CONTRIBUTIONS TO THE PROBLEM OF THE RELATION BETWEEN THE FOREST AND WATER IN JAPAN

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1. General Consideration of the River and Precipitation in Japan.

Out of the whole dominion of Japan we shall for the moment confine ourselves to the following chief islands, namely Honsyu, Sikoku and Kyusyu. In these islands the land is mountainous on the whole, leaving only small proportions of flat area. The drainage areas of 135 principal rivers in those islands concerned the mountainous and hilly portions occupy 78% on the average. Especially the central part of Honsyu, or the main island, contains a large number of high peaks, some of which rise to an elevation of 3,000 metres above sea level. Several volcanic chains traverse these islands, and a few of the volcanoes are still active.

Mountains are well chiselled by the actions of rain and snow, and their slopes are generally steep. This fact would cause landslips and similar disasters, unless the mountain sides are in general densely clad with forests, which are in places of very luxuriant growth. The area occupied by forests and grassy plains is reported to amount to 57% of the whole area of the islands under consideration, and 47% are wooded land.

The greater parts of our islands experience abundant precipitation, the annual amount of which reaches 2,000 mm. or so, and there are two main rainy seasons. One of the rainy seasons is what is called the "Bai-u" which is a prolonged wet period lasting usually about four weeks commencing in the middle of June. Since rice-planting is done about the beginning of this season farmers are anxious about whether the "Bai-u" comes earlier or later.

The another rainy season is a period which begins in August and lasts until October inclusive. During this season, the typhoon which originates somewhere in the far southern sea, takes its way often over or near our islands accompanying thereby violent wind and heavy rain, often doing enormous damages of various kinds along the passage of its center. By the violent typhoon of September 6th, 1914, the speed of the wind recorded at the observatory in Isigakijima, one of our southern islands, was 51.8 m/sec. and the one experienced on September 14th, 1923, brought, according to the observation made at our station on Mt. Odaigahara, in the province of Yamato, rainfall of 1612.5 mm. in 68 hours 35 minutes by its passage.

In winter, our area is swept by the prevailing northwesterly monsoon, and when the monsoon wind develops after having passed a continental depression it makes the water vapour taken in it during its travel over the Sea of Japan condense on the slopes of mountains facing it. So, in this season the sides on the central mountain ranges facing the Sea of Japan are visited by frequent snowfalls. Especially, the northern slopes of the mountains and hills in central Honsyu are noted with abundant snowfalls. Our recent experience in great snowfalls in January and February, 1927, proved that there was a certain place where the depth of snow on the ground was measured as much as 8 m. 18 cm. It would be needless to point out at great length that, such big mass of snow cause disturbances upon trafics and also damages, among others, to forests by breaking branches.

In the following table, the average monthly amounts of precipitation observed at some of our Forest Meteorological Stations are given, the stations being chosen to represent various territories.

Table I. Amount of Precipitation (mm).

	Kitaoguni (Kyusyu)	Motoyama (Sikoku)	Tokaiti (W. part of Honsyu)	Tokamati (Japan Sea side of Honsyu)	Ikaho (Pacific side of Honsyu)	Kakunodate (NE. of of Honsyu)
January	71.0	83.6	87.8	435.2	26.7	185.3
February	100.2	138.2	79.2	262.1	56.6	132.3
March	150.0	180.9	108.5	212.1	70.6	135.8
April	181.8	234.5	95.0	116.9	126.4	107.9
May	172.9	220.0	149.0	111.1	171.8	117.0
June	542.2	352.1	215.8	124.6	241.3	111.8
July	376.8	479.4	262.0	158.7	289.2	300.5
August	198.3	463.3	97.3	152.1	480.8	192.6
September	195.0	505.6	178.2	203.9	248.5	211.5
October	132.7	217.2	76.5	172.6	163.0	163.0
November	86.2	105.1	72.2	230.5	68.6	213.6
December	69.0	81.4	101.1	415.8	30.7	207.5
Year	2276.1	3061.3	1522.6	2595.6	1974.2	2078.8

As to the seasonal variation of the water stage of river, it follows naturally the similar course to that of precipitation. The water stage is generally high during the two rainy seasons, floods occurring mainly in these seasons, and it is low during the periods between both seasons. The thaw of snow takes place during March and April and these months are another season of high water in the northern districts. And there are two other seasons of low water, the one being before the "Bai-u" and after the thaw of snow, and the other during coldest months of January and February. Of these low water periods, those in the hottest and coldest seasons are more conspicuous than the remaining one, and the discharges of rivers use in these times to decrease to such a degree that the water becomes too scanty for generating sufficient electric power, making consequently some hydraulic power plants to provide themselves with heat engine. The low water in the early summer impedes transplantation of rice plant, and disturbances are not infrequently caused among people in the rural districts, in order to get enough water to flood their own fields. The following table shows some examples of the average monthly stages of rivers in various territories:—

Table II. Variation of the Mean Monthly Water Stages.
(in Syaku, 1 Syaku = 33 cm.)

River	Tikugo-gawa (Kyusyu)	Yosino-gawa (Sikoku)	Takahasi-gawa (W. part of Honsyu)	Ara-kawa (Pacific side of Honsyu)	Kuzuryu-gawa (Japan Sea side of Honsyu)	Kitakami-gawa (NE. part of Honsyu)
Station	Tukawaki	Motoyama	Niimi	Kowaisi	Asahi	Terabayasi
January	0.83	1.72	2.06	0.77	2.41	1.15
February	0.87	2.21	2.38	0.80	2.56	1.08
March	0.96	2.72	2.62	1.30	3.17	1.66
April	1.06	3.22	2.45	1.94	4.38	2.75
May	0.90	3.18	2.16	2.59	3.50	1.68
June	1.16	3.30	2.32	2.42	3.01	0.92
July	1.52	4.45	2.86	2.69	3.37	1.31
August	1.22	3.90	2.00	2.73	2.67	1.68
September	1.20	4.16	2.25	2.86	3.21	1.99
October	1.07	2.73	2.02	3.13	3.01	2.18
November	0.89	1.99	1.82	1.63	2.84	2.02
December	0.82	1.84	1.85	1.22	2.71	1.50

Of many ways of utilization of rivers in this country, that which is the most important to the lives of the people is the irrigation for the paddy fields. For this demand, the discharges of rivers at the low water periods during growing season of rice plant, is said to be critical at present, the utilization having reached the maximum capacity of the available water. Of the ways of utilization of river for the purpose of transportation, one worthy of mention is that is practised along the head-water regions for the conveying timber. The method known as "Teppo-nagasi" or shooting timber is as follows:—The water of a stream to be utilized is checked by a temporary dam built by logs and branches across the stream and when water becomes high enough to carry desired number of timber which were gathered to the basin from the neighbouring valley, the dam is breaked suddenly and the timber gathered flows down the dam in rushing water. Repeating the method down the stream, the timber is brought by and by to a place where other ways of transportation are available.

On the other hand, the demand of water for water power plant is increasing year after year. Recent development of our industry necessitates electric power with an increasing rate of twice in every five years, which is exciting rapid increase of the utilization of river in this direction. The authority concerned estimates the available water powers in Japan to be about 14,000,000 horse powers, of which two third have already been in use, and the remaining one third is going to be exhausted in near future. This new demand of water contradicts sometimes the existing demand for irrigation, and also the various constructions in connection with water power plants make transportation of timber by water impossible in some places, and fishing in certain places, which as a consequence, menace the people in the districts concerned.

Now, we shall turn our attentions to calamities brought forth by river. Besides enormous losses caused in towns and cultivated fields in the lower valleys by overflowing, landslips occurring in the headwater regions foot up to very great sum. It is estimated by an expert of our Forest Bureau that the expenses for mountain-side works to be born by various departments of the government and local authorities reached a sum not less than 6,000,000 Yen for the year of 1928. This sum is about thrice as larger as that experienced ten years ago, though a portion of such an increase is due to the

restoration works of demage of mountain-sides caused by the terrible earthquakes of 1923.

Such circumstances of rivers and their economical relations drew early attentions of the authorities concerned to manage forests with a view to improve degrees of the utilization of rivers as well as to reduce calamities in relation to rivers. Meanwhile, the scientific researches into the abilities of forest in controlling the discharge of rivers have not been neglected. Among various attempts in this line, one specially worth while to note here is the organization of the nets of the Forest Meteorological Stations. The organization was put in practice by a part of the temporary fund for the river improvement works set in the national treasury, by the approval of the Imperial diet after the great floods in 1910. The stations were placed at the headwater regions of certain prominent rivers in Honsyu, Sikoku and Kyusyu. The works in the stations were began in 1912 and the whole plan of the organization was completed in 1919, and at that time the stations were 39 in all. They were put under the supervision of the Forestry Experimental Station. The organization was readjusted in 1922 and again in 1923 and there remains 16 stations at present. At first, the main tasks of the stations were to make routine observations of various meteorological elements, because though there were already local metorological stations in each prefecture, they were placed in towns or ports, so that, as far as mountainous districts are concerned, precise meteoroligical conditions remained unrevealed at that time. After the final readjustment, more endeavours were paid for the observations and researches of matters concerning the relation between forest and water, such as researches into mountain slips and avalanches, measurements of discharges of streams, run-off over surface of various kinds, etc. The reports of our researches were published (in Japanese) in the Publications of our Institution.

In the present paper, I intend to make a review of the results hitherto obtained of researches in the line of the relation between forest and water in this country, but as to well known mechanical effects of water, I leave them out of our attentions.

2. Comparison of the Amount of Precipitation In and Out of Forest.

Portion of rainfall that intercepted by tree crowns. At twelve Forest Meteorological Stations, observations were made in order to compare the amount of precipitation falling on the forest floor with that on the neighbouring open land. To measure the precipitation under tree crowns certain number of raingauges, say 5 to 10, were set at various parts of a chosen area in a forest and the mean of the amounts caught by them was taken as the precipitation in that forest. The positions of the stations and other remarks ar given below:—

Table III. List of Station.

