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INFLUENCE OF PHYSIOGRAPHIC FACTORS ON MAXIMUM RUNOFF

Pertti Seuna


Physiographic factors were used as the independent variables in a multivariate regression analysis to explain a long term average and a 20-year value of spring and summer maximum runoffs. A satisfactory degree of determination was reached in general, using two to four characteristics, defined from maps or readily available statistics. The altitude of the basin, the percentages of fine soils and impermeable surfaces, and the density of drainage network increased significantly both spring and summer maximum runoffs. The volume of growing stock remarkably decreased spring maximum runoff, while high percentages of cultivated land increased it. Drainage area explained significantly the instantaneous and exceptional maxima, those of summer especially.

Index words: maximum runoff, physiographic factors, multivariate regression analysis, extremity, peaked tendency.

1. INTRODUCTION

A network of small hydrological basins in Finland was completely renewed in 1958 to 1962 (Mustonen 1965b, 1965c). Measuring weirs were built with continuous water stage recording and various meteorological observations were begun. Physiographic factors were studied using maps and point line surveys. At the end of 1977 part of the basins had been in operation for 20 years. On the basis of the observation data from 1958 to 1977 frequency analyses were carried out for various runoff quantities using observation series ten years or more in length (Seuna 1982). Thirty seven basins of the total amount of 58 were available for this analysis (Fig. 1 and 2, Table 1).

In this study regression analyses of maximum runoff are presented based on the frequency analyses mentioned.

2. METHODS AND DATA

Using a multivariate regression analysis equations for spring and summer maximum runoffs were calculated. Only variables, which could be defined from maps or from readily available statistics were
These were e.g. drainage area, percentage of cultivated land, altitude, volume of growing stock, etc. Some long-term averages of meteorological factors were also included and these can be regarded as basin factors as well. In the analysis 37 basins with observation series ten or more years were included (n = 37).

The dependent variables were as follows:

- $MHq_w$ = mean value of the spring maximum runoff
- $MHq_s$ = mean value of the summer maximum runoff
- $MHq_{w\text{inst}}$ = mean value of the instantaneous spring maximum runoff
- $MHq_{s\text{inst}}$ = mean value of the instantaneous summer maximum runoff
- $Hq_{w1/20}$ = spring maximum runoff with return period of 20 years
- $Hq_{w\text{inst}1/20}$ = instantaneous spring maximum runoff with return period of 20 years
- $Hq_{s1/20}$ = instantaneous summer maximum runoff with return period of 20 years

In addition to this, the ratios of $MHq_{w\text{inst}}$ and $MHq_{w1/20}$ and $Hq_{w1/20}$; $MHq_{w\text{inst}}1/20$ and $Hq_{w1/20}$; and the respective ratios for summer maximum were explained using the same independent variables.

The independent variables, with their means, standard deviations and variation ranges, used in the regression analysis, are presented in Table 2. The correlation matrices of the independent and dependent variables are shown in Tables 3 and 4, respectively.

A number of transformations of the independent variables were tested, such as $A, \ln A, (\ln A)^{-1}, A^{1/2}, A^{1/3}, A^{-1/2}, A^{-1/3}, C, C^2, C \ln B, B, B_0, B_d, b_1, b_1^{1/2}, b_1, b_1^2, C + I_1, (C + I_1)^2, C + B + I_1, D, D_1, D^2, F, F_1, F_1^{1/2}, F_1^{1/3}, F_1^{1/4}, F_1^{1/5}, F_1^{1/6}, F_1^{1/8}, F_1^{1/9}, F_1^{1/10}, F_1^{1/12}, \ln F_1, F_1 C, G_1, G_1^2, G_1 + I_1, (G_1 + I_1)^2, G_1, G_1^2, G_1 + I_1, (G_1 + I_1)^2, G_1, L_1, k_1, L_1, S_1, L_1, S_1, L_1, S_1, W_1, W_1, E_1, E_1, E_1, E_1, S_1, t_1, T_1, P_1, P_1^2, P_1, F_1^2, W_1, W_1, W_1, W_1, W_1, W_1, W_1, W_1, W_1.

In the transformations $\ln A$ and $(\ln A)^{-1}$, $A$ was taken in hectares in order to avoid values of $A$ smaller than one.

In Tables 5 and 6 the ten best independent variables to explain maximum runoffs and the ratios of runoff are presented. The best transformation of each variable has been taken. For the runoff ratios the root transformations of $F_1$ were not tried.

### 3. SPRING MAXIMUM RUNOFF

Mean spring maximum runoff ($MHq_{w}$) could be best explained by tree stand ($F_1^{1/3}, r = -0.68; F_1, r = -0.52$), the altitude of the basin ($E_1, E_1, E_0, r = 0.58, 0.61, 0.53$, respectively), average snow cover ($W_1, W_1, W_1, W_1, W_1, W_1, W_1, W_1, W_1, W_1$; $r = 0.52, 0.57, 0.54, 0.55$, respectively), mean annual temperature ($T_1, r =$...
and the percentage of open bog ($B_{o,r} = 0.45$). Some of the best combinations are presented in equations (1) — (9).

\[
MHq = -0.57 F - 0.015 C^2 - 0.88 C + 0.19 E_0 + 0.40 Wm + 90 \\
R = 0.887 \quad (6)
\]

\[
MHq = -28 F_{s^{1/3}} + 228 \\
R = 0.676 \\
s_e = 28
\]

\[
MHq = -28 F_{s^{1/3}} + 0.33 E_o + 191 \\
R = 0.866 \\
s_e = 19
\]

\[
MHq = -0.52 F_s + 0.017 C^2 - 1.0 C + 0.30 E_o + 125 \\
R = 0.870 \\
s_e = 20
\]

\[
MHq = -0.50 F_s + 0.018 (C + I_s)^2 - 1.2 (C + I_s) + 0.29 E_o + 126 \\
R = 0.875 \\
s_e = 19
\]

\[
MHq = -0.91 F_s + 0.33 E_o + 21 A^{-1/2} + 125 \\
R = 0.885 \\
s_e = 18
\]

\[
MHq = -0.93 F_s + 0.34 W_m + 0.23 E_o + 20 A^{-1/2} + 98 \\
R = 0.896 \\
s_e = 18
\]

\[
MHq = -29 F_{s^{1/3}} + 0.23 E_o + 0.37 W_m + 160 \\
R = 0.880 \\
s_e = 19
\]

Fig. 2. The measuring weir of the Tuurajoa basin (No 91, Fig. 1).
### Table 1. Data on basin characteristics at the end of the observation period 1958—1977.

<table>
<thead>
<tr>
<th>Drainage basin</th>
<th>Area (km²)</th>
<th>Cultivated land (%)</th>
<th>Peat land (%)</th>
<th>Forest on firm land (%)</th>
<th>Tree stand (% m² ha⁻¹)</th>
<th>Mean slope (%)</th>
<th>Max altitude m a.s.l.</th>
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</thead>
<tbody>
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<td>40</td>
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</tbody>
</table>

**Mean**

- Area: 18.27 km²
- Cultivated land: 18.5%
- Peat land: 22.1%
- Forest on firm land: 57.9%
- Tree stand: 52.9 m² ha⁻¹
- Mean slope: 5.8%
- Max altitude m a.s.l.: 159.9

**Standard deviation**

- Area: 24.27 km²
- Cultivated land: 22.1%
- Peat land: 16.1%
- Forest on firm land: 20.8%
- Tree stand: 29.3 m² ha⁻¹
- Mean slope: 3.4%
- Max altitude m a.s.l.: 106.0

1) before 3/1968 A = 3.01 km², 2) before 3/1968 A = 3.37 km²

In these equations the independent variables are significant at the risk < 0.1 per cent, except for C in eq. (3) and (6), C + I₂ in eq. (4), E₀ in eqs. (8) and (9) (risk < 1 per cent), and E₀ in eq. (6), and Wₘ in eq. (6) and (8) (risk < 5 per cent). The T-value of the variable Wₘ in eq. (9) is 1.92, which is little below the 5 per cent risk level. The equations (4), (7) and (9) are presented as nomographs in Figs. 3, 4 and 5, respectively.

