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RUNOFF RESULTING FROM RAINFALL

by

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Abstract

The total runoff due to all rainfall for ten years from May to October was measured in three experimental watersheds situated in South Finland. The influences affecting summer runoff have been analyzed on the basis of these observations. A method which uses only rainfall observations to predict runoff was applied.

1. *Introduction*

The moderate amount and even distribution of rainfall throughout summer characterizes the Finnish climate. The daily rainfall exceeds 50 mm on an average of only once in 20 years, and rainstorms in June and July do not usually cause runoff because of the dryness of the soil. The runoff due to rainstorms in May, August, September, and October is usually of only slightly greater importance. Summer rainstorms, however, sometimes cause floods (especially in lakeless catchment areas) which are more serious than the spring floods due to snowmelt. These summer floods are usually unexpected and can be dangerous.

The causes of summer runoff in Finland have never been extensively investigated. The only previous study is very old (RENQVIST [5]).Finnish hydrologic research has been concentrated on the runoff due to snowmelt, as this is the most important consideration in the Finnish climate. The study of summer runoff in large watersheds with many lakes is difficult, because the summer rainstorms are not usually extensive enough and the runoff is usually very small. In small lakeless watersheds even smallest amount of runoff can be measured immediately. Watershed storage cannot affect the runoff; in small watersheds the runoff due to each rainstorm or rainstorm period can be graphed individually.

It is important to study the influence of each rainstorm period individually, because usually the summer and autumn rainstorms infiltrate as a whole. Only exceptionally heavy rainstorms can produce significant runoff. A month is too long a period to study summer runoff, because meteorological factors loose their characteristic variations in monthly averages.

Monthly runoff cannot be estimated as the difference between rainfall and evapotranspiration because the problem is in ratio between the rainfall and the infiltration during only some days.

2. *Experimental watersheds*

Rainfall and runoff observations were made on three small experimental watersheds belonging to the Hydrotechnical Research Bureau of the Board of Agriculture during the ten years 1953 to 1962. An aerial photograph of these watersheds which are located about 40 km northwest of Helsinki is shown in fig. 1. Contour lines and ditches are shown in fig. 2. Longitudinal sections of the main ditches are shown in fig. 3. The area of watershed 11, »Hovi», is 12,0 ha and it is entirely cultivated land. The area of watershed 12, »Ali-Knuutila», is 24,6 ha and 48 per cent of it is cultivated land, 42 per cent forest and 10 per cent roads, undrained pasture, and building area. The area of watershed 13, »Yli-Knuutila», is 6,8 ha and it is entirely forest land.

The volume of growing stock in watershed 12 is 114 solid m^3/ha, and 65% of this is spruce, 30% pine, and 5% deciduous trees. Corresponding values in watershed 13 are 162 solid m^3/ha, 78%, 18%, and 4%. The cultivated land in watershed 11 was divided between various crops as follows: grass 25%, cerials 65%, and root crops 10%. Corresponding values for the cultivated land in watershed 12 were 48%, 43%, and 9%. The soil in watershed 11 is mainly clay and silty clay; in watershed 12 the soil is clay and silty clay in the cultivated land and sand morain in the forest; in watershed 13 the soil is mainly sand morain and partly silt morain.

The slope of the land surface in watershed 11 is 2,8%, in watershed 12 it is 10,0%, and in watershed 13 it is 16,0%.

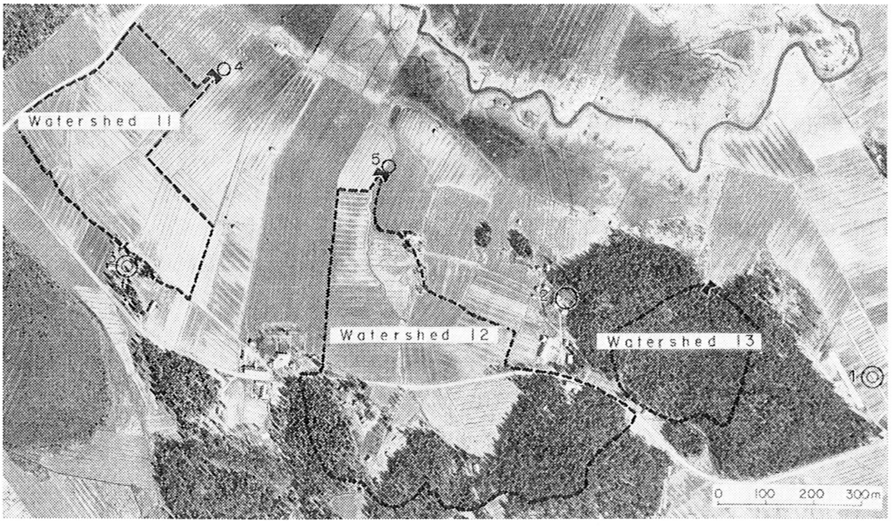

Fig. 1. Aerial photograph of the three experimental watersheds. Double circle = recording rain gage, large circle = non-recording rain gage with Nipher windshield, small circle = non-recording rain gage without windshield.