Station	Height above s.l.	Long. E.	Lat. N.	Tree*	Density of crown	Age of tree	Remark
Numakunai	m 310	141° 14′	39° 58′	*Sugi*	0.7	20	slope towards E., hollow.
Ikaho	691	138 55	36 30	„	0.6	60	flat
Ikaho	691	138 55	36 30	Broad-leaved	0.8	10—70	slope towards NW.
Myogi	427	138 46	36 18	*Sugi*	0.8	25	slope towards N., hollow.
Mitumine	1116	138 49	35 56	„	good	180	slope towards SW.
Katuyama	169	136 30	36 4	*Akamatu*	0.7	27	slope towards S.
Daikisan	462	136 14	35 31	*Akamatu* & broad leaved	not good	15—33	slope towards E.
Syuzan	362	135 38	35 9	*Sugi*	0.6	30	steep slope towards NE.
Matuyama	442	135 57	34 28	*Sugi* & *Hinoki*	good	28—29	slope towards W.
Motoyama	372	133 35	33 45	*Hinoki*	good	22	slope towards N.
Koisihara	497	130 50	33 27	*Sugi*	0.5	20	slope towards E.
Morimati	410	131 10	33 18	„	0.8	31	slope towards NW.
Kitaoguni	433	131 4	33 7	„	0.8	30	slope towards N.

* *Sugi = Cryptomeria japonica*, Don.
Akamatu = Pinus densiflora, S. et Z.
Hinoki = Chamaecyparis obtusa, S. et Z.

As seen from the above table, forests compared lie generally on slopes, while the sites of observation at the stations which were taken as open lands were flat, and consequently the differences in precipitations due to the

dissimilarity of the configurations of land surfaces are to be taken into consideration. Such differences were found however to be so trifle in many cases that we can neglect them, except in some special cases.

First, we shall consider the case of rain,[1] the period for which is generally from April to November in our area. The percentage of rain falling through the tree crowns to that falling on the open land are greatly influenced by the intensity of rain. The averages of such percentages as they were classified by the amount of rainfall for 24 hours at the open place are as follows:—

Table IV. Percentage of Rainfall in Forest to that out of Forest, as classified by the Amount for 24 Hours.

Class of rainfall for 24 hours	Numakunai *Sugi*	Ikaho *Sugi*	Myogi *Sugi*	Mitumine *Sugi*	Syuzan *Sugi*	Koisihara *Sugi*	Morimati *Sugi*
mm 0.1 - 5 mm	47	45	66	73	57	54	37
5 - 10	72	61	79	76	75	73	58
10 - 20	79	69	86	86	85	78	67
20 - 40	90	71	88	86	88	78	75
40 - 60	79	74	89	91	91	86	77
60 - 80	—	71	89	92	(96)	87	81
80 - 100	(91)	74	(91)	(94)	(88)	80	(83)
100 - 150	(87)	75	(97)	(90)	(96)	83	(71)
150 - 200	—	(96)	—	(102)	—	(79)	(78)
>200	—	—	—	—	—	—	(67)
mean	59	57	74	77	70	66	53

Table IV. (*continued*)

Class of rainfall for 24 hours	Kitaoguni *Sugi*	Ikaho Broad-leaved	Katuyama *Akamatu*	Daikisan *Akamatu* & broad-leaved	Matuyama *Sugi* and *Hinoki*	Motoyama *Hinoki*
mm 0.1 - 5 mm	43	82	75	63	55	53
5 - 10	62	84	82	74	75	69
10 - 20	71	87	87	77	79	70
20 - 40	74	88	88	79	81	70
40 - 60	77	86	88	77	82	68
60 - 80	81	87	88	80	(76)	74
80 - 100	79	87	(92)	(73)	(66)	(79)
100 - 150	77	(88)	(93)	(76)	(83)	(70)
150 - 200	(92)	(88)	—	—	(76)	(67)
>200	—	—	—	—	—	(72)
mean	67	84	82	69	66	62

In the table, figures in brackets are those the values of which are uncertain, as the numbers of observation were too little to get reliable means. The figures given in the row of "mean" are weighted means of the percentage for each class of rainfall, so that the values are to mean the percentage for a single rainfall of an average intensity. On the other hand, the percentages of the total amounts of rainfall in the forests for the period from April to November to those in the open places for the same period were obtained. The remainders of the both kinds of percentages subtracted from 100 would give the percentages of rainfall that are intercepted by tree crowns to the rainfall in the open places for an average single rainfall as well as for the total rainfall for a season respectively; these are summarized as follows:—

Table V. Amount of Rain intercepted by Crowns of Tree.

Station	Tree	Total of rain, April–Nov.	Percentage for a single rain		Percentage for total amount	
			under crowns	inter-cepted by crowns	under crowns	inter-cepted by crowns
Numakunai	*Sugi*	820 m.m	59%	41%	88%	22%
Ikaho	*Sugi*	1815	57	43	73	27
Myogi	*Sugi*	1711	74	26	82	18
Mitumine	*Sugi*	1635	77	23	88	12
Syuzan	*Sugi*	1278	70	30	84	16
Koisihara	*Sugi*	2268	66	34	82	18
Morimati	*Sugi*	1515	53	47	72	28
Kitaoguni	*Sugi*	1901	67	33	77	23
Ikaho	Broad-leaved trees	1815	84	16	86	14
Katuyama	*Akamatu*	1706	82	18	91	9
Daikisan	*Akamatu* & broad-leaved trees	1564	69	31	80	20
Matuyama	*Sugi* and *Hinoki*	1234	66	34	80	20
Motoyama	*Hinoki*	2607	62	38	68	32

An average value taken in the all places together and that for the kinds of trees are as follows:—

Table VI. Percentage of Rain-fall intercepted by Crowns with respect to the Amount in Open Place.

	For a single rain	For total amount
Total mean	31.8%	19.9%
Mean for *Sugi*	35	21
„ *Hinoki*	36	26
„ broad-leaved trees	24	17
„ *Akamatu*	18	9

Thus the percentage of rainfall intercepted by tree crowns with respect to that fallen in the open place is about 32% for a single rainfall and about 20% for the total amount of rainfall for a season, averaging regardless to the kinds, ages and sites of trees. As to the character of rainfall, the percentage increases as the intensity of rain is weaker, and as to the kind of tree, it is greater with the conifers than with the broad-leaved trees, except *Akamatsu* which has the least percentage of all. These percentages seem to make a seasonal variation with a range of 10% or more, and the variation owes mainly to the character of rainfall prevailing for the respective season.

The portion of rainfall that flowing down the trunk of tree. Certain portion of rainfall intercepted by tree crowns flows down by and by on the ground along the trunk of tree. Such amount of rainfall was measured at some stations, and here, as an example, the process and result tried at the compound of our Institution at Meguro, Tokyo,(2) will be described. In a *Sugi* forest having an area of 2000 m^2, 330 m^2 was chosen for the measurement. The site was flat and the mean age of trees was 35 and their mean height and mean diameter at the breast height is 15.5 m. and 19 cm. respectively. The density of trees was 152 per Tan (=992 m^2) and the density of crown was moderate and the growth of trees was not good. All trees within the chosen area were classified to three degrees according to their heights and diameters and one representative tree was selected from each class and the measurement was made with these ones.

At a heights of about one metre from the ground, a conduit tube made of an iron plate was tightly wound around the trunk, and the rain water received in this tube was conducted to a reservour. The amounts thus measured were multiplied to the number of trees belonging to the same class and dividing the total sum by the area of the forest, then we get the amount required.

The results of three years' observations as classified according to the amount of single rainfall are as follows:

Table VII. Rainfall in and out of Forest, Meguro, Tokyo.

Class of rain (mm)	0.0–3.0	3.0–6.0	6.0–10.0	10.0–20.0	20.0–40.0	40.0–100.0	>100.0	mean
Mean am. of rain in the open (mm)	1.6	4.4	7.9	14.9	30.2	57.0	132.8	
Mean am. of rain in the forest (mm)	0.6	2.4	5.4 (68)	11.3 (76)	24.4 (81)	48.5 (85)	111.4 (84)	(78)
Mean am. of rain flowing down trunk (mm)	—	0.0	0.2 (3)	0.5 (3)	1.6 (5)	2.9 (5)	14.1 (11)	(4)
Mean am. of rain sustained in crown (mm)	1.0 (62)	2.0 (45)	2.3 (29)	3.1 (21)	4.2 (14)	55.6 (10)	7.3 (55)	(18)
No. of obs.	38	26	29	47	37	29	4	

Figures in brackets are the percentages of respective amounts to the amount of rainfall in the open. Numbers in the last column are weighted means of the respective values. From the table, we observe that in our *Sugi* forest 22% of an average single rainfall are intercepted by tree crowns, of which 4% flows down the trunks of trees and 18% is sustained in crowns and evaporated directly therefrom. If we take the total amount of rainfall for this period, the respective percentages become 5% for that flew down the trunk, and 15% for that sustained in crowns.

The results obtained by the similar manner at our three stations are given in the following table, where percentages are given for the monthly amounts.

Table VIII. Rainfall in and out of Forest.