The best independent variables to explain the variance of the mean spring maximum runoff were tree stand, the altitude of the basin, the water equivalent of snow and the annual mean temperature. Of the factors indicating tree stand, the volume of growing stock was somewhat better than the coverage of tree stand (r = −0.63 and −0.52, respectively). An increase of 10 m³ ha⁻¹ in the growing stock decreased spring maximum
runoff about 7 l s⁻¹ km⁻². The nonlinear transformation (F₁₁², r = −0.68) entered some
models instead of the linear form. The altitude of
the outlet explained MHq better than the
altitude of the centre of gravity or the highest
point. It is rather interesting that the altitude
proved to explain MHq slightly better than the
more directly physical factor, the water equivalent
of snow (Table 5). The rise of 10 meters in the
altitude increased spring maximum runoff about
3—4 l s⁻¹ km⁻². Respectively an increase of 10 mm
in the water equivalent of snow increased MHq
about 8 l s⁻¹ km⁻². Drainage area did not prove to
explain especially well MHq, although it was
significant in some combinations. The trans-
formation A⁻¹₁² turned out to be the best one of
the tested area factors.

Instantaneous spring maximum runoff (MHqᵢₛₚᵣ) was best explained by tree stand (F₁₁², r = −0.78; F₁, r = −0.54), fine fractions of soil (G₂, r = 0.62; G₁², r = 0.60), the percentage of cultivated land (C₁², r = 0.60), drainage density (D₁¹₂, r = 0.58) and drainage area (A⁻¹₁², r = 0.41). Some combinations for MHqᵢₛₚᵣ are presented in eqs.

MHqᵢₛₚᵣ = 157.4 l s⁻¹ km⁻², sᵧ = 72.2 l s⁻¹ km⁻²

Table 2. The mean values, standard deviations, and variation ranges of the
independent variables (see the list of symbols).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Unit</th>
<th>Mean</th>
<th>Standard deviation</th>
<th>Minimum</th>
<th>Maximum</th>
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<tr>
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Table 3. Correlation matrix of the independent variables (see the list of symbols).

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Table 4. Correlation matrix of the dependent variables.

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Table 5. The ten best independent variables to explain maximum runoffs, and the correlation coefficients vs. runoff.

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<th>Independent variable and correlation coefficient</th>
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<td>-0.68 0.61 0.58 0.57 0.55 0.54 0.53 -0.52 0.52 -0.49</td>
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<tr>
<td>MHq_s</td>
<td>P_{1/2} W_m G_2 F_{1/2} G_2 D_g F_s G_2 F_2 W_p W_h C_2 W_m</td>
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<td>0.50 0.49 0.47 -0.47 0.45 0.42 -0.41 0.38 0.38</td>
</tr>
<tr>
<td>MHq_{w inst}</td>
<td>F_{1/2} G_2 C_2 G_f D_g F_e A_{1/3} F G_2 G_2</td>
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<td>-0.78 0.62 0.60 0.60 0.58 0.54 0.41 -0.40 -0.40 0.34</td>
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<tr>
<td>MHq_{s inst}</td>
<td>A_{1/3} D_g G_2 L_s G_2 C_2 F_{1/2} F_2 S_h S</td>
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<td>0.76 0.70 0.70 0.67 0.62 0.55 -0.54 -0.49 0.48</td>
</tr>
<tr>
<td>Hq_{w 1/20}</td>
<td>F_{1/3} F_k B_0 C_2 G_f D_g F W_m</td>
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</tr>
<tr>
<td>Hq_{s 1/20}</td>
<td>G_2 D_g G_2 C_2 F_{1/2} A_{1/3} F W_h</td>
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<td>0.75 0.72 0.71 0.70 -0.61 0.61 -0.45 0.45 0.45 0.43</td>
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<td>Hq_{w inst 1/20}</td>
<td>F_{1/8} G_2 C_2 F_{1/2} G_f D_g F_e G_f</td>
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<td>A_{1/3} D_g G_2 G_2 C_2 F_{1/2}</td>
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<td>0.84 0.80 0.78 0.70 0.66 -0.63 0.57 0.53 -0.52 0.50</td>
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Table 6. The ten best independent variables to explain the ratios of maximum runoff, and the correlation coefficients vs. runoff.

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<th>Independent variable and correlation coefficient</th>
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<td>W_p E_0 E_h W_p W_p W_m E_d E_w E_d S_p P_2</td>
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<td>-0.58 -0.57 -0.56 -0.56 -0.54 -0.52 -0.50 -0.49 -0.48 -0.46</td>
</tr>
<tr>
<td>Hq_{s 1/20}/MHq_s</td>
<td>T_s G_f D_d W_p E_p W_m E_d E_w E_d G_f</td>
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<tr>
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<td>0.67 0.64 0.62 -0.61 0.59 0.58 -0.57 -0.56 -0.54 -0.52</td>
</tr>
<tr>
<td>Hq_{w inst 1/20}/MHq_{w inst}</td>
<td>W_p W_h E_p W_m E_d E_w E_d E_d G_f</td>
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<td>-0.61 -0.61 -0.60 -0.60 -0.59 -0.57 -0.53 -0.51 -0.49 -0.46</td>
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<tr>
<td>Hq_{s inst 1/20}/MHq_{s inst}</td>
<td>D_d In A T_s G_f C_2 E_d L_w L_c L_b E_p</td>
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<td>0.60 -0.56 0.56 0.54 0.50 0.46 -0.44 -0.44 -0.44 -0.44</td>
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<td>MHq_{w inst}/MHq_w</td>
<td>In A G_f D_d G_2 C_2 L_w L_b L_c L_2 T_w</td>
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<td>-0.74 0.73 0.70 0.65 0.64 -0.59 0.58 -0.58 0.56 -0.55</td>
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<tr>
<td>MHq_{s inst}/MHq_s</td>
<td>A_{1/3} S_w S_d S_p S_m I_2 D_d G_f</td>
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<td>0.93 0.77 0.75 0.74 0.68 0.67 0.57 -0.57 -0.55 -0.54</td>
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<tr>
<td>Hq_{w inst 1/20}/MHq_{w inst}</td>
<td>G_f^2 G_2 D_d C_2 A_{1/3}</td>
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<td>0.80 0.72 0.72 0.70 0.66 -0.66 0.56 -0.53 -0.52 -0.52</td>
</tr>
<tr>
<td>Hq_{s inst 1/20}/MHq_{s inst}</td>
<td>A_{1/3} S_w D_d S_p S_m I_2 L_w</td>
</tr>
<tr>
<td></td>
<td>0.94 0.76 0.74 0.72 0.71 0.64 -0.56 0.54 -0.54 -0.54</td>
</tr>
</tbody>
</table>