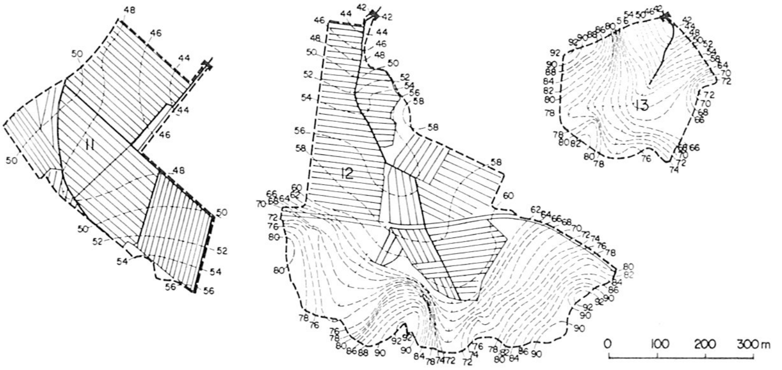

Fig. 2. Contour lines (broken lines) and ditches (unbroken lines) in the three experimental watersheds.

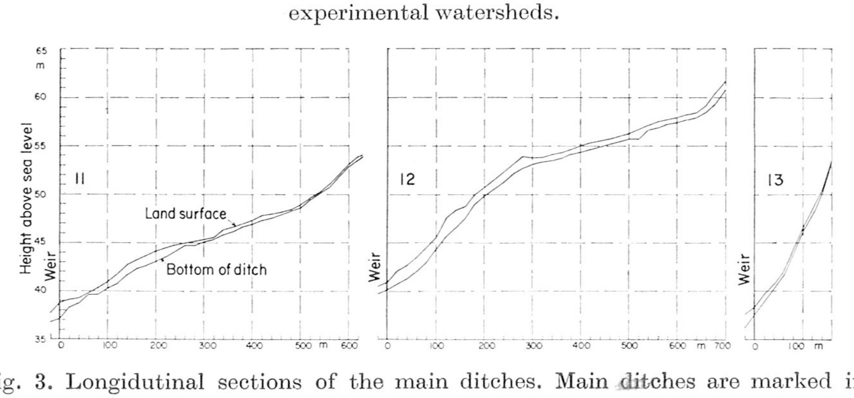

Fig. 3. Longidutinal sections of the main ditches. Main ditches are marked in

The boundaries of these watersheds were determined by the use of levelling instruments. The boundaries were easily determined in cultivated areas with the use of ditches. It does not necessarily follow that the subsurface divide is the same as the surface divide. Therefore borings were made to determine the subsurface divide particularly in the eastern part of watershed 13, because there is a spring outside the divide discharging an average of 0,2 l/s. The borings showed that the rock is near the surface in the divide. The soil layer covering this rock is nowhere thicker than 2 m. The soil surface inclines very abruply at both sides of the divide. The spring outside watershed 13 can not get any considerable amount of water from this watershed.

3. *Rainfall and runoff observations*

Rainfall statistics were obtained with the aid of a number 1 recording rain gage (fig. 1) and the daily amount was measured with a number 2 rain gage (non-recording). In summer 1962, there were three more rain gages in use.

Runoff was measured with the aid of weirs with recording gages. Runoff statistics resulting from the rainfall during the ten years 1953 to 1962 were obtained, however a few storm statistics are missing. The total runoff Q_T due to rainfall was computed from the graph (fig. 4) which shows runoff with respect to time.

The runoff due to rainfall was assumed to end when the runoff became as small as it was before the rain started. This assumption is correct

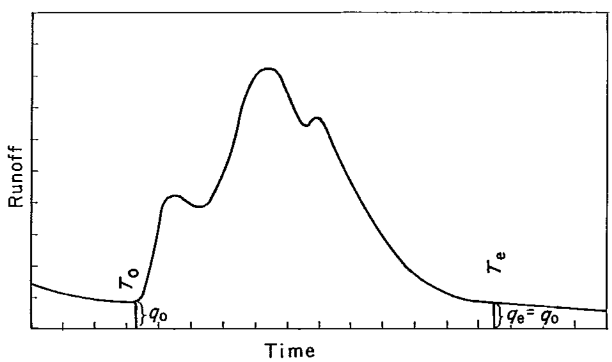

Fig. 4. Total runoff volume Q_T . Q_T is the area beneath the runoff-curve from T_o to T_e, when $q_e = q_o$.

when runoff both at the beginning and at the end is entirely base runoff. It was noticed that this usually occured about 8 hours after the rain stopped. If more rain began to fall during these 8 hours, then it was included in the same rainperiod. Most of the total runoff appeared in the ditches during the first 24 hours after the rain. Naturally all runoff appeared in the ditches much later, especially in the forest.

4. *Monthly total runoff Q_T due to rainfall*

Monthly runoff values are not as useful in hydraulic engineering as daily values. But from a common point of view monthly runoff values are of some interest.