	April	May	June	July	Aug.	Sept.	Oct.	Sum
Kitaoguni. (1914–1920). *Sugi* forest.								
1. Rain in the open (mm)	123.2	135.2	620.3	299.0	208.8	162.9	184.7	1734.1
2. Rain in forest (mm)	84.5	94.2	515.3	236.0	155.3	121.3	138.6	1345.2
3. Rain flow down trunk (mm)	9.8	11.1	60.3	28.2	17.1	12.9	16.2	155.6
4. % of (3) to (1)	8.0	8.2	9.7	9.4	8.2	7.9	8.7	9.0
5. Rain sustained in crown (mm)	28.9	29.9	44.7	34.8	36.4	29.7	29.9	233.3
6. % of (5) to (1)	23.5	22.1	7.2	11.6	17.4	18.4	16.2	13.5
Matuyama. (1915–1920). *Sugi* forest.								
1. Rain in the open (mm)	134.8	102.4	242.8	172.2	226.6	310.8	152.5	1342.4
2. Rain in forest (mm)	107.1	78.4	193.3	138.0	182.5	123.3	123.3	1081.1
3. Rain flow down trunk (mm)	20.5	14.0	39.2	24.8	33.9	41.9	22.1	196.4
4. % of (3) to (1)	15.2	13.7	16.1	14.4	14.9	13.4	14.5	14.6
5. Rain sustained in crown (mm)	7.2	10.0	10.3	9.4	10.5	10.4	7.1	64.9
6. % of (5) to (1)	5.3	9.7	4.2	5.5	4.6	3.3	4.7	4.8
Myogi. (1914–1920). *Sugi* forest.								
1. Rain in the open (mm)	95.4	186.0	200.8	205.0	382.6	352.2	153.8	1575.8
2. Rain in forest (mm)	77.2	159.7	174.5	177.7	341.3	307.2	127.3	1366.9
3. Rain flow down trunk (mm)	1.1	3.3	2.5	2.4	7.3	5.3	2.8	24.7
4. % of (3) to (1)	1.1	1.8	1.2	1.2	1.9	1.5	1.8	1.6
5. Rain sustained in crown (mm)	17.1	22.0	23.8	24.9	34.0	29.9	23.8	184.2
6. % of (5) to (1)	17.9	12.4	11.9	12.1	8.9	11.4	15.4	11.1

In the above table, the remainder of the rainfall in the open place subtracted by both that in the forest and that flew down the trunk is given as that sustained in the crowns. The rainfall flew down the trunk and that sustained in the crowns depends, of course, largely upon the species of tree and the density of crowns. A glance at the table, we find that the rainfall flew down the trunk is abnormally great at Matuyama and consequently that sustained in the crowns very small. At Matuyama, the forest under consideration occupies a steep slope facing north. Besides the known fact that the rainfall fallen on a sloped land is not the same as that on a flat land, the amount flew down the trunk of tree seems to become larger in case of a steep slope, because the crowns receive rain accompanying wind on their sides instead of their tops. To test the difference of rainfall due to the dissimilarity of the configurations of lands we cleared a part of the forest after our comparative observations have come to an end and set there a raingauge.(3) Observations for one season proved that the gauge at the cleared slope caught almost always a larger amount of rainfall than that in the flat place, the difference amounting to 4% of that in the flat place on the average. Correcting the percentages at Matuyama just obtained by this difference, we get 14% for the rainfall flew down the trunk and 9% for that sustained in the crowns with respect to the amount in the open place.

Recently, another measurements(4) were tried in the same *Sugi* forest in Kitaoguni Station as formerly observed. This time, the observation of rainfall was made by such a method that a vessel made of an iron plate, having an area of 190×364 cm.^{2} and a height of 20 cm., was set on the forest floor, taking two trees in it. The rainfall get into the vessel through the crowns together with that flew down the trunk was conducted to a reservoir, where the amount was measured.

The results for 18 months during 1925 to 1927, excluding the winter months, as classified according to the amount of a single rainfall are as follows:—

Table IX. Rainfall in and out of Forest, Kitaoguni.

1. Class of rain (mm)	0–1	1–3	3–6	6–10	10–20	20–40	40–70	>70
2. Rain in the open (mm)	0.6	2.3	4.5	8.3	15.1	29.7	56.7	122.9
3. Rain in forest (mm)	0.1	0.9	2.2	5.4	11.2	24.5	49.8	109.8
4. (2)–(3)	1.5	1.4	2.3	2.9	3.9	5.2	6.9	13.1
5. % of (4) to (2)	83.3	60.9	51.1	34.9	25.8	17.5	12.2	10.7
6. No. of obs.	18	18	16	18	18	20	10	10

The difference given in the fourth row or the percentage in the fifth row gives the amount of rainfall which was sustained in tree crowns and evaporated directly therefrom. The weighted mean of these percentages for the each class of rain is 39.7%, while taking the total amount of rainfall for this period, the percentage amounts to 17%. The value corresponding to the latter has been 14% in the former observation. The difference between the percentages obtained by both observations must be due partly to the growth of trees for about ten years elapsed since the mean date of the former observation and partly to the difference of the methods of observations.

Summarizing the results, thus far obtained, of the percentages of the amount of rain sustained in crowns of *Sugi* tree to that in the open place are as follows:—

Tokyo	Kitaoguni (former)	Matuyama	Myogi	Kitaoguni (later)	mean
15%	14%	9%	11%	17%	13.2%

As we have already seen, our *Sugi* forest intercept 21% of the rain for a season in its crowns on the average. Our result just obtained tells us that 13,2% are kept in crowns and finally evaporated therefrom. The difference of the both percentages, i.e., 7.8% is therefore the portion of rainfall which flows down the trunk.

The percentage of rainfall intercepted in crowns has been 20% on the average for various kinds of forest, so that we may say as a rough estimation that the values of percentages just enumerated may be applicable to general forest without making any specification with regard to the kind of tree dominating the forest. It should however be born in mind that the broad-leaved forest has somewhat smaller and the *Akamatu* forest still smaller percentage.

Snowfall. In the case of snow, the amount received in raingauges set in the forest floor does not show the similar relation to the case of rain with respect to that in a gauge in the open place, because snow lying on tree crowns fall by either its own weight or the action of wind and also by thawing independently more or less to the actual snowfall in the open place. But the difference between the total amounts received in raingauges in the open place and in the forest for a season or the percentage of the latter to the former should represent the portion of snowfall which has eventually fallen down on the forest floor through crowns and consequently the remainder of the percentage subtracted from 100 should give the portion intercepted by crowns. The following table shows the portion of snowfall intercepted on tree crowns thus obtained at some stations in the snowy districts, the numbers being averages for several years.

Table X. Ratio of Snow intercepted by Crowns to That in the Open Place.

Station	Tokamati	Mitumine	Innai	Yokota	Daikisan	Katuyama	Nikko
Tree	*Sugi*	*Sugi*	*Sugi*	Broad-leaved	Broad-leaved	Broad-leaved	Broad-leaved
Ratio (%)	11.6	18.9	24.5	29.7	22.3	8.3	21.6

The mean of the percentages in these seven places amounts to 19.6%, being nearly equal to the corresponding value in the case of rain.

Again, taking the ratio of the mean depth of snow lying on the forest-floor for every five days to that on the open place for the corresponding days, we obtain the portion of snowfall falling on the forest floor through crowns on various occasions, if an assumption that the densities of the lying snow have no difference be allowed. Subtracting such ratio in percentage from 100, we shall obtain the portion of snowfall intercepted by crowns on various occasions. The following table shows the mean of the portion intercepted by crowns thus obtained for the places above mentioned.

Table XI. Ratio of Snow intercepted on Tree Crowns to That of the Open Place.

Station	Tokamati	Mitumine	Innai	Yokota	Daikisan	Katuyama	Nikko
Ratio (%)	42.4	43.3	23.2	43.8	24.4	22.1	12.8

The mean of the percentages in these seven places amounts to 30.3%, being again nearly equal to that for an average single rainfall.

Thus we see that the portion of snowfall intercepted on tree crowns is nearly equal to that of rainfall on the average for various kinds of trees. Of this portion, the amount flew down the trunk or that finally evaporated on tree crowns cannot be measured directly. The rate of evaporation from the surface of snow directly or after once melted, is ovbiously smaller than that in the case of rain, but the opportunities of evaporation are far greater in case of snow than that of rain, and the same may be said as to the opportunities of the flowing down of the melted water of snow along the trunk. As a rough estimation, we may therefore assume that the portion of precipitation which is finally evaporated in crowns without coming down to the forest floor has a similar ratio to the total amount of precipitation, no matter whether it falls as rain or as snow.

Occult precipitation. The effect of forest upon the rain formation in favour of increasing the amount have attracted interests of many writers, but we have no opportunity to test this fact in our country. One of the effects of this kind is that the forest in the mountain catches fog in its leaves and makes to come down in drops on the forest floor. This kind of precipitation is known as the *Ki-ame,* meaning tree rains, in this country. As an example of the observation of this kind of precipitation, I shall give

a result obtained at our Odaigahara Station.[5] The station lies on a high mountain in the province of Nara, not far distant from Nara, a famous city with historical monuments, and its height above the sea level is 1566 metres. Several raingauges were set on the floor of forest which is composed mainly from *Momi, Abies firma,* maxed with some broad-leaved trees, and the mean of the amounts received in the raingauges were compared with that received in one set in a cleared place. In the following table the amounts of rainfall for the warm months in 1922 are given, the amounts being summed up separately according to two cases, one those accompanied no fog and the other those accompanied fog.

Table XII. Rainfall in and out of Forest, Odaigahara.

	April	May	June	July	Aug.	Sept.	Oct.	Sum
Rainfall accompanied no fog								
1. Rain in the open (mm)	55.9	27.0	306.9	26.3	167.4	48.7	99.5	731.7
2. Rain in forest (mm)	42.4	21.0	209.0	18.7	117.8	35.7	67.7	512.3
3. (1)-(2) (mm)	13.5	6.0	97.9	7.6	49.6	13.0	31.8	219.4
4. % of (3) to (1)	24	22	22	29	30	27	32	30
Rainfall accompanied fog								
1. Rain in the open (mm)	264.8	182.5	55.6	469.4	100.1	229.7	606.5	1908.6
2. Rain in forest (mm)	292.8	167.4	55.4	517.1	80.6	215.9	449.8	1779.0
3. (1)-(2) (mm)	−28.0	15.1	0.2	−47.7	19.5	13.8	156.7	129.6
4. % of (3) to (1)	−11	8	0	−10	19	6	26	7

Thus, when rain falls accompanying fog, the difference of the amounts in and out of forest and its percentage to the amount in the open place is small, and sometimes the difference becomes negative, i.e., the amount is greater in the forest than out of it. In July, which is the most foggy month, the gain in the forest amounts to 10% of the amount in the open place.