MHq_{w inst} = 106 A_{1/3} - 2.0 F_s + 0.93 W_m + 93
R = 0.896
s_e = 33

MHq_{s inst} = 113 A_{1/3} - 1.9 F_s + 0.34 E_0 + 158
R = 0.890
s_e = 34

MHq_{w inst} = 83 A_{1/3} - 1.6 F_s + 0.013 (C + I_2) - 0.63 (C + I_2) + 0.99 W_m + 82
R = 0.903
s_e = 34

MHq_{w inst} = 96 A_{1/3} - 2.2 F_s + 0.94 W_m + + 71 k_o + 78
R = 0.908
s_e = 32

MHq_{w inst} = 73 A_{1/3} - 1.3 F_s + 0.039 G_f^2 - 1.2 G_f + 0.42 E_0 + 139
R = 0.906
s_e = 33

In these equations the variables are significant at the risk < 0.1 per cent, except for W_m in eq. (15) (risk < 1 per cent) and k_o in eq. (16), F_s and E_0 in eq. (17) (risk < 5 per cent). The variable C + I_2 in eq. (15) is not significant (T-value = 1.18), and the same holds with cultivated land in general in the equations for MHq_{w inst}. For practical reasons it was included in the equation (15), however. The variable G_f is not quite significant in eq. (17), although the T-value = 1.95 is near to the 5 per cent risk level. The equations (13) and (14) are presented in Figs. 6 and 7, respectively.
As stated above, the instantaneous spring maximum runoff ($MH_{q, \text{inst}}$) was best explained by indices representing fine fractions of soil ($G_{fi}^2$, $r = 0.62$, $0.60$, respectively). The squared forms showed clearly better explaining ability in comparison with the linear forms. In statistically significant correlation with $MH_{q, \text{inst}}$ were also tree stand ($F_\text{s}$ and $F_\text{st}$, $r = -0.54$ and $-0.53$), the density of main channels ($D_d$, $r = 0.49$), drainage area ($A^{-1/3}$, $r = 0.41$), percentage of forest ($F$, $r = -0.40$), percentage of coarse soils ($G_r$, $r = -0.40$) and average water equivalent of snow on 15 March ($W_m$, $r = 0.34$). The transformation $F_\text{s}^{1/3}$ explained well $MH_{q, \text{inst}}$ ($r = -0.78$), but did not improve the models with two or more variables. The equation (16) explained 82 per cent of the variance of $MH_{q, \text{inst}}$ but still the standard error of estimate was $32.1 \text{ s}^{-1} \text{ km}^2$ or 20 per cent of $MH_{q, \text{inst}}$ and 44 per cent of the original standard deviation.

An increase of 1 m$^3$ ha$^{-1}$ in the growing stock caused a decrease of $2.1 \text{ s}^{-1} \text{ km}^2$ in the instantaneous spring maximum runoff. A ten millimeters increase in the water equivalent of snow increased $MH_{q, \text{inst}}$ by 9—10 $\text{s}^{-1} \text{ km}^2$. The percentage of impermeable surfaces had a very strong influence, being the best as a quadratic transformation. It decreased $MH_{q, \text{inst}}$ till about the percentage of six, but increased runoff remarkably in higher percentages. However, the range of impermeable surfaces was 50 narrow — only from 0 to 8 per cent — in the data base that it is not justified to assume as strong influence in higher percentages, say over ten.

For the spring maximum runoff with return period of 20 years ($H_{q, w}^{1/20}$) the best independent variables were tree stand ($F_\text{s}$ and $F_\text{st}$, $r = -0.60$ and $-0.53$), the percentages of open bog ($B_\text{o}$, $r = 0.44$), forest ($F$, $r = -0.43$), coarse soils ($G_r$, $r = -0.41$), cultivated land ($C^2$, $r = 0.41$), clay soils ($G_{cl}^2$, $r = 0.40$), the altitude ($E_o$, $r = 0.40$) and fine soils ($G_{fi}^2$, $r = 0.39$). Of the $F_\text{s}$ transformations $F_\text{s}^{1/3}$
correlated with $H_{qw} \ 1/20$ slightly better ($r = -0.68$), than the linear form.

Some combinations for $H_{qw} \ 1/20$ are presented in eqs. (18) — (22).

\begin{align*}
H_{qw} \ 1/20 & = 223 \ l \ s^{-1} \ km^{-2}, \ s_y = 70 \ l \ s^{-1} \ km^{-2} \\
H_{qw} \ 1/20 & = -57 \ F_s^{1/3} + 428 \\
R & = 0.678 \\
s_e & = 52
\end{align*}

\begin{align*}
H_{qw} \ 1/20 & = -1.9 \ F_s + 44 \ A^{-1/2} + 301 \\
R & = 0.745 \\
s_e & = 48
\end{align*}

\begin{align*}
H_{qw} \ 1/20 & = -1.8 \ F_s + 48 \ A^{-1/2} + 0.39 \ E_o + 257 \\
R & = 0.817 \\
s_e & = 42
\end{align*}

\begin{align*}
H_{qw} \ 1/20 & = -1.2 \ F_s + 43 \ A^{-1/2} + 0.57 \ E_o - 1.16 \ F + 278 \\
R & = 0.845 \\
s_e & = 40
\end{align*}

\begin{align*}
H_{qw} \ 1/20 & = -1.8 \ F_s + 42 \ A^{-1/2} + 0.28 \ E_o + 0.014 \ (C + I_s)^2 - 1.27 \ (C + I_s) + 280 \\
R & = 0.824 \\
s_e & = 43
\end{align*}

In these equations the independent variables are significant at the risk $< 0.1$ per cent, except for $E_o$ in eq. (20), $F_s$ in eq. (21), which are significant at the $< 1$ per cent risk and $F$ in eq. (21) and $A^{-1/2}$ in eq. (22) (risk $< 5$ per cent). $E_s$ and $C + I_s$ in eq. (22) are not significant (T-values = 1.58 and 1.01, respectively). For practical reasons, however, the equation was taken. The equation (20) is presented as a nomograph in Fig. 8.

The influences of the growing stock, the altitude and the percentages of impermeable surfaces approximately equalled to their effects on $H_{qw} \ inst$. The increase of the drainage area (A) from one to ten square kilometers caused a decrease of 30 l s$^{-1}$ km$^{-2}$ and to 100 km$^2$ a decrease of 40 l s$^{-1}$ km$^{-2}$ in $H_{qw} \ 1/20$. The equation (21) explained 72 per cent of the variance of $H_{qw} \ 1/20$.

The instantaneous spring maximum runoff with return period of 20 years ($H_{qw} \ inst \ 1/20$) was best explained by fine fractions of soil ($G_{s2}, G_{s2}, C^2, r = 0.73, 0.72, 0.71$, respectively) (Table 5). The density of main channels ($D_{m2}, r = 0.68$), tree stand ($F_o, r = -0.55, F_s, r = -0.51$ and $F_{s1/6}, r = -0.84$), the percentage of coarse soils ($G_o, r = -0.55$), forest percentage ($F, r = -0.53$) and drainage area ($A^{-1/3}, r = 0.46$) were also in statistically significant correlation with $H_{qw} \ inst \ 1/20$. Some combinations for $H_{qw} \ inst \ 1/20$ are presented in eqs. (23) — (28).
In these equations (23) — (28) the independent variables are significant at the risk < 0.1 per cent, except for A in eq. (25), Gf in eq. (28) (risk < 1 per cent) and Gf in eq. (25), C in eq. (26), C + I in eq. (27) and A, F, B0 in eq. (28) (risk < 5 per cent). The equation (28) explained 83 per cent of the variance of Hq_w inst 1/20. A number of equations with the degree of determination around 90 per cent were rejected because of the quadratic transformation of the impervious surfaces, which was based on a very narrow range of data. The equation (27) is presented as a nomograph in Fig. 9.