The total rainfall during the summer months of the ten years 1953

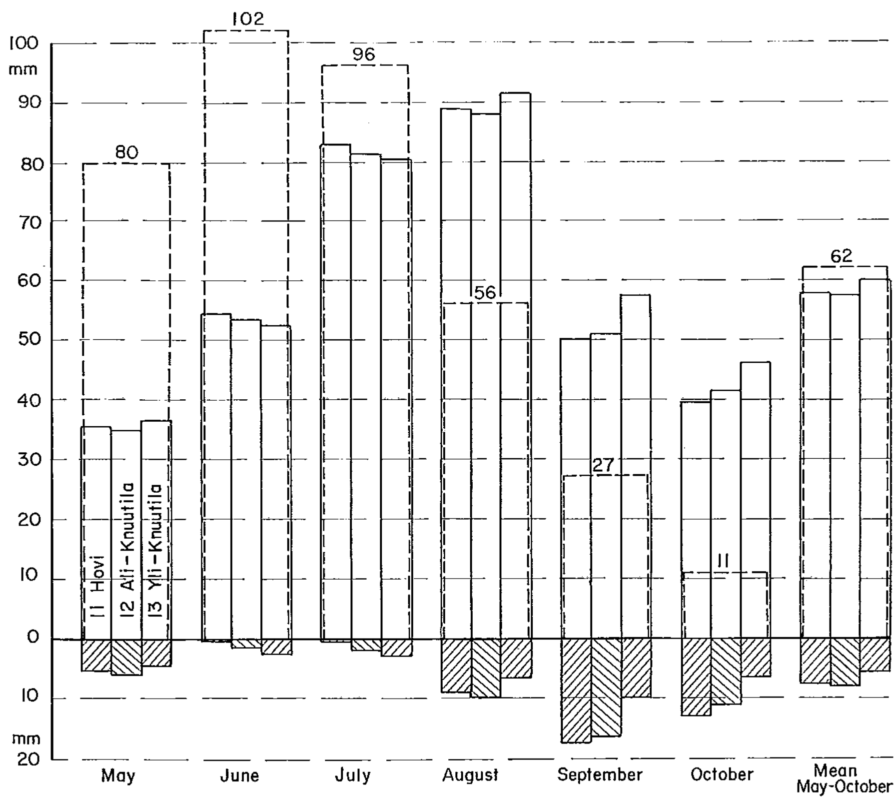

Fig. 5. Monthly rainfall (whole column with unbroken line); runoff resulting from rainfall (shaded part of column); *PET* (column with broken line) on an average in the years 1953 to 1962 in experimental watersheds in Vihti (mm).

Table 1. Monthly rainfall (mm) and total runoff (mm) resulting from this rainfall,

Year	May			June			July		
	P	Q_T	%	P	Q_T	%	P	Q_T	%
Watershed 11 (cultivated land)									
1953	49	0,1	0,2	64	3,2	5,0	115	0,4	0,3
1954	21	1,8	8,6	27	0,0	0,0	117	0,1	0,1
1955	76	15,5	20,4	49	0,6	1,2	20	0,0	0,0
1956	18	0,2	1,1	62	0,1	0,2	61	0,1	0,2
1957	42	14,5	34,5	64	0,2	0,3	75	0,0	0,0
1958	74	17,6	23,8	34	0,3	0,9	93	0,3	0,3
1959	27	0,2	0,7	39	0,1	0,3	54	0,2	0,4
1960	11	1,1	10,0	88	0,1	0,1	104	0,4	0,4
1961	37	0,2	0,5	64	0,1	0,2	114	0,3	0,3
1962	55	0,7	1,3	59	0,3	0,5	81	2,6	3,2
Σ	410	51,9	12,7	550	5,0	0,9	834	4,4	0,5
Watershed 12 (cultivated land and forest land)									
1953	49	3,5	7,1	64	4,3	6,7	115	1,8	1,6
1954	21	3,0	14,3	27	0,0	0,0	117	1,3	1,1
1955	76	22,1	29,1	49	3,4	6,9	20	0,2	1,0
1956	18	0,8	4,4	62	1,5	2,4	61	0,8	1,3
1957	42	13,4	31,9	64	1,9	3,0	75	1,0	1,3
1958	74	9,7	13,1	34	1,2	3,5	93	1,7	1,8
1959	27	2,3	8,5	39	0,2	0,5	54	0,5	0,9
1960	11	0,0	0,0	88	0,6	0,7	104	3,1	3,0
1961	37	1,0	2,7	64	0,4	0,6	114	5,5	4,8
1962	55	3,0	5,5	59	1,5	2,5	81	4,4	5,4
Σ	410	58,8	14,3	550	15,0	2,7	834	20,3	2,4
Watershed 13 (forest land)									
1953	49	3,8	7,8	64	4,7	7,3	115	2,9	2,5
1954	21	1,1	4,8	27	0,5	1,9	117	2,7	2,3
1955	76	19,0	25,0	49	2,7	5,5	20	0,8	4,0
1956	18	1,0	5,5	62	3,3	5,3	61	2,2	3,6
1957	42	7,6	19,0	64	5,2	8,1	75	3,3	4,4
1958	74	5,9	8,0	34	1,1	3,2	93	4,2	4,5
1959	27	3,0	11,0	39	0,5	1,3	54	1,6	3,0
1960	11	0,0	0,0	88	2,0	2,3	104	4,5	4,3
1961	37	0,1	0,3	64	2,3	3,6	114	3,8	3,3
1962	55	3,5	6,4	59	2,9	4,9	81	3,2	4,0
Σ	410	45,0	11,0	550	25,2	4,6	834	29,2	3,5

and the runoff percentage in the three watersheds for the period 1953 to 1962.