This example shows us that this kind of precipitation is never negligible in forested region, especially when the land is situated on a higher elevation. But if we take the warm season for which precipitation is of the form of rain, as a whole, the amount of precipitation of such kind becomes generally only a trifle percentage of the total amount of the rainfall for that season. So, in our investigation of the present problem, we may put the effect of forest upon the rain formation out of our consideration.

3. Comparison of the Discharges of Streams under Various Kinds of Surface Conditions of their Drainage Areas.

For the investigation of the relation between forest and water, it is most direct and practical to compare the discharges of streams having drainage areas of similar conditions with regard to the climate, geological formation and configuration of land, but having different vegetations on the lands.

Such attempt[6] was carried out in this country as early as 1906 and the sites selected for the purpose were the national forests at Kasama, Ota and Asio in the Kanto Districts. The measurements of discharges were conducted by officials of the respective divisional forest offices under the supervision of the Tokyo District Forest Office. Here I shall give briefly the results obtained by these preliminary observations.

Descriptions of sites. (a) Ota district, Ibaraki Prefecture. Long. 140° 35′E., Lat. 36°35′N.

Here, three divisions were set, i.e., the young wood, coniferous and broad-leaved forest.

Young wood division:—Area, 21.07 ha.; height, 224–458 m. above the sea level; species of tree, *Sugi* and *Hinoki* (artificially planted); mean height of trees, 1.5 m.

Conifer division:—Directly to the north of the young wood division; area, 36.27 ha.; height, 222–464 m. above the sea level; species of tree, mainly *Sugi* and *Hinoki* mixed with some *Momi*; mean height of trees, 29 m.

Broad-leaved division:—473 m. distant to the north of the conifer division; area, 15.67 ha.; height, 327–380 m. above the sea level; forest in the upper part of the division is similar to that of the conifer and that in the lower, 70% of the whole division, is the broad-leaved forest, the mean height of trees being 13 m.

The bedrocks of this district are volcanic, and they are covered with

surface soil of a thickness more than 30 cm., except the greater part of the broad-leaved division, where surface soil does not exceed 20 cm.

The annual mean air temperature is 12.5°C and the annual amount of precipitation is about 1600 mm.

(b) Kasama district, Ibaraki Prefecture. Long. 140°10′E., Lat. 36°15′N.

Three divisions of the conifer, broad-leaved forest and non-forested land were set.

Conifer division:—Southeast slope of the Mt. Atago (303 m. above s. l.); area, 7.32 ha.; height, 150–300 m. above the sea level; a single forest of *Sugi*, the mean height of trees being 13 m.

Broad-leaved division:—860 m. to the southeast of the conifer; area, 5.81 ha.; height, 130–300 m. above the sea level; forest mainly broad-leaved trees mixed with a small number of conifers, and about one fifth of the broad-leaved forest is occupied by evergreens and the remaining decidious, the mean height of trees being about 9 m.

Non-forested division:—Adjoining to the broad-leaved division; area, 5.18 ha.; before clearning one third occupied by conifers and the remaining by broad-leaved trees. From the roots young shoots sprouted every year which were cut away frequently.

The geological formation of the district belongs to the palaeozoic system, consisting mainly of contact slate. The surface soil has generally a thickness of about 25 cm.

The annual mean air temperature is 14.0°C and the annual amount of precipitation is about 1650 mm.

(c) Asio district, Totigi Prefecture. Long. 139°330′E., Lat. 35°40′N.

The two divisions of the broad-leaved forest and non-forested land were set.

Broad-leaved division:—Area, 298.55 ha.; height, 788–1370 m. above the sea level; the mean height of trees, 4.5 m.

Non-forested division:—26 km. away to the west of the broad-leaved division; area 259.95 ha.; height, 630–1250 m. above the sea level; the area is a part of the damaged ground by fumes from the Asio copper mines. Surface soil is scarcely seen.

The annual mean air temperature is 9.3°C and the annual amount of precipitation is about 2300 mm.

Comparison of the coefficients of run-off. At the lowest part of the stream in each division, a gauging weir having a definite section was built in which the velocity of stream was perfectly removed and then the water was dropped through the mouth of weir. The amount of the discharge was calculated through the water level read at the weir. The observations of the water level were made usually five times a day and temporarily at every half an hour when there was a rain of any considerable amount.

The annual amounts of precipitation and run-off were counted from December of the preceding year to November and they were expressed by the depth in mm. for every drainage area. Omitting the years in which observations of the precipitation or run-off were defective for some days by some causes, the annual amounts of precipitation and run-off and the ratio of the latter to the former, i.e., the coefficient of run-off are given below:—

Table XIII. Coefficient of Run-off.

Ota district.

Year	Young wood		Conifer		Broad-leaved		Precipitation
	Run-off (mm)	Coeff. (%)	Run-off (mm)	Coeff. (%)	Run-off (mm)	Coeff. (%)	(mm)
1908	851.8	56.4	705.9	46.8	859.4	56.9	1509.3
1909	862.7	57.4	691.8	46.0	942.2	62.7	1502.7
1910	1034.2	55.7	843.7	45.5	—	—	1856.1
1911	857.7	48.5	764.3	43.2	1008.5	57.0	1768.0
1912	726.3	47.7	647.6	42.6	881.3	57.9	1521.3
1913	809.0	52.7	685.3	44.6	883.6	57.6	1534.9
mean	857.0	53.1	723.1	44.8	915.0	58.4	1615.4

Kasama district.

Year	Non-forested		Conifer		Broad-leaved		Precipitation
	Run-off	Coeff.	Run-off	Coeff.	Run-off	Coeff.	
1908	—	—	654.4	38.6	553.7	32.6	1697.4
1909	—	—	618.2	38.1	509.9	31.4	1624.4
1910	—	—	609.8	37.3	562.0	34.4	1635.2
1911	397.3	26.2	502.7	33.2	415.6	27.4	1515.5
1912	389.9	25.8	438.5	29.0	401.9	26.6	1510.0
1913	377.6	23.8	553.1	34.9	455.4	28.7	1584.9
mean	388.3	25.3	562.8	35.2	483.1	30.2	1594.6

Asio district.

Year	Non-forested		Broad-leaved		Precipitation
	Run-off (mm)	Coeff. (%)	Run-off (mm)	Coeff. (%)	(mm)
1910	701.8	29.1	1425.6	59.2	2408.4
1911	420.8	21.0	869.0	43.4	2003.1
1912	400.3	19.0	878.1	41.8	2101.8
1913	390.8	27.2	566.0	39.3	1438.4
mean	478.4	24.1	934.7	45.9	1987.9

The ratios of the annual run-off to the annual precipitation, i.e. the coefficients of run-off have different values not only in different districts, but even at various divisions in the same district. The difference in the coefficients at different divisions in the same district cannot be attributed to the dissimilarity of the vegetation over respective areas, because in Ota the broad-leaved forest division has the largest coefficient and the conifer the smallest, the young wood coming to the midway of the both, while in Kasama the coefficients at the broad-leaved and conifer divisions are reverse in order to those observed in Ota, which tells us the fact that the coefficient is more influenced by conditions of land itself than by the vegetation upon it.

Again, as regards the non-forested and forested divisions in Kasama district, the average coefficients for the same number of years of observation, i.e., three years, are as follows:

Division	Non-forested	Conifer	Broad-leaved
Coeff. of run-off (%)	25.3	32.4	27.6

Thus, the coefficient is smallest at the non-forested land and largest at the conifer, but such order of values cannot be accepted as having any meaning, as the data are inaccurate. It is rather safe to take the result to mean that the diffrence between the coefficients of the non-forested and the broad-leaved divisions is never considerable, if any. In Asio district, the the coefficients at the non-forested land is about one half as large as that of the broad-leaved, showing simply a better percolation of the ground at the non-forested, as there is practically no surface soil. Another fact to be remembered is that the coefficients in Kasama district are much smaller than those in Ota, in spite of the annual amounts of precipitation are nearly equal in both places.

Discharge immediately following rain. Here, the discharge immediately following rain was obtained by the manner that the total discharge for swelling hours following a rain was subtracted by the discharge for a unit time at the beginning of the rise of water multiplied by the swelling hours, the swelling hours bing counted from the time of the rising of water until the time when the level drops to the initial stage. In the following table, such amounts of discharge, the hours to attain the maximum level and the swelling hours for Ota and Kasama districts are given. The data were obtained from the results of the every half an hour's observation of the water stage.

Table XIV. Discharge immediately following Rain.

Ota district.

	I			II		
	Young wood	Conifer	Broad-leaved	Young wood	Conifer	Broad-leaved
Duration of rain (hour)	8.29	,,	,,	23.9	,,	,,
Amount of rain (mm)	12.00	,,	,,	53.5	,,	,,
Mean am. for an hour (mm)	2.26	,,	,,	2.69	,,	,,
No. of obs.	29	,,	,,	3	,,	,,
Hours to attain the max. level (hour)	6.38	6.10	6.81	15.3	15.0	15.5
Swelling hours (hour)	20.9	18.1	24.5	103.2	120.5	144.3
Percent. of increased discharge to rain (%)	2.11	1.57	3.07	46.10	45.50	53.62

Kasama district.

	Conifer	Broad-leaved
Duration of rain (hour)	9.54	,,
Amount of rain (mm)	16.6	,,
Mean am. for an hour (mm)	1.98	,,
No. of obs.	16	,,
Hours to attain the max. level (hour)	5.83	5.47
Swelling hours (hour)	25.1	30.5
Percent. of increased discharge to rain (%)	2.21	3.23

The figures given in the table are average values. In Ota district, the results are classified to (1) and (2). The class (1) is a group of such cases in which a single rainfall did not exceed 30 mm. and (2) is that of rainfalls larger than this amount. In the class (1) the percentage of the increased discharge to the rainfall is 2 or 3%, and the duration of swelling hours is 2 or 3 times as longe as the duration of rain, while in the case (2)

these numbers increases to about 50% and 5 times or so respectively.