In the equations (23) — (28) tree stand, fine soils and drainage area affected most. An increase of 1 m³ ha⁻¹ in growing stock caused a decrease of about 3 l s⁻¹ km⁻² in Hq_w inst 1/20.

\[
\begin{align*}
Hq_w \text{ inst } 1/20 &= 293 \text{ l s}^{-1} \text{ km}^{-2}, \ s_y = 149 \text{ l s}^{-1} \text{ km}^{-2} \\
Hq_w \text{ inst } 1/20 &= -358 F_s^{1/6} + 966 \\
R &= 0.839 \\
s_e &= 83 \\
(23) \\
Hq_w \text{ inst } 1/20 &= -133 F_s^{1/3} + 129 A^{-1/3} + 699 \\
R &= 0.877 \\
s_e &= 74 \\
(24) \\
Hq_w \text{ inst } 1/20 &= 158 A^{-1/3} - 2.8 F_s + 0.112 Gf^2 - 4.8 Gf + 357 \\
R &= 0.895 \\
s_e &= 70 \\
(25) \\
Hq_w \text{ inst } 1/20 &= 179 A^{-1/3} - 3.4 F_s + 0.047 C^2 - 3.0 C + 386 \\
R &= 0.888 \\
s_e &= 73 \\
(26) \\
Hq_w \text{ inst } 1/20 &= 173 A^{-1/3} - 3.3 F_s + 0.054 (C + I_s)^2 - 3.6 (C + I_s) + 389 \\
R &= 0.890 \\
s_e &= 72 \\
(27) \\
Hq_w \text{ inst } 1/20 &= 113 A^{-1/3} - 1.7 F_s + 0.14 Gf^2 - 4.7 Gf + 3.8 B_0 + 288 \\
R &= 0.913 \\
s_e &= 65 \\
(28) \\
\end{align*}
\]

**4. SUMMER MAXIMUM RUNOFF**

The basin mean of daily summer maximum runoff (MHq_s) was best explained by the percentage of fine soils (Gf², Gf², r = 0.45, 0.47, resp.), summer precipitation (P_s, r = 0.50), tree stand (F,⁴/₁₈, r = -0.47) and drainage density (D_d). The abundance of snow also indicated increased summer maximum runoff. In general MHq_s could not be explained satisfactorily with the variables used, as can be stated from eqs. (29) — (35).
\[
MHq_s = 43.5 \, \text{l s}^{-1} \text{km}^{-2}, \quad s_y = 14.7 \, \text{l s}^{-1} \text{km}^{-2}
\]

\[
MHq_s = 0.38 \, P_s - 29
R = 0.500
s_e = 12.9
\]

\[
MHq_s = 0.80 \, G_c + 0.16 \, E_0 + 24
R = 0.712
s_e = 10.6
\]

\[
MHq_s = 0.012 \, (I_s + G_c)^2 + 0.27 \, (I_s + G_c) + 0.15 \, E_0 + 25
R = 0.733
s_e = 10.5
\]

\[
MHq_s = 0.016 \, (I_s + G_c)^2 + 0.13 \, E_0 + 0.055 \, P_s - 8
R = 0.761
s_e = 10.0
\]

\[
MHq_s = 0.72 \, G_c + 0.16 \, E_0 + 0.36 \, I_s + 22
R = 0.755
s_e = 10.1
\]

\[
MHq_s = 0.70 \, G_c + 0.15 \, E_0 + 1.25 \, I_s^2 - 6.9 \, I_s + 29
R = 0.818
s_e = 9.0
\]

\[
MHq_s = 0.57 \, G_c + 0.15 \, E_0 + 1.42 \, I_s^2 - 9.0 \, I_s - 0.26 \, B + 38
R = 0.852
s_e = 8.3
\]

In these equations the independent variables are significant at the risk < 0.1 per cent, except for \(P_s\) in eq. (29) (risk < 1 per cent), \(I_s\) in eq. (33) and \(B\) in eq. (35), (risk < 5 per cent). In eq. (31) \(I_s + G_c\) is not significant (T-value = 1.30), but the equation can be considered logical and practical. The same applies to \(P_s\) in eq. (32) (T-value = 1.94). The equation (32) is presented as a nomograph in Fig. 10.

The variable \(I_s\), in as a quadratic transformation, especially, was rather decisive to explain the variance of \(MHq_s\). It was included in eqs. (33) — (35). The narrow data base, as mentioned before, makes the regression coefficients of \(I_s^2\) unstable and high. For these reasons \(I_s\)-values greater than 8 per cent should not be used, which is the highest percentage of \(I_s\) in the data.

For the mean instantaneous summer maximum \(MHq_s\) the best independent variables were drainage area \((A^{-1/3}, r = 0.76)\), percentage of fine soils \((G_r^2, r = 0.70; G_p^2, r = 0.62)\), drainage density \((D_d, r = 0.68)\), the percentage of impervious surfaces \((I_s^2, r = 0.67)\) and percentage cultivated land \((C^2, r = 0.55)\). Some combinations for \(MHq_s\) are presented in eqs. (36) — (42).
In these equations the independent variables are significant at the risk < 0.1 per cent, except for $A$ and $I_s$ in eq. (40), and $A$ in eq. (41), which are significant at the risk < 1 per cent, and $G_f$ in eq. (39), $I_s$ in eq. (41), which are significant at the risk < 5 per cent. The variable $C$ in eq. (41) is not significant at the risk < 5 per cent (T-value = 1.64), however, for practical reasons a model containing field percentage was included. The equations, which include $I_s$ in squared form, such as eq. (42), explain $MH_q_{st}$ markedly well. They are, however, to be applied with caution and not for $I_s$ greater than ten per cent. The equation (37) is presented as a nomograph in Fig. 11.

The summer maximum runoff with return period of 20 years ($H_q_{5 1/20}$) was best explained by the percentage of fine soils ($G_f^2$, $r = 0.75$; $G^2$, $r = 0.71$), drainage density ($D_d$, $r = 0.71$), field percentage ($C^2$, $r = 0.70$), drainage area ($A^{-1/3}$, $r = 0.61$) and tree stand ($F_{a,112}$, $r = -0.61$). Some combinations for $H_q_{5 1/20}$ are shown in eqs. (43) — (49).

$$MH_q_{st} = 40 A^{-1/3} + 0.075 G_c^2 - 1.77 G_c + 5.2 I_s^2 - 19 I_s + 47$$
$$R = 0.952$$

$$s_c = 18$$

$$H_q_{1/20} = 0.037 G_f^2 + 0.31 A - 101$$
$$R = 0.828$$

$$s_e = 35$$

$$H_q_{1/20} = 0.037 (G_f + I)^2 + 0.97 P - 88$$
$$R = 0.843$$

$$s_e = 29$$

$$H_q_{1/20} = 0.052 G_f^2 - 1.13 G_f + 0.31 P_a - 94$$
$$R = 0.842$$

$$s_e = 30$$

$$H_q_{1/20} = 0.058 (G_f + I)^2 - 1.6 (G_f + I_s) + 0.29 P_a - 81$$
$$R = 0.861$$

$$s_e = 28$$

$$H_q_{1/20} = 0.030 C^2 - 1.09 C + 0.31 P_a + 9.2 I_s - 100$$
$$R = 0.849$$

$$s_e = 30$$

$$H_q_{1/20} = 0.026 (C + I)^2 - 0.69 (C + I_s) + 0.34 P_a - 115$$
$$R = 0.827$$

$$s_e = 31$$

In these equations the independent variables were significant at the risk < 0.1 per cent, except for $P_a$ in eq. (44) and (48), $C + I_s$ in eq. (49), which are significant at the risk < 1 per cent, and $I_s$ in eq. (48) (risk < 5 per cent). The equation (45) is presented as a nomograph in Fig. 12.