August			September			October			(V · · · X)		
P	Q_T	%	P	Q_T	%	P	Q_T	%	P	Q_T	%
128	35,8	28,0	70	14,8	21,1	23	5,7	24,8	449	60,0	13,4
114	5,2	0,5	112	31,6	28,2	59	24,5	41,5	450	63,2	14,0
33	0,0	0,0	78	0,0	0,0	83	0,7	0,8	339	16,8	5,0
171	20,6	12,0	26	0,4	1,5	57	14,0	24,6	395	35,4	9,0
121	4,8	4,0	126	40,1	31,8	104	58,6	56,3	532	118,2	22,2
48	0,3	0,6	23	0,1	0,4	34	0,4	1,2	306	19,0	6,2
61	0,7	11,5	3	1,8	60,0	35	0,0	0,0	219	3,0	1,4
95	0,5	0,5	50	1,4	2,8	26	2,2	8,5	374	5,7	1,5
92	10,3	11,2	24	0,1	0,4	55	6,7	12,2	386	17,7	4,6
115	11,4	9,9	132	87,1	66,0	51	17,8	34,9	493	119,9	24,3
978	89,6	9,2	644	177,4	27,5	527	130,6	24,8	3943	458,9	11,6
128	16,1	12,6	70	15,0	21,4	23	5,2	22,6	449	45,9	10,2
114	11,3	9,9	112	28,1	25,1	59	17,3	29,3	450	61,0	13,6
33	0,0	0,0	78	0,0	0,0	83	2,9	3,5	339	28,6	8,4
171	19,8	11,6	26	1,8	6,9	57	11,4	20,0	395	36,1	9,1
121	21,0	17,4	126	49,5	39,3	104	44,4	42,7	532	131,2	24,7
48	0,8	1,7	23	0,1	0,4	34	0,9	2,6	306	14,4	4,7
61	0,0	0,0	3	0,0	0,0	35	0,0	0,0	219	3,0	1,4
95	4,6	4,8	50	6,4	12,8	26	2,0	7,7	374	16,7	4,5
92	11,6	12,6	24	0,8	3,3	55	11,0	20,0	386	30,3	7,8
115	14,9	13,0	132	62,7	47,5	51	15,9	31,2	493	102,4	20,8
978	100,1	10,2	644	164,4	25,5	527	111,0	21,1	3943	469,6	11,9
128	13,1	10,2	70	5,9	8,4	23	1,9	8,3	449	32,3	7,2
114	5,1	4,5	112	10,2	9,1	59	6,6	11,2	450	26,2	5,8
33	0,2	0,6	78	1,0	1,3	83	2,6	3,1	339	26,3	7,8
171	15,2	8,9	26	1,0	3,8	57	6,1	10,7	395	28,8	7,3
121	10,5	8,7	126	26,6	21,1	104	29,3	28,2	532	82,5	15,6
48	1,2	2,5	23	0,5	2,2	34	1,2	3,5	306	14,1	4,7
61	0,7	1,1	3	0,0	0,0	35	0,1	0,3	219	5,9	2,7
95	5,4	5,7	50	2,9	5,8	26	1,3	5,0	374	16,1	4,2
92	5,4	5,9	24	1,4	5,8	55	3,6	6,5	386	16,6	4,3
115	9,4	8,2	132	48,9	37,0	51	9,0	17,6	493	76,9	15,6
978	66,2	6,8	644	98,4	15,3	527	61,7	11,7	3943	325,7	8,3

to 1962, and the runoff resulting from it is shown in table 1. In a few cases (when the recording gages were not in operation or when the snowmelt in May affected the runoff) the runoff was evaluated with the aid of nomograms (fig. 7).

The ten years runoff values in table 1 are shown more clearly in fig. 5. The monthly potential evapotranspiration (*PET*) is also shown in fig. 5. *PET* was obtained by using the method of U.S. Weather Bureau (Kohler & Richards [1], Lamoreux [2]). This method is based on Penman's theory. Air temperature and dew point were measured near the watersheds in Vihti, as was the solar radiation in Ilmala (37 km from Vihti) and the wind velocity in Seutula (33 km from Vihti).

The ten years period 1953 to 1962 was 9% rainier than the normal period (1931 to 1960) in so far as it concerned the summer half of the year. This can be seen by comparing the values in table 1 with the values in table 2.

Table 2. Rainfall (mm) during the summer months of the period 1931 to 1960 in some places in Finland.

	Vihti	Lappeenranta	Tampere	Jyväskylä	Kuopio	Kajaani
May	39	39	42	44	37	38
June	46	48	48	58	56	67
July	73	71	75	74	62	72
August	75	79	75	74	70	72
September	65	61	57	66	67	63
October	64	64	57	62	57	53
V ... X	362	362	354	378	349	365

It is noteworthy to see that only June, July, and August in the period 1953 to 1962 were rainier than in the normal period (1931 to 1960), but only in August did the great amount of rainfall increase runoff.

The runoff in the summer half of an average year is usually between 8% and 12% of the rainfall (table 1). The runoff in the beginning of May is about 10% to 15% of the rainfall, because the soil is still very moist after the snowmelt. It has been noticed that the rainfall in June and July does not normally produce noticeable runoff, even if this rainfall is double the normal, as it was in 1953, 1954, and 1961. The heavy rainfall at the end of August usually causes some runoff, but the monthly runoff cannot be very large, even if the rainfall is double the normal, as it was in 1956. The runoff in August is usually slightly less than 10% of the rainfall. In September and October the rainfall usually produces significant runoff when the rainfall is greater than normal. September 1962 was very exceptional in this respect, because the *PET* in June, July, and August was only 70% of the normal, and the rainfall was 30% greater than normal. The rainfall in September was double the normal and it produced significant runoff, namely between 37% and 66% of the rainfall. The 10 years average September runoff value (15% to 28% of the rainfall) is not really representative, because it was disproportionately affected by the very exceptional 1962 value. Normally this percentage is slightly less than 20. The runoff in October is about 30% of the rainfall in a normal year.