On comparing two divisions in each district, one sees that the duration of the swelling hours is shorter in the coniferous than in the broad-leaved forest, and the percentage of the increased discharge against the rainfall is smaller in the former than in the latter, which is coincidental in both districts, in spite of the dissimilarity of the conditions of lands between them.

Next, we shall see the maximum discharge for an hour during a swelling water following a rainfall. In the following table, the average of the hourly maximum discharge classified by the amount of a rainfall is given for each district.

Table XV. Hourly Maximum Discharge.

Ota district.

Class of rain (mm)		0–20	20–50	50–100	>100
Amount of rain (mm)		12.80	33.43	62.66	156.33
No. of obs.		2	23	12	3
Hourly max. discharge	Young wood	1.0	2.55	6.63	42.43
	Conifer	0.7	1.66	4.68	30.83
	Broad-leaved	1.9	3.24	8.83	41.23

Kasama district.

Class of rain (mm)		0–20	20–50	50–100	>100
Amount of rain (mm)		12.47	32.78	71.77	119.13
No. of obs.		17	34	12	3
Hourly max. discharge	Conifer	0.98	1.46	2.94	3.57
	Broad-leaved	1.22	2.06	3.76	6.57

Asio district.

Amount of rain (mm)		73.4
No. of obs.		15
Hourly max discharge	Broad-leaved	3.52
	Non-forested	5.59

The amount of discharge is expressed by 1,000 cubic Shaku per 1 Cho, (1,000 cubic Shaku=27.83 m.^{3}, 1 Cho=0,992 ha.), of area.

It is a matter of course that the hourly maximum discharge varies in different districts even with a similar class of rainfall. With regard to the different divisions in the same district, it is not conceivable that the differences of these amounts between both divisions are due thoroughly to the dissimilarities in the vegetation, because the effects of the conditions of lands themselves are never negligible, though we have no means to estimate the magnitude of the later effects. In spite of such difficulty, it would not be absurd to think as a common fact throughout these districts that the hourly maximum discharge is larger in the broad-leaved than in the coniferous forest. In Ota district, the hourly maximum discharge in the young wood division comes to the midway of the both, and in Asio district, where the ground of the non-forested division is in a state more permeable than that of the broad-leaved, the non-forested basin has a greater hourly discharge. In short, the results seen in these paragraphs are sufficient to confirm that the forest mainly formed of conifers has a larger retentive power of rain water than that of the broad-leaved trees, and the latter kind of forest has a greater power than the non-forested land.

Discussion of the result. Our results, which are the first of any attempt made in our country in this direction, have shown us diverse values of the coefficients of the annual discharges. Though such may be expected, the fact that in two districts, Ota and Kasama, where the annual precipitations are nearly equal, the coefficient in the one place is about twice as large as that of the other place, gives us as opportunity to criticize which value be reasonable, if a drainage basin gets no water from outside or loses water to outside by no other way than run-off. In such a basin, the relation must be held that the annual run-off is equal to the annual precipitation minus the annual evaporation for an average year. We can therefore get a reasonable value of the coefficient of the annual run-off, if we can know the amount of the annual evaporation from the surface under consideration. It is however no easy task to estimate the amounts of evaporation occurring on land surfaces of various kinds. But let us try to do this for a very simple case.

The rate of evaporation from a soil surface, bare or planted, depends not only upon the climatic condition but also upon the wetness of the soil as well as upon the height of the surface above the water table. Our short experiment(7) has proved that when the wetness of the soil lies above a certain limit, so that it contains water enough to follow the evaporating capacity which is to be determined by the condition of air and the temperatur of the evaporating surface, the rate of evaporation from a soil surface is parallel to that from an evaporimeter. When the wetness of the soil becomes lower than this limit, the rate of evaporation from it does no

longer follow that from the evaporimeter. The former case is experienced in wet lands such as a swamp or in an ordinary land during rain or some hours after it. In our country, we have no region where the annual number of days with precipitation less than one third of the year, and our observations in mountainous regions show that annual number of days with precipitation varies from 152 to 246 days. Reflecting moreover upon the fact that on mountains, there occurs frequently occult precipitation and also there the rate of evaporation is relatively small, the assumption that the evaporation from land surface keeps a certain ratio to that from an evaporimeter is not absurd, or it may give the maximum limit of the evaporation at least.

I have seen that a soil planted with grasses(8) evaporates 56% as much as that shown by the evaporimeter for a warm season on the average. By this value, we can get the amount evaporated from the land surface for a warm season from the data obtained from evaporimeters, if we assume the whole area under consideration to be covered with grasses. Next, we have to consider the amount of rainfall which is to be sustained by grass leaves and evaporated therefrom. For this amount we have unfortunately no experimental data available, but as a rough estimation, it may not be probably too little at least to take it to be 5% of the total amount of rainfall for a season. For the amount of the evaporation in the cold season, or the season of snow, which is generally four months from December to March, there is also no accurate data to help us, because the results by means of any ordinary evaporimeter is far from the actual evaporation from the surface of snow. Only datum(9) at our disposal is one obtained by Mr. Katutani of the Tizu Forest Meteorological Station. He estimated the evaporation from the surface of snow to be 5% of the precipitation for the same period, the value being obtained from the result of observation of the thawing water of snow by means of a lysimeter. Converting this percentage to that of the amount of evaporation by an evaporimeter for the same period, we get 23%. Thus, we take one fourth of the amount of evaporation get by our evaporimeter as a previsional value of the evaporation from the surface of snow for a season.

Having adopted these assumptions we have tried to estimate the annual amounts of dissipation by evaporation and their percentages to the annual amounts of precipitation for several places in the Kanto Districts, and the results are as follows:—

Table XVI. Probable Value of Coefficient of Run-off.

1. Loclity	Nikko	Ikaho	Myogi	Mitumine	Mito	Tokyo
2. Long, E.	139°27′	138°55′	138°46′	138°49′	140°28′	139°46′
3. Lat. N.	36°46′	36°30′	36°18′	35°56′	36°23′	35°41′
4. Height above s.l. (m)	1270	691	427	1116	31	6
5. Annual precipitation (mm)	2177.7	1996.3	1797.7	1902.1	1474.7	1564.1
6. Precip. for April to Nov. (mm)	1793.2	1811.7	1628.6	1653.0	1185.4	1276.2
7. Evaporation for April to Nov. (mm)	647.4	770.4	612.6	532.9	960.6	764.6
8. 56% of (7)	362.5	431.4	343.6	298.4	537.9	428.2
9. 5% of (6)	89.7	90.6	81.4	82.7	59.3	63.8
10. Evaporation for Dec. to March (mm)	188.0	244.0	243.4	216.8	257.3	252.3
11. ¼ of (10)	47.0	61.0	60.9	54.2	64.3	63.1
12. Total dissipation (8+9+11)	499.2	582.9	486.0	435.3	661.5	555.1
13. (12)/(5)×100	22.9	29.2	27.0	22.9	44.9	35.5
14. Coeff. of run-off (100–(13)	77.1	70.8	73.0	77.1	55.1	64.5

The table shows that the value of the coefficient of the annual discharge varies from 71 to 77% in the upper and from 55 to 65% in the lower valley in the Kanto Districts. Of the places given in the table, Mito lies at the shortest distance from Ota and Kasama, and Nikko from Asio. Thus, the coefficients at the broad-leaved and the young wood division in Ota district, i.e. 58.4% and 53.1% respectively, seem to be reasonable ones, if the drainage basins are in a similar condition to that we have assumed, and the coefficients in other districts are too small, which is due probably to leaking in underground. In the above estimation of the probable value of the coefficient of run-off, I have put the effects of forest upon various values out of the consideration, which will not, I believe, disturbe our result by reason that I shall propound later on.

Next, I shall make comment upon the discharge following rain. As we have already seen, the broad-leaved divisions in the both districts have larger amount of increased discharge and longer time of swelling hours than the case of the conifers. As to the conditions of lands of the divisions compared with, the conifer division in Ota has an area some twice as large as the broad-leaved and the slope of the basin is steeper in the former than in the latter, while the thickness of surface soil and humus is greater in the former than in the latter. In Kasama, these conditions are nearly alike in

both divisions, except that the thickness of humus is somewhat greater in the coniferous than in the broad-leaved. Thus in Kasama district, the conditions of land in each division may be said to be fairly comparable, but in Ota district some of the conditions are favourable to one while other features are advantageous to the other, which may be regarded to cancel each other approximately. The result which is concordant with both districts may be considered to prove that the effects of the different kinds of forests make the predominating cause of the difference between the increased discharges in the respective divisions immediately following rain. For such effects of different kinds of forests, the fact that the broad-leaved trees intercept less amount of rain in their crowns and consequently let more rain pass through the crowns to the forest floor than the conifers, is probably one, but not all, of the main causes. The different effects brought forth in the physical nature of soils by the different kinds of trees must also be taken into consideration, though we are not in a position as yet to declare positively.

Another point worth while to note here is that the percentage of the discharge immediately following rain is very small against the corresponding rainfall until a rainfall reaches a certain amount, say nearly 30 mm. in the case of Ota district, and it increases abruptly to 50% or so, when a rainfall exceeds the limit. When the intensity of rain reaches greater than the absorbing rate of the land surface, the water would flow down the surface and this must be so called surface run-off in the real sense. And, when the surface covers, such as for instance fallen leaves and raw humus, and the porous humus soils become saturated with rain water, the difference in the rate of percolation between these layers and the soil underneath them would force the water once contained in them to flow down the slope along the surfaces of the discontinuity of the rate of percolation. Such is the second stage of the discharge immediately following rain, when its duration and amount reaches a certain degree. The discharge in this stage should be greater as the surface covers are more loose and the shallow surface soil is more porous, and also as these layers are separated more distinctly from the soil underneath them. It may be true that the floor of the broad-leaved forest is more favourable to allow soon run-off of the second stage, which was one of the probable causes of the larger discharge after rain in the broad-leaved division. That the surface run-off in the real sense is rather a small portion, regardless to the kinds of land surface, is seen from our observation[10] at Kitaoguni Station. At Kitaoguni, the surface run-off of two slopes, one grassy land and the other *Sugi* forest, was observed for 18 months from 1925 to 1927, excluding winter months. The angle of slope of the grassy land is 18° and that of the *Sugi* forest 26°. The results are summarized as follows:—

Table XVII. Surface Run-off.