The instantaneous summer maximum runoff with return period of 20 years ($H_q_{st}$) was best explained by drainage area ($A^{-1/3}$, $r = 0.84$), drainage density ($D_d$, $r = 0.77$) and the percentages of fine soils ($G_f^2$, $r = 0.78$; $G^2$, $r = 0.70$). The dependent variable could be explained with high degree of determination, but a great number of the best combinations had to be rejected due to unacceptable distribution of the residuals. In eqs. (50) — (55) some acceptable combinations for $H_q_{st}$ are shown.

$$MH_q_{st} = 58 A^{-1/3} + 0.021 (G_f + I_s)^2 + 23$$

$$H_q_{st} = 119.1 l s^{-1} km^{-2}, s_y = 53.2 l s^{-1} km^{-2}$$

$$H_q_{st} = 0.037 G_f^2 + 100$$
$$R = 0.753$$

$$s_e = 35$$

$$H_q_{st} = 0.035 G_f^2 + 0.31 P_a - 101$$
$$R = 0.828$$

$$s_e = 31$$

$$H_q_{st} = 0.037 (G_f + I_s)^2 + 0.97 P - 88$$
$$R = 0.843$$

$$s_e = 29$$

$$H_q_{st} = 0.052 G_f^2 - 1.13 G_f + 0.31 P_a - 94$$
$$R = 0.842$$

$$s_e = 30$$

$$H_q_{st} = 0.058 (G_f + I_s)^2 - 1.6 (G_f + I_s) + 0.29 P_a - 81$$
$$R = 0.861$$

$$s_e = 28$$

$$H_q_{st} = 0.030 C^2 - 1.09 C + 0.31 P_a + 9.2 I_s - 100$$
$$R = 0.849$$

$$s_e = 30$$

$$H_q_{st} = 0.026 (C + I_s)^2 - 0.69 (C + I_s) + 0.34 P_a - 115$$
$$R = 0.827$$

$$s_e = 31$$

Mean instantaneous summer maximum runoff $MH_q_{st} = 58 A^{-1/3} + 0.021 (G_f + I_s)^2 + 23$
Hq$_{\text{inst}}$ 1/20 = 389 $A^{-1/3}$ - 346 $F_s^{1/9}$ + 517
R = 0.899
s_e = 118

Hq$_{\text{inst}}$ 1/20 = 302 $A^{-1/3}$ + 0.106 ($I_s$ + $G_f$)$^2$ - 12
R = 0.917
s_e = 107

Hq$_{\text{inst}}$ 1/20 = 357 $A^{-1/3}$ + 0.064 ($C + I_s$)$^2$ - 1.30 ($C + I_s$) - 14
R = 0.901
s_e = 118

Hq$_{\text{inst}}$ 1/20 = 394 $A^{-1/3}$ + 0.052 $C^2$ + 21 $b_i$ - 83
R = 0.907
s_e = 115

Hq$_{\text{inst}}$ 1/20 = 322 $A^{-1/3}$ + 0.12 ($G_f$ + $I_s$)$^2$ + 26 $b_i$ - 74
R = 0.934
s_e = 97

In these equations the independent variables are significant at the risk < 0.1 per cent, except for $b_i$ in eqs. (54) and (55), and $C + I_s$ in eq. (53), which are significant at the risk < 5 per cent. The equation (55) is presented as a nomograph in Fig. 13.

5. RUNOFF RATIOS

5.1 Spring

The instantaneous spring maximum runoff (MH$q_w$$_{\text{inst}}$) was on average 1.31 times the daily spring maximum (MH$q_w$) and a standard deviation of 0.23. In the following some combinations for the relationship of MH$q_w$$_{\text{inst}}$/MH$q_w$ are presented, eqs. (56) - (59).

MH$q_w$$_{\text{inst}}$/MH$q_w$ = $0.35 A^{-1/3}$ + 1.09
R = 0.732
s_e = 0.16

MH$q_w$$_{\text{inst}}$/MH$q_w$ = $0.28 A^{-1/3}$ + 0.0044
(R + $I_s$) + 1.05
R = 0.837
s_e = 0.13

MH$q_w$$_{\text{inst}}$/MH$q_w$ = $0.29 A^{-1/3}$ + 0.0044 $C$ - 0.067 $\tau_w$ + 1.17
R = 0.865
s_e = 0.12

All the independent variables were significant at the risk < 0.1 per cent, except for $\tau_w$ in eq. (59), which

Fig. 12. A nomograph for the summer maximum runoff with return period of 20 years $Hq_s 1/20 = 0.037 (G_f + I_s)^2 + 0.97 F_s - 88.$

Fig. 13. A nomograph for the instantaneous summer maximum runoff with return period of 20 years $Hq_{s\text{inst}} 1/20 = 322 A^{-1/3} + 0.12 (G_f + I_s)^2 + 26 b_i - 74$.
was significant at the risk < 5 per cent.

According to the equation (57) the relationship \( \text{MHq}_{1/20}/\text{MHq} \) for a basin consisting 100 per cent cultivated land and impervious surfaces is 34 per cent greater than for a forested basin.

The spring maximum runoff with return period of 20 years (\( \text{Hq}_{1/20} \)) was on average 1.91 times the mean spring maximum (\( \text{MHq}_{1/20} \)) and a standard deviation 0.26. In the following some combinations to explain the relationship \( \text{Hq}_{1/20}/\text{MHq}_{1/20} \) are presented.

\[
\text{Hq}_{1/20}/\text{MHq} = -0.0040 \ W_p + 2.40
\]
\[
R = 0.577 \\
s_e = 0.22
\]

\[
\text{Hq}_{1/20}/\text{MHq} = -0.0031 \ W_p - 0.0041 \ G_r + 2.53
\]
\[
R = 0.636 \\
s_e = 0.21
\]

In these equations the variable \( G_r \) in eq. (61) was significant at the risk < 5 per cent, the others were significant at the risk about 0.1 per cent. The ratio between spring maximum with return period of 20 years and the average spring maximum could not be explained at a satisfactory level.

The instantaneous spring maximum runoff with return period of 20 years (\( \text{Hq}_{1/20} \)) was on average 1.92 times the instantaneous mean maximum (\( \text{MHq}_{1/20} \)), and a standard deviation of 0.27. In the following some combinations for the relationship \( \text{Hq}_{1/20}/\text{MHq}_{1/20} \) are presented, eqs. (62) — (64).

\[
\text{Hq}_{1/20}/\text{MHq}_{1/20} = 0.0044 \ W_p + 2.47
\]
\[
R = 0.611 \\
s_e = 0.22
\]

In these equations the variable \( G_r \) in eq. (64) was significant at the risk < 5 per cent, except for \( F \) in eq. (68). A and \( B_0 \) in eq. (70) (risk < 1 per cent) and \( G_f \) in eq. (68) and \( E_p \) in eq. (71) (risk < 5 per cent). The ratio \( \text{Hq}_{1/20}/\text{MHq}_{1/20} \) could not be explained at a satisfactory level with the variables available.