The *PET* in May to October in the years 1953 to 1962 was on an average 375 mm. This is the same as the amount of rainfall in a normal period (1931 to 1960). It can therefore be said that the normal evenly distributed amount of rainfall does not cause significant runoff in the summer half of the year. The evapotranspiration keeps the rainfall in balance.

In early spring the soil is saturated with water resulting from the snowmelt, but the great *PET* in spring quickly reduces the moisture in the soil. In August the rainfall exceeds the *PET* and the water content of the soil begins to increase. The total *PET* in May, June and July is on an average 100 mm greater than the rainfall. So there is a soil moisture deficiency of 100 mm in the beginning of August. This deficiency decreases during autumn, when the rainfall exceeds the *PET*. The soil at the end of October is usually as moist as at the beginning of May. These values are, of course, average figures, whereas the actual rainfall and *PET* figures differ greatly from the average figures and so cause runoff.

Evapotranspiration does not equal *PET* in October because the vegetation begins to decrease and therefore cannot transpire as effectively as it did in June and July.

This examination shows that the runoff resulting from rainfall is decisively dependent on the relation between the rainfall in every rain period and the water content of the soil immediately before this rain period. If the rains are evenly distributed and the rainfall is not more than during a normal period, then the cultivated clay soil and the soil in a dense forest can absorb all the rainfall. Exceptionally heavy rains however can cause runoff in July, if the rainfall rate is greater than the infiltration rate (MUSTONEN [4], WÄRE [7]), but this is of no importance in the Finnish climate.

The runoff in each of the three watersheds does not differ considerably. The greatest runoff differences are in September and October when the runoff in cultivated land is more than in forest land. In watershed 12 42% of the land is forest. Therefore it would be natural to think that the runoff from watershed 12 would be about the mean of the runoff from watershed 11 and 13. However, the runoff in September from watershed 13 was 5 mm, and in October 3 mm greater than it ought to have been according to the forest percentages. These differences are very small and they could have been caused by many reasons, for example, on the basis of the stand of the forest.

The volume of timber stock in watershed 12 was 114 solid m^3/ha, and in watershed 13 it was 162 solid m^3/ha, or 40% more. The average height of the timber stock in watershed 13 was 19 m and in watershed 12 it was three meters less.

In dense coniferous forests like those in watershed 12 and 13 the average interception is 20 to 30% of the rainfall (SEPPÄNEN [6]) or in this case in September during the years 1953 to 1962 it was 12 to 20 mm. It can be assumed that interception increases by 20% when the volume of stock increases by 40%. So the 40% increase in the volume of stock caused a 3 to 4 mm increase in runoff.

The roads, building areas, and undrained pasture land in watershed 12 increased runoff, because the rain cannot infiltrate these areas as well as forest or cultivated land.

In June and July the runoff from cultivated land is smaller than from forest land. The rainfall infiltrates clay soil very easily when the soil supports a dense vegetation. In autumn when heavy rains fall after the harvest the cultivated land produces greater runoff than forest land which has vegetation that transpires continually. The sandy soil in the forest can absorb water more easily than the moist cultivated land.

5. *Estimating runoff resulting from rainfall*

The runoff resulting from a rain period depends on the characteristics of the rain and the moisture content of the soil before the rain. We can easily measure the rainfall amount and intensity with the use of networks of rain gages. However, the measuring of moisture deficiency in the soil is very difficult.

In humid climates the moisture deficiency in the soil can be determined indirectly with the aid of base runoff, if continuous runoff observations are made and if the runoff is always great enough.

The most accurate method of determining moisture deficiency in the soil is by recording the daily rainfall and evapotranspiration. The soil moisture capacity in different parts of the watershed must also be determined e.g. through multiple correlation (KOHLER & RICHARDS [1]).

It is of interest to note how accurately the runoff resulting from a rain period can be determined with the use of rainfall readings alone. To do this the method described by LINSLEY, KOHLER and PAULHUS [3] was applied. In this method total runoff (Q_T) is a function of rainfall (P), rain duration (D), date and antecedent precipitation index I_A (1)

$$Q_T = f\,(P, D, \text{date}, I_A) \tag{1}$$

The moisture deficiency in the soil is indicated by I_A. It was determined from equation (2)

$$I_{A\,n} = k \cdot I_{A\,n-1} + P_{n-1} \tag{2}$$

$I_{A\,n}$ = antecedent precipitation index
$I_{A\,n-1}$ = antecedent precipitation index of previous day
P_{n-1} = rainfall of previous day
k = recession factor ranging as follows:

in May	= 0,94
in June	= 0,90
in July	= 0,86
in August	= 0,88
in September	= 0,92
in October	= 0,96

Factor k shows variations in potential evapotranspiration and seasonal phases of vegetation. The same I_A values were used in all watersheds. However, the evapotranspiration is different in cultivated areas and in the forest during the different seasons. Therefore dates were used as correction variables. Since runoff does not add to the residual moisture in the soil, the index of precipitation minus runoff should be a better moisture index than I_A. This procedure would be very cumbersome to use without a remarkable improvement, and it was not therefore used in this investigation. The computation of I_A was started in spring, and it was assumed that I_A equalled 60 at the end of the snowmelt. Fig. 6 shows a variation of I_A in the dry summer of 1959 and in the rainy summer of 1962.