Mean am. of rain (mm)	2	5	8	15	29	55	112
No. of obs.	18	16	20	21	23	12	14
Forested land							
Surface run-off (mm)	—	—	0.05	0.14	0.88	1.68	4.27
% to rain	—	—	0	1	3	3	4
Max. run-off	—	—	0.2	0.9	4.0	5.3	9.7
Grassy land							
Surface run-off (mm)	—	—	0.05	0.14	0.63	1.85	4.81
% to rain	—	—	0	1	2	3	4
Max. run-off (mm)	—	—	0.6	1.0	0.7	10.2	16.3

Thus, it may be seen that the surface run-off reaches only 4% even in case of such a heavy rain as amounting to more than 100 mm.

4. Comparison of Discharges during Before- and After-deforestation Times of the Same Drainage Basin.[11]

The forest of the broad-leaved division in Ota district was cut from August 1, 1914, when the course of our experiment mentioned in the last chapter came to an end and the transportation of timber was completed in July, 1915. The similar observations to those before the clearing were continued until November, 1919. After the clearing, the area remained generally as a grassy land mixed with zebra grass and by the end of the experiment, young broad-leaved trees of a few feet high were seen here and there. The results of the comparison of discharges during before- and after-deforestation times are summarized below.

Change of Coefficient of Run-off. The amounts of the annual precipitation and annual run-off, and the coefficients of the run-off for three years before the deforestation as well as for six years since the beginning of the

cutting are as follows:

Table XVIII. Coefficient of Run-off for Before- and After-deforestation Years.

Year	1911	1912	1913	1914	1915	1916	1917	1918	1919
Annual precip. (mm)	1768.0	1521.3	1534.9	(1390.3)	1716.6	1619.0	1481.2	1347.9	1455.9
Annual run-off (mm)	1008.5	881.2	883.6	(713.3)	901.0	1117.5	983.5	784.2	806.0
Coef. of run-off (%)	57.0	57.9	57.6	(50.5)	52.5	67.3	66.4	59.0	55.4

As there were some observations missed in 1914, the values for that year are uncertain, though the values were corrected from the data obtained in a neighbouring place. The coefficients of the run-off for the year 1914 and 1915, are exceptionally small, but as the area was under disturbed conditions in these years, we shall put for a while these years out of our attention. Among others, we notice at first that the coefficient of the run-off made an abrupt increase in the year 1916, i.e., the third year from the beginning of the cutting. The coefficients in three years of the before-deforestation time remained nearly constant, though the amount of precipitation varied with a range of more than 200 mm., while those in the after-defforestation time seem to decrease year after year. Now, taking three years' mean for each period, the annual precipitation and the coefficient of the run-off were 1608 mm. and 57.5% respectively for the before-deforestation time, i.e., 1911–1913, while they were 1483 mm. and 64.2% respectively for the after-deforestation time, i.e., 1916–1918. By using the coefficient of the run-off for the before-deforestation time, we can estimate the amount of the run-off for the after-deforestation years in case the forest be in the same condition as that of the before-deforestation time. Thus, 57.5% of the mean amount of precipitation for three years after the deforestation, i.e., 1483 mm., gives 853 mm. as the expectant run-off against the actual mean run-off of 962 mm., showing a gain of the actual run-off by 109 mm. or 7.3% of precipitation. If we take the precipitation in 1916, the third year from the beginning of the cutting, we expect run-off to be 931 mm., and the gain of the actual run-off is 187 mm. or 11.6% of the precipitation. These gains of the actual run-off may be said to be an order of the precipitation sustained by tree crowns, remembering that such portions of precipitation are 9–17% for the conifers and they are somewhat smaller for the broad-leaved trees. Thus, we may say that when a forest on a drainage basin was cleared, the coefficient of the run-off increases in and after the third year from the beginning of cutting by the amount nearly equal to the portion of precipitation which is expected to be sustained in crowns.

Discharge immediately following rain. The amount of discharge increased immediately after a rainfall was obtained by a similar manner to that explained in the last chapter. Classifying the the data according to the amount of a rainfall, average values are summarized as follows:—

Table XIX. Comparison of Discharges immediately following Rain.

	No. of obs.	Mean am. of rain (mm)	Mean intensity of rain (mm/hour)	Swelling hours (hour)	Increased/discharge/Rain (%)	Ratio
		Class of rain: 1.0–9.9 mm.				
Before-defor.	22	6.53	1.75	14.7	1.88	1
After-defor.	12	7.05	1.22	29.1	2.87	1.53
		Class of rain: 10.0–19.9 mm.				
Before-defor.	18	14.06	2.06	33.3	3.30	1
After-defor.	13	15.13	2.14	5.9	6.45	1.97
		Class of rain: 20.0–29.9 mm.				
Before-defor.	6	23.33	2.13	58.5	8.42	1
After-defor.	8	23.10	2.23	66.9	13.75	1.61
		Class of rain: 30.0–39.9 mm.				
Before-defor.	1	33.30	1.51	75.0	28.10	1
After-defor.	3	34.03	1.33	99.2	42.90	1.53
		Class of rain: 50.0–69.9 mm.				
Before-defor.	2	63.60	3.28	179.0	66.45	1
After-defor.	2	57.15	1.47	183.0	35.15	0.53

The ratio of the increased discharge to the amount of rainfall for the after-deforestation time to the corresponding ratio for the before-deforestation time is given in the last column of the table. The results in cases when a rainfall exceeded 30 mm. are uncertain, as the data are very scanty. As to the rainfall less than 30 mm., we can recognize plainly that the ratios of the increased discharge to the corresponding rainfall are smaller in the before-deforestation than in the after-deforestation time, being the latter 1.5 to 2 times as much as the former. The large part of such excess discharge in the after-deforestation time may probably be attributed to the difference of the

portions of rainfall intercepted by crowns. Again the fact that this ratio increases abruptly when the amount of a rainfall exceeded about 30 mm. is seen also in the after-deforestation time, though our data are too scanty to judge the order of the effect of deforestation upon this stage of discharge.

Comparison of the rates of the decrease of daily discharge during dry spell. When there is no rain for several days successively, the rate of the decrease of daily discharge is very rapid when the initial level of water is high and it becomes very slow when the level of water drops to a certain stage. This change in the rate of the decrease is quite distinct and the limit of the height of water level in which such change of rate occurs in our stream seems to be about 12 cm. of the gauge. This level of water is therefore to indicate us a point of discontinuity in the state of discharge; presumably the direct effect of rain would finish when the water level attained this height and thereafter the discharge of the streams is fed by water percolated into the underground. A few cases were obtained from our data under restrictions that the initial water level does not exceed the height just defined and there was no rain for several days successively, then the average daily amounts of discharges during those days are as follows:—

	Before-deforestation time (average of 6 cases).								
Days	0	1st	2nd	3rd	4th	5th	6th	7th	8th
Daily discharge	204.28	190.15	184.00	176.07	170.33	167.60	161.93	158.17	154.98
	After-deforestation time (average of 7 cases).								
Daily discharge	206.40	189.73	182.26	175.44	168.90	163.50	157.94	153.80	148.56

The amount of discharge is given by the mean hourly amount of the nominated day, and it is expressed by 1 cubic Shaku per 10 Cho. The mean amounts of the daily discharge for these successive days are expressed by an equation such as:—

$$W = ae^{-\lambda t}$$

where W is the mean hourly amount of discharge of a day, t is the number of days elapsed since the beginning of time, e the base of Napierian logarithm, and a and λ constants. Determining the values of constants by means of the least square, we get.

Before-deforestation time $W = 4748.16e^{-0.03279t}$ $\pm 1.54\%$

After-deforestation time $W = 4787.30e^{-0.03845t}$ $\pm 1.51\%$

From the values of λ, we learn that the rate of the decrease is greater in the after-deforestation than in the before-deforestation time. Again, assuming that the rate of the decrease of daily discharge $-\frac{\Delta w}{\Delta t}$ is inversely proportional to the days elapsed, we get an equation as

$$-\frac{\Delta w}{\Delta t}=\frac{A}{t},$$

where A is a constant. The equation may be written as

$$\frac{w_0-w}{\log t}=A,$$

where w_0 is the discharge at the beginning of the period and w that on tth day. Applying this assumption to our data, we get the values of A on diverse occasions. The constant A may be considered to depend upon w_0, the initial discharge, as well as upon θ, the mean air temperature for the period in which A was determined, and put

$$A=aw_0+b\theta,$$

where a and b are constants. Determining the values of a and b by the means of the least square, we get

Before-deforestation time $\quad A=0,448w_0-2,645\theta$

After-deforestation time $\quad A=0,235w_0+0,567\theta$

Here w_0 is expressed by 1,000 cubic Syaku per 10 Cho. From these empirical equations we learn that the effect of temperature upon the constant of the rate of decrease of daily discharge is contrary according as the time is either before or after the deforestation and the rate becomes smaller with increasing temperature in the before-deforestation and larger in the after-deforestation time, nothing to say with respect to the absolute value. This result confirms us at any rate, that the trees prevent in a measure the forest floor from drying by sun's heat in the hot summer, which is unavoidable for an unforested land.