The instantaneous spring maximum runoff with return period of 20 years (\( \text{Hq}_{1/20} \)) was on average 2.50 times the daily mean maximum (\( \text{MHq}_{1/20} \)), and a standard deviation of 0.59. In the following some combinations for the relationship \( \text{Hq}_{1/20}/\text{MHq}_{1/20} \) are presented, eqs. (65) — (71).

\[
\text{Hq}_{1/20}/\text{MHq} = 0.025 \ G_f + 2.15
\]
\[
R = 0.787 \\
s_e = 0.37
\]

\[
\text{Hq}_{1/20}/\text{MHq} = 0.83 \ A^{-1/3} - 0.015 \ F + 2.89
\]
\[
R = 0.854 \\
s_e = 0.31
\]

\[
\text{Hq}_{1/20}/\text{MHq} = 0.60 \ A^{-1/3} + 0.014 \ C + 1.88
\]
\[
R = 0.833 \\
s_e = 0.33
\]

\[
\text{Hq}_{1/20}/\text{MHq} = 0.60 \ A^{-1/3} - 0.010 \ F + 0.011 \ G_f + 2.59
\]
\[
R = 0.882 \\
s_e = 0.29
\]

\[
\text{Hq}_{1/20}/\text{MHq} = 0.80 \ A^{-1/3} - 0.011 \ F_s + 0.20 \ T_a + 2.01
\]
\[
R = 0.866 \\
s_e = 0.31
\]

\[
\text{Hq}_{1/20}/\text{MHq} = 0.40 \ A^{-1/3} + 0.023 \ G_f + 0.019 \ B_0 + 1.80
\]
\[
R = 0.876 \\
s_e = 0.29
\]

\[
\text{Hq}_{1/20}/\text{MHq} = 0.43 \ A^{-1/3} + 0.020 \ G_f + 0.020 \ B_0 - 0.0012 \ E_p + 2.01
\]
\[
R = 0.893 \\
s_e = 0.28
\]
5.2 Summer

The instantaneous summer maximum runoff ($\text{Hq}_{\text{inst}}$) was on average 1.53 times the daily summer maximum ($\text{Hq}_5$) and a standard deviation of 0.67. The ratio could be explained with rather high degree of determination, eqs. (72) — (73).

$$\frac{\text{Hq}_{\text{inst}}}{\text{Hq}_5} = 1.30 A^{-1/3} + 0.74$$  \hspace{1cm} (72)

$$R = 0.927 \quad s_e = 0.26$$

$$\frac{\text{Hq}_{\text{inst}}}{\text{Hq}_5} = 1.15 A^{-1/3} + 0.10 I_s + 0.70$$  \hspace{1cm} (73)

$$R = 0.951 \quad s_e = 0.21$$

The independent variables in these equations were significant at the risk < 0.1 per cent.

The summer maximum runoff with return period of 20 years ($\text{Hq}_{1/20}$) was on average 2.73 times the mean summer maximum ($\text{Hq}_5$) and a standard deviation of 0.61. In the following some equations for the ratio $\frac{\text{Hq}_{1/20}}{\text{Hq}_5}$ are presented, eqs. (74) — (76).

$$\frac{\text{Hq}_{1/20}}{\text{Hq}_5} = 0.28 T_a + 1.94$$  \hspace{1cm} (74)

$$R = 0.671 \quad s_e = 0.46$$

$$\frac{\text{Hq}_{1/20}}{\text{Hq}_5} = 0.61 A^{-1/3} - 0.0076 W_e + 3.24$$  \hspace{1cm} (75)

$$R = 0.768 \quad s_e = 0.40$$

$$\frac{\text{Hq}_{1/20}}{\text{Hq}_5} = 0.19 T_a + 0.00013 C^2 + 0.096 S_w + 2.00$$  \hspace{1cm} (76)

$$R = 0.811 \quad s_e = 0.37$$

In these equations the independent variables are significant at the risk < 0.1 per cent, except for $S_w$ in eq. (76), which is significant at the risk < 1 per cent.

The instantaneous summer maximum runoff with return period of 20 years ($\text{Hq}_{\text{inst}} 1/20$) was on average 3.05 times the average instantaneous summer maximum ($\text{Hq}_{\text{inst}}$) and a standard deviation of 0.99. The ratio $\frac{\text{Hq}_{\text{inst}} 1/20}{\text{Hq}_{\text{inst}}}$ could not be explained satisfactorily with the variables used, as shown in the equations (77) — (79).

$$\frac{\text{Hq}_{\text{inst}} 1/20}{\text{Hq}_{\text{inst}}} = 0.63 D_d + 2.09$$  \hspace{1cm} (77)

$$R = 0.598 \quad s_e = 0.81$$

$$\frac{\text{Hq}_{\text{inst}} 1/20}{\text{Hq}_{\text{inst}}} = 0.45 D_d + 0.24 T_a + 1.69$$

$$R = 0.673 \quad s_e = 0.75$$

$$\frac{\text{Hq}_{\text{inst}} 1/20}{\text{Hq}_{\text{inst}}} = 0.42 T_a + 0.00068 (C + I_d)^2 - 0.052 C + 2.20$$

$$R = 0.732 \quad s_e = 0.71$$

In these equations the independent variables are significant at the risk < 0.1 per cent, except for $D_d$ in eq. (78) and $C$ in eq. (79) (risk < 1 per cent) and $T_a$ in eq. (78) (risk < 5 per cent).

The instantaneous summer maximum runoff with return period of 20 years ($\text{Hq}_{\text{inst}} 1/20$) was on average 4.97 times the daily average of summer maximum ($\text{Hq}_5$). The standard deviation of the ratio was 3.70. The ratio $\frac{\text{Hq}_{\text{inst}} 1/20}{\text{Hq}_5}$ could be explained well, eqs. (80) — (84).

$$\frac{\text{Hq}_{\text{inst}} 1/20}{\text{Hq}_5} = 7.3 A^{-1/3} + 0.533$$  \hspace{1cm} (80)

$$R = 0.941 \quad s_e = 1.27$$

$$\frac{\text{Hq}_{\text{inst}} 1/20}{\text{Hq}_5} = 6.8 A^{-1/3} + 0.39 T_a - 0.28$$

$$R = 0.952 \quad s_e = 1.17$$

$$\frac{\text{Hq}_{\text{inst}} 1/20}{\text{Hq}_5} = 6.6 A^{-1/3} + 0.035 G_f + 0.48$$

$$R = 0.952 \quad s_e = 1.16$$

$$\frac{\text{Hq}_{\text{inst}} 1/20}{\text{Hq}_5} = 6.7 A^{-1/3} + 0.048 G_f + 0.32 b_i - 0.36$$

$$R = 0.964 \quad s_e = 1.03$$

$$\frac{\text{Hq}_{\text{inst}} 1/20}{\text{Hq}_5} = 7.3 A^{-1/3} + 0.025 C + 0.27 b_i - 0.39$$

$$R = 0.956 \quad s_e = 1.13$$

The variables in these equations are significant at the risk < 0.1 per cent, except for $G_f$ in eq. (82), $b_i$ in eq. (83) and $C$ in eq. (84) (risk < 1 per cent), and $T_a$ in eq. (81) and $b_i$ in eq. (84) (risk < 5 per cent).
6. INFLUENCE OF INDEPENDENT VARIABLES

From the regression equations and correlation coefficients some conclusions can be drawn as far as the significance of the independent variables is in concern.