The method of estimating total runoff (Q_T) was determined by using the coaxial method of graphical correlation (LINSLEY & KOHLER &

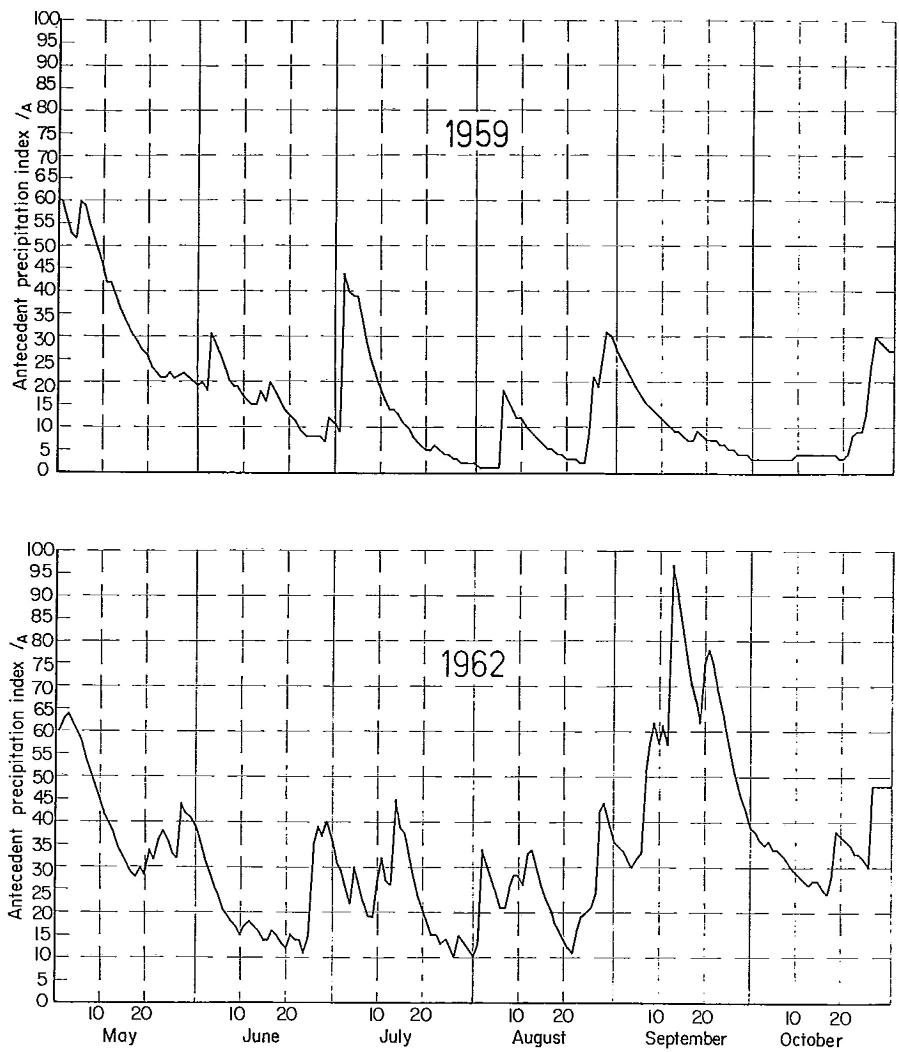

Fig. 6. Antecedent precipitation index for the dry year 1959 and for the wet year 1962.

PAULHUS [3]). The figures used in the above method were obtained from the total rainfall statistics which were taken during ten years.

The use of ordinary linear correlation in this case would have been very difficult, because only some independent factors have linear in-