Comparison of the effect of the conditions of the preceding month upon the monthly run-off. The correlation coefficients between the monthly run-off and the amount of precipitation in the preceding month were as follows:—

Before-deforestation time $\quad r=0.70 \quad \pm 0.05$

After-deforestation time $\quad r=0.47 \quad \pm 0.08$

Also, the correlation coefficients between the monthly run-off and the discharge on the last day of the preceding month were as follows:—

Before-deforestation time $\quad r=0.74 \quad \pm 0.04$

After-deforestation time $\quad r=0.48 \quad \pm 0.08$

The both sets of the correlation coefficients show a concordant result that the effect of the condition of the preceding month upon the monthly run-off is more conspicuous in the before-deforestation than in the after-deforestation time.

Wetting resistance. Before the effect of a rainfall is perceived on the water level of a stream, some portion of the rainfall is wanted to wet soil covers and surface soil to some extent, which we shall call "wetting resistance." The wetting resistance of a definite drainage area would depend upon the dryness of the surface cover and the surface soil. On the other hand, the height of the water level of a stream may be taken as an indicator of the dryness of the soil of the drainage basin, because the water level tends to remain in equilibrium with the water table of the basin. The stream would be fed by the underground water when the level of the latter is relatively higher in the hydrostatic sense, while it would give its water to the underground water when its level is relatively higher than the water table. The higher the water table the more the surface soil would be wet, and *vice versa*.

Table XX. Comparison of the Amount of Rain necessary to make the Water Level rise by the Same Magnitude.

Class of initial water level 1	No. of obs. 2	Mean of water level 3	Am. of rain wanted to make rise of 1 Bu of water level 4	Am. of discharge corresponding to the rise of water level by 1 Bu 5	(4/5) 6
		Before-deforestation time.			
Sun Sun		Sun	mm	mm	
2.3–3.0	16	2.75	2.15	0.00304	708
3.1–3.5	6	3.27	2.52	410	615
3.6–4.0	7	3.69	2.90	485	598
4.1–4.5	3	4.20	2.67	585	457
		After-deforestation time.			
2.3–3.0	8	2.60	2.63	0.00289	910
3.1–3.5	15	3.28	2.75	410	670
3.6–4.0	13	3.74	2.32	485	478
4.1–4.5	7	4.31	2.34	607	385

On this ground, we have classified the amount of rain which fell during the time, in which the rise of the water level of the stream by 1 Bu or 0.3 cm. observed, according to the water levels at the beginning of the rise of water, and the results are summarized in the table XX.

The figures given in the sixth column of the table mean the ratio of the amount of precipitation necessary to make the water level rise by 1 Bu to the amount of the discharge corresponding to that rise of the water level from respective initial levels. The result shows that this ratio is larger when the water level of the stream is lower, that is to say, the surface soil is dry, and is smaller when the water level is high or the surface soil wet. Comparing the both times, the before- and after-deforestation, the ratio is larger in the after-deforestation than in the before-deforestation time when the water level is lower than about 3.5 Sun or 10.6 cm., and the relation becomes reverse when the water level is higher than that stage. In other words, when the water level is relatively lower or the surface soil is relatively dry, the amount of rainfall necessary to rise the level by the same height is less in the before-deforestation than in the after-deforestation time, while when the water level is relatively high or the surface soil is relatively wet, the same amount of rainfall makes the water level higher in the after-deforestation than in the before-deforestation time. The facts just mentioned above, confirm that the forest can increase the retentive capacity of ground for rain water in the wet season and also, if we take the interception of rainfall by crowns into consideration, we could say definitely that the forest can reduce effectively the wetting resistance in the dry season.

5. Summary of the Results of Comparative Observations of the Run-off.

The results of our observations of the run-off which were described in the last two chapters are briefly summarized as follows:—

1. Our results of the measurements of the run-off made in three districts in the Kanto gives diverse values of the coefficients of the run-off, or the ratio of the annual run-off to the annual precipitation, which are enumerated below:—

Ota district: the young wood division, 53.1%; the broad-leaved division, 58.4%; the conifer division 44.8%.

Kasama district: the non-forested divisions, 25.3%; the conifer division, 35.2%; the broad-leaved division 30.2%.

Asio district: the non-forested division, 24.1%; the broad-leaved division, 45.9%.

From these results, we cannot draw any conclusion as to the effects of the kinds of forest upon the values of the coefficient of run-off, of which the conditions of land has probably more important effects. Of these values of the coefficient of run-off, that of the broad-leaved division in Ota district is estimated to be what is expected as a reasonable value of the coefficient, if a basin is completely isolated from the outside area with respect to the underground water.

2. The effect of the kind of forest upon the stream flow is fairly perceived in the discharge immediately following rain. The increased amounts of the discharges following rains and the hourly maximum discharges are both larger in the broad-leaved than in the coniferous forest and the duration of swelling of water after rain is also longer in the former than in the latter.

3. The increased amount of the discharge following a rainfall is an order of 2 or 3% of the rainfall when the rainfall is less than about 30 mm., but it increases abruptly to a larger percentage when the rainfall exceeds that amount. Of the nature of such discharge, besides so called surface run-off, we have to consider the rain water which was once absorbed in the surface covers and in the shallow soil and then flows in the stream along the surfaces of the discontinuity of the rate of percolation, which is probably greater in the broad-leaved than in the coniferous forest.

4. Comparing the coefficients of the run-off in the before- and after-deforestation time of the same drainage basin, they are found to make an abrupt increase in the third year from the beginning of the cutting and then to decrease gradually to tend to that in the former time. The amount of the increase of the run-off in the third year is the order of the portion of rainfall which is expected to be sustained by tree crowns in the former state.

5. The increased discharge immediately following rain is greater in the after-deforestation than in the before-deforestation time, the ratio of the

latter to that of the former time being 1.5 or more.

6. The rate of the decrease of the daily discharge, when there was no rain for several days successively, is greater in the after-deforestation than in the before-deforestation time. The effect of temperature upon the rate of the decrease is reverse according as the case be either the before- or after-deforestation time. In the before-deforestation time, the rate of the decrease becomes relatively small as the air temperature rises, while in the after-deforestation time, the relation is reverse.

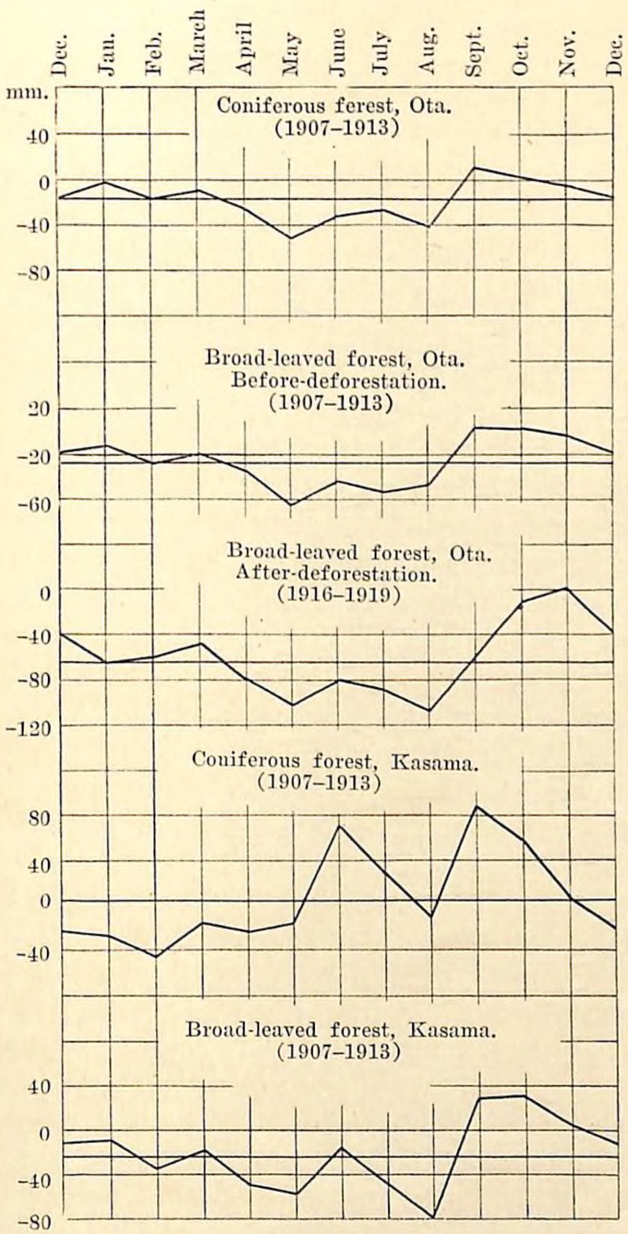
7. The degree of the effect of the condition of the weather or the water stage in the preceding month upon the monthly amount of the run-off is greater in the before-deforestation than in the after-deforestation time, which means that the forest has a faculty to make the retentive capacity of ground for water greater.

8. The wetting resistance of the land is smaller in the before-deforestation than in the after-doforestation time when the land is relatively dry, while it becomes larger in the former than in the latter time when the land is wet, the fact being concordant with the faculty of forest seen in the last paragraph.

6. Seasonal Variation of the Residual Water in the Ground.

The remainder of the monthly amount of precipitation subtracted by both the monthly amount of the dissipation water by evaporation and of the run-off would give the residual water reserved in, or squeezed from, the ground. To see the seasonal variation of the accumulated amount of such residual water, I have tried calculating as follows:—The monthly precipitation, from which the monthly amount of the dissipation is subtracted, is to be added in sequence, being started from any month. On the other hand, the monthly amount of the run-off should also be added in the same manner. Subtracting the latter sums from the former, we would get the relative value of the accumulated amount of the residual water for each month. Here, the monthly amount of dissipated water was obtained from the monthly amount of evaporation measured by an ordinary evaporimeter multiplied by the ratio of the annual amount of dissipated water to the annual amount of evaporation, the former amount being obtained by subtracting the annual

Annual Variation of Risidual Water.



amount of the run-off from the annual amount of the precipitation.