The drainage area (A) did not markedly affect the daily mean maxima, but was a strong independent variable for the instantaneous and unusual maxima of the smallest basins. This was supported by the fact that area did not appear in the models developed without the three smallest basins (basins 11—13). These results can be considered logical, if the fact is taken into account that, in the case of basins of this size, all water from snowmelt and rainfall comes to the measuring point during one day (Mustonen 1965 c). For summer maxima the areal conciseness, on the other hand, may produce large daily maxima in the smallest areas due to the dependence of rainfall intensity on area. The best transformation of area was generally $A^{-1/3}$, which emphasizes the exceptionality of the smallest basins ($A < 1$ km$^2$). Almost as good was $A^{-1/2}$, which had, however, a skewer distribution than $A^{-1/3}$ or $A^{1/3}$.

For $Hq = 1/20$ the use of $A^{-1/3}, A^{-1/2}, \ln A$ and their inverse values tended to result in an unsatisfactory distribution of the residuals. For this reason the linear term of A was added, but it resulted in an illogical combination and could not be accepted.

Drainage area was the most effective independent variable in explaining the ratios of the exceptional to average and of the instantaneous to daily maximum runoff, i.e. the extremity and the peaked tendency of the basin and flood. The transformation $A^{-1/3}$ alone explained more than 85 per cent of the variances of the ratios $MHq_{\text{inst}}/MHq$ and $Hq_{\text{inst}}^{1/20}/MHq$.

The percentage of cultivated land ($C$) increased in higher percentages especially instantaneous maxima both for spring and summer. The quadratic transformation appeared better than the more linear one as shown earlier by Kaitera (1939) and Mustonen (1965 c) for the spring maximum. A general relative form for $C$ was $-C + 0.017 C^2$ for the daily spring maximum, which is somewhat less steep than those presented earlier. The minimum is reached at 29 per cent of $C$, when the relative decrease of spring maximum runoff is 13 per cent of the mean. The maximum relative increase was 59 per cent for 100 per cent cultivated land. The minimum presented by Kaitera occurred at about 15 per cent and that by Mustonen at 24 per cent.

The distribution of $C$ and especially that of $C^2$ was rather skew and this may influence the results. However, the regression coefficients of $C$ and $C^2$ were notably stable in different combinations and for different dependent variables. When the regression equations $Hq = f(C, C^2)$ were computed, the relative coefficients of the quadratic term were, with a value of $C$ equal to $-1$, for $MHq$, $MHq_{\text{inst}}$, $Hq_{\text{inst}}^{1/20}$ and $Hq_{\text{inst}}^{1/20}$:

- MHq: 0.013, 0.018, 0.015, 0.020, respectively and for
- MHq to $Hq_{\text{inst}}^{1/20}$: 0.017, 0.029, 0.031 and 0.026, respectively. Hence the relative influence of the field percentage for the summer maximum runoff was greater than for the spring maximum, although $C$ appeared in the spring models, but was substituted by fine soils in the summer models.

As could be expected, the field percentage increased the extremity and the peaked tendency of the basin. This was shown clearly in the ratios of the instantaneous to daily and of the exceptional to average, which were the greater, the more cultivated land there was in the basin. The increase of about three per cent in field percentage caused the increase of one percent in the ratio of $MHq_{\text{inst}}/MHq$.

The percentage of sub-drained field ($C_s$) had no clear effect on maximum runoff, and it did not appear in the models, either. Results of an experimental study support this finding (Seuna and Kauppi 1982). The plot of $C_s$ versus maximum runoffs showed a relationship resembling that of $C$, but weaker. It is to be noted, however, that the small variation of $C_s$ restricts the explaining ability of this variable.

The percentage of forest ($F$) especially decreased spring maximum runoff but also the summer maximum. The primary reasons for the reduction are evidently the delay in the snowmelt conditions caused by forest and the permeable soils associated with forest ($r_F, G = 0.79$). However, forest percentage did not generally appear in the models due to a better independent variable, $F_s$.

Forest also decreased the extremity and the peaked tendency of maximum runoff, especially for the ratios of spring maximum runoff $MHq_{w, \text{inst}}/MHq_w$, $Hq_{w, \text{inst}}^{1/20}/MHq_{w, \text{inst}}$ and $Hq_{w, \text{inst}}^{1/20}/MHq_w$.

The percentage of swamp lands ($B$) had a decreasing effect on summer maximum runoff. It also appeared in some summer models. For spring maximum runoff there was no significant correlation; $B$ did not come to these models, either.

Swamp lands decreased the extremity of the maximum runoffs. Especially the runoff ratios of the summer maxima were decreased with the increase in the percentage of swamp lands.

The percentage of open bog ($B_o$) increased
spring maximum runoff, but decreased summer maximum. It also appeared in some spring models. In an open bog, snow is accumulated in an abundance (Mustonen 1965 a), and the conditions of snowmelt resemble those for cultivated land. It has also been presented (Kaitera 1939) that snowmelt waters are stored behind the snow banks of the bog and then abruptly discharged in high peaks. The decreasing effect on summer maxima could be caused by the storage capacity of such bog, which might cut the peaks to some extent. SPThis conclusion is substituted by the runoff ratios of summer maximum runoffs, which are decreased by the increase of open bog. On the other hand, no influence caused by open bog on the extremity of spring runoffs could be observed.

The percentage of forest-drained area (Bd) did not show strong correlation with maximum runoff. It came to some summer models of Hq 1/20 with an increasing effect of about 1.5 l s⁻¹ km⁻² for one per cent’s drained area. It seems evident that the decreasing effect of swampland (Bb and B) on summer maxima was removed by draining. On spring maximum runoff no influence of forestry drainage was observed.

The percentage of forestry drainage was in negative correlation with runoff ratios; however, to a smaller degree than the percentage of peatlands (B). This could be interpreted as a small growth in the extremity of runoff maxima.

The influence of the index of forestry drainage (bj) did not differ from that of the mere drainage percentage, although the time factor was included in the index. However, bj improved the residual distribution of the Hq inst 1/20 equations in such a way that it was included in some final models.

The percentage of impervious surfaces including open bedrocks (Ic) explained the summer maximum runoff well. Because of the narrow variation range of Ic, the quadratic transformation, which would have been much better, was avoided in the final equations. Generally Ic was added to the field percentage (C) or to the percentage of fine soils (Gf and G). The combination 1.2 (Ic)² — 6.0 Ic in equations of MHq, would result in 1 400 l s⁻¹ km⁻² of runoff, if the drainage basin were completely impermeable. This is not probable, although the maximum 20 minutes rainfall with return period of 20 years amounts to 16 700 l s⁻¹ km⁻² in Finland (Kuusisto 1980). In an urban area, 67 per cent paved, the maximum peak of 5400 l s⁻¹ km⁻² has been measured (Melanen and Laukkanen 1981).

The increase of impervious surfaces also increased the extremity of maximum runoffs.

The drainage density of main ditches (Di) showed a strong increasing effect on maximum runoff, especially those of summer. However, in the models it was mostly substituted by the drainage area (A) and field percentage (C). The regression coefficients of Di for Hq 1/20 and Hq inst 1/20 were approximately 36, while the mean density of main channels of the basins was 1.5 km⁻¹.

Drainage density also strongly increased the extremity of the basins, both for summer and spring maximum runoffs. For example, if the drainage density increased from one to two km⁻¹, the ratio of MHq inst/MHq increased by 15 per cent.