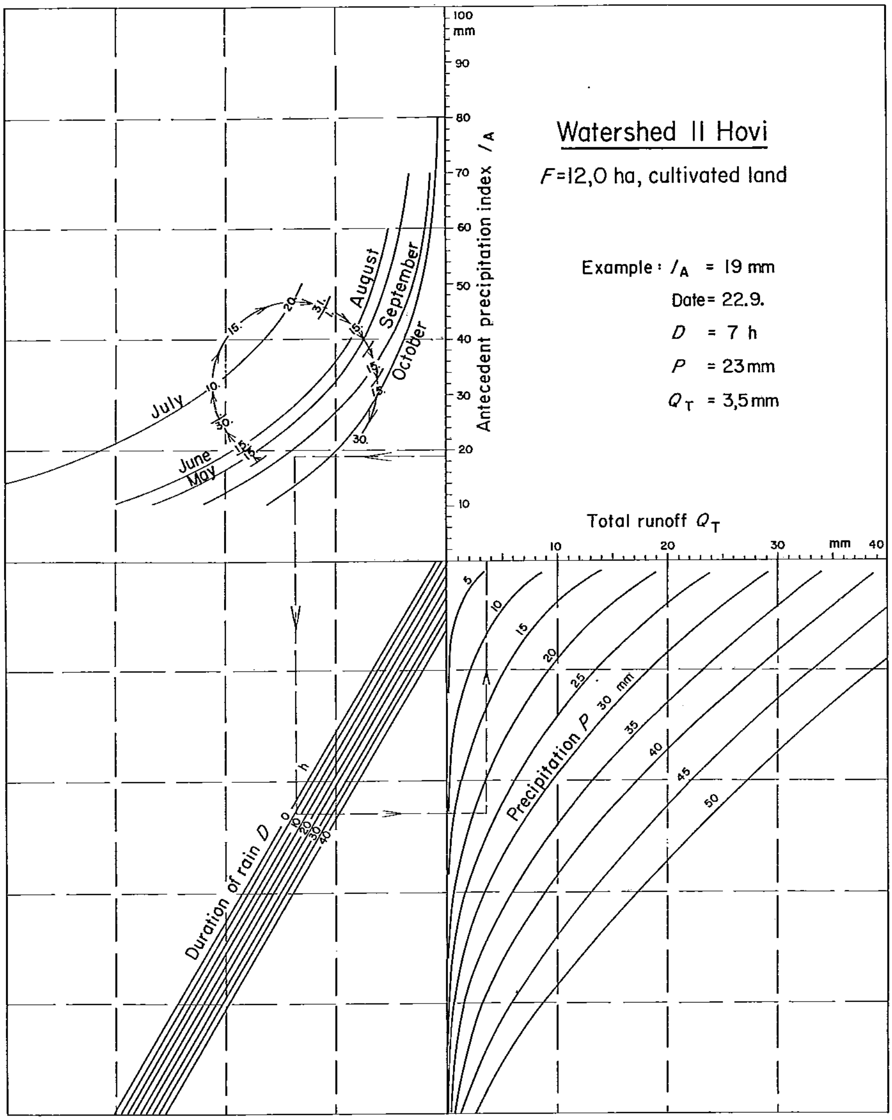

Fig. 7. Rainfall — runoff relation in watershed 11.

fluence. Graphical correlation is an excellent method of establishing the mathematical form of a hydrologic law.

The rainfall — total runoff relation in watershed 11 Hovi, is shown in fig. 7.

The accuracy of developed nomograms for estimating total runoff resulting from rainfall, can be tested in many ways. We can for example estimate the standard error of the computed total runoff (Q_T) and then compare this standard error with the Q_T average. But as Q_T is usually very small, especially in summer ($Q_T \approx 0$), this comparison is not very clear to see. The average runoff resulting from all rainperiods occuring in July during the ten years in watershed 11 was 0,05 mm, and with the use of fig. 7 the standard error was computed to be 0,47 mm, which is 1000 % of the average runoff. However we can estimate the total

Table 3. Total runoff (mm) resulting from the observed rainfall in all three watersheds, measured (Q_{To}), computed (Q_{Tc}) and the positive and negative differences between these two (grouped monthly).

	P	Q_{To}	Q_{Tc}	$Q_{To} - Q_{Tc}$	
				+	—
	11 Hovi				
May	324	54	51	14	11
June	540	5	3	3	1
July	794	4	6	3	5
August	920	80	70	34	24
September	554	169	166	24	21
October	465	130	132	33	35
	12 Ali-Knuutila				
May	240	42	44	5	7
June	530	15	16	5	6
July	851	21	22	6	7
August	937	100	99	19	18
September	625	164	161	21	18
October	446	113	121	21	29
	13 Yli-Knuutila				
May	214	37	37	7	7
June	506	23	22	6	5
July	846	29	32	7	10
August	953	66	66	15	15
September	624	98	93	16	11
October	473	62	62	16	16

runoff resulting from the July rainfall periods so accurately that the standard error (0,47 mm) is only 5% of the average rainfall (10 mm). This accuracy is satisfactory in river regulation.

The correlation between the observed runoff and the computed runoff is shown in fig. 8. On the basis of these figures we can conclude that large runoffs can be determined with greater relative accuracy than small runoffs. In river regulation, only the rainfall which causes a large amount of runoff is of any significance.

The correlation coefficient, as mentioned above, was 0,912 in watershed 11, 0,976 in watershed 12, and 0,931 in watershed 13.

The positive and negative differences between the observed and the computed runoff resulting from all the rainfall during the ten years period are shown in table 3 (grouped monthly).

These positive and negative differences together compose the sum of errors in this method. For example this sum of errors in watershed 11 was 4 to 5 mm in September or 27% of the observed runoff or 8% of the rainfall. Corresponding values in watershed 13 in September were 27 mm, 27% and 4%. Errors in monthly sums are not in reality so great, because the positive and negative errors partly nullify each other.

In table 4 we can see the same considerations as in table 3, but grouped yearly. In this table we can see that considerable errors occured in years with exceptional evapotranspiration (like 1955 and 1962), because this method uses the average recession factor.

The largest errors were in watershed 11, where the standard error of runoff for the whole summer was on the average 15 mm or 34% of the observed runoff or 4% of the rainfall. Corresponding values in watershed 12 were 9 mm, 20%, and 2% and in watershed 13 they were 7 mm, 22%, and 2%.

To make this procedure more accurate the observed potential evapotranspiration can be used for estimating moisture deficiency in the soil.

Figure 7 clearly shows the importance of the amount of rainfall and of the moisture deficiency in the soil. It can be seen that rainfall produces large runoff only when it falls in large amounts and the soil is moist. In table 5 monthly runoff in July and September were computed by using fig. 7. Monthly rainfall was assumed to fall in 3, 5, 15, or 30 rains. The resulting rainfall was assumed to be 75 mm (normal) and 150 mm (double the normal) in July and 60 mm (normal) and 120 mm (double the normal) in September. I_A was assumed to be the average during the years 1953 to 1962 at the beginning of the month.

