japanese red pine with artificial forest of Japanese cypress	1937–Continued Clear cuting Forest fire, planting
Kitatani	17.3	150	31	W	Graywacke Clay-slate Quartz-porphyry	1,113	290	Natural forest of Japanese red pine with artificial forest of Japanese cypress	1937–Continued Clear cutting Partial clear cutting
SARUKAWA (Miyazaki)									
No. 1	6.56	320	35	NE	Shale	2,782	1,876	Natural laurel-leaved forest	1959–Continued Clear cutting, Planting
No. 2	9.17	290	32	N	Shale	2,782	1,726	Natural laurel-leaved forest	1959 Continued
No. 3	8.18	250	32	NNE	Shale	2,782	1,989	Artificial forest of Japanese cedar	1959–Continued Clear cutting, Planting

influential, so that flood flow becomes larger than before the cutting.

Peak discharge of snow-melt flood is also recognized to increase by clear cutting by about 10% of that before the cutting. Even a considerably low rate of selective cutting expresses its effect on peak discharge of snow-melt flood.

3) Forest cutting and low flow

In the less-rain areas, low flow is decreased by evapotranspiration of forests. Even in areas with relatively much rains, low flow is also decreased by forests in small watersheds where the base flow is composed mainly of subsurface runoff from the relatively shallow soil strata.

By clear cutting, low flow in small watersheds is increased, but it gradually decreases by the recovery of forest vegetation, and after about 10–15 years, it returns to a same level as before cutting.

It must be noticed here that all the results shown above are experimental results obtained from small watershelds of several ha to several tens ha. As to the scanty runoff from large watersheds, it has been reported that the scanty runoff is mainly related to surface geology of the watersheds, and no clear relation to forest cover can be recognized.

Future research subjects

Forest hydrologic research in Japan has its history of about 75 years. As stated above, based on long-term watershed experiments, effects of changes in forest cover on streamflow have been made clear. However, the results obtained so far and the scope of our knowledge are not necessarily sufficient, and many problems still remain to be solved. Major subjects of them will be shown below.

When cutting or forestation is made in a tributary small watershed of a large watershed, there is a problem what point of the downstream of the large watershed their effect can reach. Experiment to clarify it has not been made. In practice, relation between forest and flood in such a case is a problem.

Effect of forest on low-flow is still left to be not so clear. As to this problem it is considered that studies on relationships between hydrologic characteristics of upper soil layer geology of watershed, vertical distribution of tree root system, behavior of gravitational water in soil layers, etc. and base flow may play an important role in solving the problem.

It is also important in making clear the role of forests for water budget of watershed to clarify quantitatively individual hydrologic phenomena such as interception, evapotranspiration, percolation, etc. in stands of many major forest types. At the same time, development of precise methods of measuring these hydrologic factors is needed.

For water conservation, it is required to establish a desirable forest management system. Particularly, it is necessary to clarify quantitatively the relationship of clear cutting or area rate of selective cutting to runoff. In recent years, two-storied high forest system and contour belt cutting system are regarded as forest working systems desirable for water conservation, but their relation to runoff has to be made clear.

It is regarded as urgent to clarify the effects of changes in land utilization caused by convertion of forest lands to golf courses, housing areas, livestock ranges, etc. on streamflow and water quality of rivers. In addition, water pollution caused by recreation activities in forests has become an important problem recently. On the other hand, it is considered important to clarify snow-melting mechanism and to have a grasp on actual pictures of snow-melt runoff in mountainous watersheds in spring, in relation to conservation and enhancement of water resources.

Thus, forest hydrologic research will become more and more important in the future for finding out desirable working systems for water conservation, and for establishing desirable technology in the multi-purpose utilization of forests. At the same time, appropriate forest administrations are required for the full manifestation of water conservation functions of forests. At present, however, labor is not sufficiently available for the practice of proper forest workings in Japan, due to increasing deserted villages in mountainous areas. There is a sociological problem how to keep people staying in mountainous villages, which has to be solved.

References

1) Endo, T., Katsumi, S. & Funaki, T.: On the effects of forest cutting upon water yield during the summer season. *Ann. Rep. Hokkaido Branch. Gov. Forest Exp. Sta.*, 1960, 181–214 (1961) [In Japanese with English summary].
2) Fujieda, M. & Abe, T.: Effects of regrowth and afforestation on streamflow on Tatsunokuchiyama experimental watershed. *Bull. For. & For. Prod. Res. Inst.*, No. 317, 113–138 (1982) [In Japanese with English summary].
3) Maruyama, I. & Inose, T.: Experiment of forest influences upon streamflow at Kamabuchi. The first report. *Bull. Gov. Forest Exp. Sta.*, No. 53, 1–44 (1952) [In Japanese with English summary].
4) Nagami, S., Yoshino, S. & Abe. T.: Effect of cutting on runoff for warm season. (Experiment on forest influence upon streamflow at Takaragawa. 3rd report). *Bull. Gov. Forest Exp. Sta.*, No. 170, 59–74 (1964) [In Japanese with English summary].
5) Nakano, H. & Kikuya, A.: Effect of changes in forest conditions, especially cutting, on runoff (II). Effects on storm runoff and peak discharge due to a rainfall. *Bull. Gov. Forest Exp. Sta.*, No. 170, 1–58 (1964) [In Japanese with English summary].
6) Nakano, H.: Effect on streamflow of forest cutting and change in regrowth on cut-over area. *Bull. Gov. Forest Exp. Sta.*, No. 240, 1–251 (1971) [In Japanese with English summary].
7) Ono, S. & Kawaguchi, T.: Influence of timber cutting on runoff from the snow. *Ann. Rep. Tōhoku Branch. Gov. Forest Exp. Sta.*, No. 8, 204–211 (1967) [In Japanese].
8) Shimizu, T.: Relation between scanty runoff from mountainous watershed and geology, slope and vegetation. *Bull. For. & For. Prod. Res. Inst.*, No. 310, 109–128 (1980) [In Japanese with English summary].
9) Shirai, J. & Takeshita, M.: Experiment on forest influences upon streamflow at Sarukawa (Report 4). Runoff, water loss and storage of Sarukawa experiment forest. *Bull. Gov. Forest Exp. Sta.*, No. 216, 127–166, (1968) [In Japanese with English summary].

(Received for publication, July 1, 1982)