The annexed figure shows diagrammatically the seasonal variation of the relative amount of the residual water thus calculated for four divisions in Ota and Kasama districts and that for the after-deforestation time in the broad-leaved forest in Ota. Of the curves shown, that of the coniferous forest in Kasama district seems to be somewhat abnormal, but the others have similar variations. Broadly speaking, the residual water in ground is relatively small, or the land is relatively dry from April to August, and it is relatively large, or the land is relatively wet, from September to March. In detail, we see in the dry period, that the curves rise in June, which represent an effect of the "Bai-u" season. It may be observed from the curves, that the much water is reserved in the ground during the period from September to November, to which the discharges in the coldest months is to be related closely, because the greater part of the precipitation in those months lies on the ground in the form of snow. Also, we can perceive that the low water period in May is to be fed by the reserved water during the period of thawing, and that in August by the water reserved during the "Bai-u" season.

To what extent can the forest exert its influence upon the stream flow under the circumstances just seen, is not accurately known from our data. The comparison of the curves for the before- and after-deforestation times seems to tell us that the deforestation acts to lengthen the dry period in a measure.

The curves are fairly consistent with each other showing a tendency that the cold season is a period of the reservation of water in ground and the warmer season is that of squeezing out the reserved water. Besides that the precipitation in the cold season lies on the ground in the form of snow, the water would also be retained in the ground, because the low temperature would retard movement of water in the ground, while in the warmer season, more easy movement of water in the ground together with a greater rate of evaporation would facilitate to make the ground dry. In the warmer season, the effect of forest upon the protection of the drying of the ground may easily be suggested from the nature of the influences of forest upon the run-off. In the coldest months, the degree of the lowering of the water level must depend mainly upon the amount of the reserved water in autumn as well as the coldness of the season. In this connection, it would be conceivable that the forest has effects upon these two factors in favour of mitigating scarcity of the discharge in these months. According to the observations at the Tizu Forest Meteorological Station,(12) we learn that the snow on the ground is melted from its base even in the coldest season, and that the effect of such melted water upon the discharge of a spring as well as a stream flow is plainly recognizable. Unfortunately we have no observed data at present to judge the extent by which the forest exerts any influence upon melting of snow from its base.

7. On the Relation between the Forest and the Coefficient of Run-off.

Let us remark, in passing, about the problem whether the forest can make the coefficient of run-off increase or decrease. Our comparative observations in the coniferous and the broad-leaved divisions in Ota and Kasama districts have shown contradicting results each other in both districts, which is to be taken to mean that the effects of the different kinds of forests upon the coefficients of run-off is, if any, so slight that it is surpassed by the effect of the difference, so trifle as it is, in the condition of land. Also, the comparison of the non-forested and forested divisions in Kasama district, though the data are rather uncertain, seems to prove that the coefficient of run-off is not larger, at any rate, in the non-forested than in the forested land. Lastly, the comparison of the before- and after-deforestation time in Ota district shows us that the coefficient of run-off becomes larger in the after-deforestation for some years since the third year from the beginning of the cutting and the amount of the excess of the run-off is the order of the portion of precipitation expected to be intercepted by crowns of trees.

From these results it may be difficult to draw a decisive conclusion upon the present problem, yet so much is clear that there exists certain difference between the before- and after-deforestation time, as shown by our comparative experiments.

We meet not rarely with advocates having an opinion that the forest should decrease eventually the amount of run-off by the enomous amount of its water requirement. Many reliable data of careful experiments hitherto published seem to be never advantageous to such a view. Under the present condition of our knowledge, it is, I believe, impossible to criticize this problem strictly from the estimation of the income and outlay of water on the various kinds of land surface, because in the estimation of dissipation water from any kind of land surface, we can never avoid to take in more or less arbitrary assumptions. It is, therefore, rather safe to deduce the conclusion from the data of actual measurements of the run-off.

We have fortunately two excellent and authoritative reports published abroad, one by Dr. Engler's in Switzerland(13) and the other by C. G. Betes and A. J. Henry's in the United States.(14)

Dr. Engler's final result of the comparison of the discharges in drainage basins under the similar conditions of climate and land, with the exception that the one is covered by forest and the other is mainly meadow, is as follows;—

	Forested land	Non-forested land
Run-off	60% of precipitation	60% of precipitation
Evaporation from vegetation	15 ,,	10 ,,
Evaporation of vegetation	20 ,,	6 ,,
Direct evaporation from ground	5 ,,	24 ,,
Sum	100 ,,	100 ,,

That is, he has proved that the coefficient of run-off is not altered by the difference of vegetation over the land.

In the experiment made at Wagon Wheel Gap, Co., U.S.A., two basins, A and B, were selected. After making comparative observations on the run-off and climatic conditions for several years, the forest in B basin was cleared and similar observations to those previous were continued. The ratio of the annual amount of the run-off at B to that at the controlling area A was 1.017 on the average for eight before-deforestation years, and the corresponding ratio was 1.170 for seven after-deforestation years, showing thus the excess of the run-off for the after-deforestation years by 0.153 with respect to the run-off at the controlling basin. The ratios in the after-deforestation years were largest in the third year from the beginning of the cutting of forest and they seem to decrease generally year after year.

The average excess of the discharge in the after-deforestation time was 0.96 inch, of which 0.80 inch flew in the spring flood period, 0.09 inch in the summer months and 0.07 inch in the five winter months. Of this excess discharge, the writers say, "If it be said that all of the excess discharge after the (spring) flood period is due to decreased transpiration during summer —which plainly is not the case— there is still left the largest part of the total, or about 0.80 inch, which appears as excess during the flood, and most of which can be accounted for only as saving during the winter accumulation period. Both lack of interception by tree crowns, and a slightly earlier melting in spring, reducing the loss by evaporation, probably contribute to this end."

The writers also say, "The fact that the order of magnitude of the streamflow excess during the second period is, except in the first year after the denudation, the same as that for the amounts of snowfall, makes it appear altogether probable that interception by tree cowns, which was practically eliminated by denudation, is a larger factor in evaporation losses during the winter."

The results obtained at Wagon Wheel Gap resemble in many respects to our results of the comparison of the before- and after-deforestation times at Ota district, except some minor points in detail, which may be attributed to the dissimilarity of climatic conditions of both countries.

Supported by such authoritative results, we venture to deduce the following two facts:

1. Under the similar conditions of the geological formation, the configuration of land and climate, the coefficient of run-off is no way influenced by the vegetation over the drainage areas, or it is just the same thing, the amount of dissipation from the land surface, including vegetation over it, remains the same, disregarding the difference of the vegetation.

2. When the forest on a drainage basin was cleared, the coefficient of run-off would be increased for some years after a period of transition, and this excess of discharge is nearly equal to that amount of precipitation which is intercepted by tree crowns and evaporated therefrom. And this excess discharge tends to decrease year after year until finally reach the previous value of the coefficient.

Such bold expressions should be subjected to severe criticisms, but from the data at our disposal we are led to such conclusions. Assuming our idea as established facts, I shall here add a few words about the possibility of such facts.

First, I shall take up my second statement. Under a given climatic condition, the vegetation over a given land area should tend to take a certain feature. When we disturb an existing vegetation, say by clearing, then it would recover sooner or later to the previous one, if the disturbance was of such a kind that it does not change the conditions of climate and land. But, some time must be elapsed to attain quite the same stage of vegetation as before the disturbance. From the hydrological stand point, this transition period may be considered to take such a course as:—When forest was cleared, the lower vegetation hitherto flourished on the forest floor would not persist under the direct sun, still it cannot at once give place to a new vegetation suited for the new condition. The decrease of the discharge in the year of the beginning of cutting or the next year, as we have seen, would probably mean such stage of the transition period. Such a period would not, however, continue very long, and soon afterwards a new vegetation adopted for the new condition would begin to sprout and seedlings of the trees which predominated before the clearing would begin to grow. By the third year after the beginning of the deforestation the new vegetation is likely to attain such a stage that the amount of the dissipation from the land surface, including the vegetation, becomes equal to the corresponding amount before the deforestation, but the portion of the precipitation sustained in leaves of vegetation in this stage is less than that substained by crowns of trees in maturity before the deforestation. Such is the second stage in the transition period. During this period, the secondary vegetation would take its proper course of succession year after year and finally it would attain the same condition as before the deforestation with respect to the hydrological relations.

Then, we shall come to our first statement. That under the same condition of climate and land, there may exist different vegetation, such as described by Engler, is a contradicting fact to what we have assumed in the beginning of the last paragraph. Thus, what is expressed by this statement means that the basins under the comparison have the similar conditions as regards the primary elements of climate, such as the insolation and precipitation, as well as the geological formation and the configuration of land, but the fact that the existing vegetations over the areas are not similar, let us expect some differences in both the secondary elements of climate, such as the temperature and humidity of air, and the minor edaphic conditions, such as the structure and moisture content of the surface soil. Thus, Engler's conclusion is to be understood hydrologically to mean that when there are two areas of different vegetation under the similar conditions of the land and climate in the primary sense, both lands keep their states of the hydrological equilibrium after some changes of their conditions in the secondary sense, so that the amounts of water dissipated from the land surfaces are equal for both and consequently the coefficients of run-off are also equal. In other words, when different portions of a certain area, which is originally in the similar conditions with respect to climate

and land, were made to be occupied by different vegetations by some means, say either by certain natural forces or artificial demands, the conditions of respective portions are so adjusted that the losses of water from the land surfaces, including those due to the vegetations, are equal, irrespective of the vegetation.

Thus, that we could specify no substantial effect of the kinds of forest upon the coefficients of run-off, as shown by our first experiments, may alway be expected.

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ABBREVIATIONS OF OUR PUBLICATIONS (in Japanese).

Bul. F. E. S. .... Bulletin of the Forestry Experimental Station.
S. Rep. F. M. S. .... Special Report of the Forestry Meteorological Station.
Jour. Met. .... Journal of Meteorology Relating to Forestry and Hydrology.

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發行所　農林省林業試驗場

印刷所　三秀舍
東京市神田區美土代町二ノ一

印刷者　島連太郎
東京市神田區美土代町二ノ一