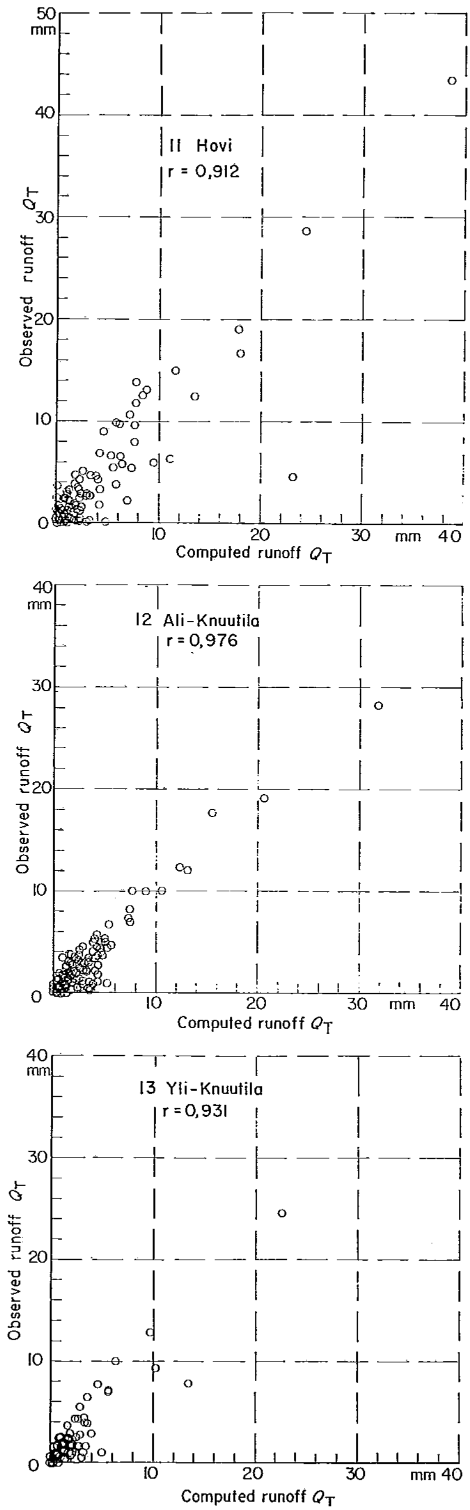

Fig. 8. Correlation between observed and computed total runoff in watersheds.

Table 4. Total runoff (mm) due to observed rainfall in watersheds in Vihti observed (Q_{To}) computed (Q_{Tc}) and the positive and negative differences (grouped yearly).

	P	Q_{To}	Q_{Tc}	$Q_{To} - Q_{Tc}$	
				+	−
	11 Hovi				
1953	412	50	25	26	1
1954	421	63	55	13	5
1955	294	17	34	5	22
1956	356	34	20	16	2
1957	478	112	131	15	34
1958	287	19	20	2	3
1959	203	1	5	1	5
1960	331	6	8	3	5
1961	361	17	30	4	17
1962	454	120	97	27	4
	12 Ali-Knuutila				
1953	438	45	37	11	3
1954	423	59	56	7	4
1955	299	27	45	5	23
1956	401	35	37	7	9
1957	475	123	123	11	13
1958	261	15	15	3	3
1959	181	3	7	0	4
1960	340	17	22	4	9
1961	340	30	41	0	1
1962	471	102	85	25	8
	13 Yli-Knuutila				
1953	423	32	29	7	4
1954	432	26	31	1	6
1955	281	19	26	3	10
1956	372	27	24	7	4
1957	506	82	81	16	15
1958	240	14	11	4	1
1959	183	6	9	0	3
1960	348	16	17	4	5
1961	347	17	27	4	14
1962	484	77	58	22	3

Table 5 shows that the runoff in July was only 8 mm, although the monthly rainfall was 150 mm which came in three rainfalls of 50 mm each. But if the rainfall in September had been double the normal it would have caused 15 mm of runoff even though the total rainfall would

Table 5. The influence of rainfall on runoff in July and September in watershed 11 (cultivated land).

Number of rains	Runoff in July (mm)		Runoff in September (mm)	
	$P = 75$ mm	$P = 150$ mm	$P = 60$ mm	$P = 120$ mm
3	0,1	8	11	70
5	0	1	5	65
15	0	0	0	32
30	0	0	0	15

have been distributed in 30 rainfalls, but if this same rainfall had been distributed in only three rainfalls, then it would have caused very great runoff, in fact more than half of the total rainfall.

The rough computation in table 5 shows, that it is not enough to know only the monthly rainfall when estimating runoff. Each rainperiod must be treated separately.

6. *Conclusions*

1. Rainfall during the summer half of the year (May to October) in South Finland causes runoff on an average of between 30 and 60 mm or 10% of the total summer rainfall in small watersheds. In May the corresponding values are 5 mm or 10%, in June and July 0 to 3 mm or 0 to 5%, in August slightly less than 10 mm or 10%, in September 15 mm or slightly less than 20% and in October about 20 mm or 30%.

2. *PET* during the summer half of the year in South Finland is on the average 375 mm, or about the same as the rainfall. If the rainfall is distributed evenly during the summer, it causes no runoff.

3. Runoff resulting from rainfall depends on the amount of rainfall and the moisture content of the soil. Each rainfall or rainperiod must therefore be treated separately and not on a monthly basis. Evapotranspiration during the rain is a factor of secondary importance, but naturally evapotranspiration affects the moisture content of the soil and in this way the runoff also.

4. Runoff resulting from rainfall can be estimated fairly accurately by using rainfall measurements alone ($r = 0{,}912 \cdots 0{,}976$). Exceptionally large run offs, which are the most important ones in river regulation, can be estimated with the greatest relative accuracy. Greater accuracy in determining runoff can be obtained by using *PET* as a supplementary consideration.

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