The volume of growing stock (F3) decreased spring maximum runoff and was one of the best independent variables for it. The increase of 1 m³ ha⁻¹ in tree stand caused a decrease of 0.7 l s⁻¹ km⁻² in the daily mean maxima, but a somewhat greater decrease in the instantaneous or exceptional maximum runoff. The plot of F3 vs. Hq showed a slight curvature. Of the several transformations tested, the third to twelfth roots of F3 showed the highest correlations with Hq (Table 7). The smaller roots better represented daily spring maxima; the highest ones fitted best to the instantaneous summer maxima. The root transformations improved a few models consisting of only one or two independent variables, but not the models containing more variables. As stated before, tree stand causes delay in snowmelt and also positively correlates with coarse soils, which both tend to decrease runoff peaks.

The coverage of tree stand (F4) had much of a similar effect on the spring maximum runoff as the volume of growing stock. Usually information on the coverage of tree stand is not as easily available as that of F3. For this reason it was omitted from the models, although it would have been even better for MHq inst and Hq inst 1/20.

The percentage of coarse soils (Gc) decreased both spring and summer maximum runoffs. It was a slightly weaker independent variable than the indices of fine soils (Gf and G). It did not enter the best models.

The coarse soils also reduced the extremity of maximum runoff. The index of coarse soils was also formed without fine sand moraine, but it proved to be a weaker independent variable than Gc. On the other hand, coarse soils better refer to low flows, on physical basis.

The percentage of fine soils (Gf) and the percentage of clay soils (Gd) correlated well with the summer maximum and the instantaneous spring maximum runoff. The increasing effect was
Table 7. Correlation coefficients between maximum runoffs and tree stand transformations.

<table>
<thead>
<tr>
<th></th>
<th>MHq_w</th>
<th>MHq_s</th>
<th>MHq_w inst</th>
<th>MHq_s inst</th>
<th>Hq_w 1/20</th>
<th>Hq_s 1/20</th>
<th>Hq_w inst 1/20</th>
<th>Hq_s inst 1/20</th>
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</thead>
<tbody>
<tr>
<td>F</td>
<td>-0.24</td>
<td>-0.08</td>
<td>-0.40</td>
<td>-0.18</td>
<td>-0.43</td>
<td>-0.31</td>
<td>-0.53</td>
<td>-0.26</td>
</tr>
<tr>
<td>F_c</td>
<td>-0.52</td>
<td>-0.19</td>
<td>-0.54</td>
<td>-0.09</td>
<td>-0.53</td>
<td>-0.24</td>
<td>-0.55</td>
<td>-0.13</td>
</tr>
<tr>
<td>F_s</td>
<td>-0.63</td>
<td>-0.28</td>
<td>-0.53</td>
<td>-0.02</td>
<td>-0.60</td>
<td>-0.16</td>
<td>-0.51</td>
<td>0.01</td>
</tr>
<tr>
<td>F_s 1/2</td>
<td>-0.68</td>
<td>-0.38</td>
<td>-0.68</td>
<td>-0.21</td>
<td>-0.67</td>
<td>-0.34</td>
<td>-0.69</td>
<td>-0.23</td>
</tr>
<tr>
<td>F_s 1/3</td>
<td>-0.68</td>
<td>-0.42</td>
<td>-0.74</td>
<td>-0.33</td>
<td>-0.68</td>
<td>-0.45</td>
<td>-0.77</td>
<td>-0.37</td>
</tr>
<tr>
<td>F_s 1/4</td>
<td>-0.66</td>
<td>-0.45</td>
<td>-0.76</td>
<td>-0.40</td>
<td>-0.67</td>
<td>-0.51</td>
<td>-0.81</td>
<td>-0.46</td>
</tr>
<tr>
<td>F_s 1/6</td>
<td>-0.62</td>
<td>-0.46</td>
<td>-0.78</td>
<td>-0.47</td>
<td>-0.64</td>
<td>-0.57</td>
<td>-0.84</td>
<td>-0.55</td>
</tr>
<tr>
<td>F_s 1/8</td>
<td>-0.59</td>
<td>-0.47</td>
<td>-0.77</td>
<td>-0.51</td>
<td>-0.61</td>
<td>-0.59</td>
<td>-0.84</td>
<td>-0.59</td>
</tr>
<tr>
<td>F_s 1/10</td>
<td>-0.56</td>
<td>-0.47</td>
<td>-0.76</td>
<td>-0.53</td>
<td>-0.59</td>
<td>-0.61</td>
<td>-0.84</td>
<td>-0.62</td>
</tr>
<tr>
<td>F_s 1/12</td>
<td>-0.55</td>
<td>-0.46</td>
<td>-0.76</td>
<td>-0.54</td>
<td>-0.58</td>
<td>-0.61</td>
<td>-0.84</td>
<td>-0.63</td>
</tr>
</tbody>
</table>

best indicated in the quadratic transformation, such as e.g., 0.05 G_f^2 - 1.1 G_f for Hq_s 1/20. The quadratic transformation of G_c was avoided in the final equations because of the skewness of G_c^2 distribution. Furthermore, G_f generally explained the variance better than G_c did. The influence of fine soils to a high degree equalled with that of the field percentage (C), which is natural considering the close correlation between them (r = 0.86). However, fine soils tended to especially explain summer maxima, while the field percentage explained those of spring. In the final models combinations of G_f + I_c and G_c + I_b were also used in order to obtain a better normality of the distribution of the independent variable. The distributions of the residuals were satisfactory for the mere G_f and G_c -models as well.

Fine soils clearly increased the extremity of maximum runoff; more clearly than coarse soils reduced it.

The percentage of gravel and gravel moraine (G_g) did not show any notable effect on maximum runoff. For the most part this can be counted on the small variation of G_g.

The length of the basin (L_b) had a decreasing effect on the instantaneous summer maximum runoff. It evidently means a long travelling time for runoff and had, in fact, a closer correlation with maximum runoff than the drainage area (A) in linear form did. In the models L_b stayed away, when the transformations of drainage area were included.

The length reduced the extremity and the peaked tendency of maximum runoff, but did not generally enter the best models of runoff ratios, either.

The elongation ratio of the basin (k_e) affected the instantaneous summer maximum runoff in such a way that the bigger k_e, i.e. the less elongated, the greater and more peaky the maximum runoff. It was included in some summer models.

For the extremity the effect was parallel; the rounder the basin, the more extreme the maximum runoff.

The circularity of the basin (k_c) had a similar relationship with the maximum runoff as the elongation ratio did, which was expectable. It did not enter the best models. The circularity also increased the extremity and the peaked tendency of maximum runoff.

The length of the main channel (L_c) correlated very strongly with the length of the basin (r = 0.97). Of course the influence on runoff was almost identical with that of L_b and the opposite to k_e and k_c. The same holds true for the runoff ratios.

The mean slope of the main channel (S_c) increased the instantaneous summer maximum. Because of the skewness of its distribution it was generally rejected from the final models.

The slope increased the extremity and the peaked tendency of summer maxima remarkably.

The increase in the distance from the centre of gravity to the outlet (L_w) decreased the summer maximum runoff, but had not any notable effect on the spring maxima. It also reduced the extremity and the peaked tendency of maximum runoff, especially those for summer. The influence, naturally, is parallel to that of the drainage area.

The slope from the centre of gravity to the outlet (S_w) increased the instantaneous summer maximum runoff. Due to the skewness of the distribution it was generally rejected from the final equations. The slope also increased the extremity and the peaked tendency of summer maximum runoff, especially.
The altitude of the basin (E<sub>ω</sub>, E<sub>o</sub> and E<sub>p</sub>) was one of the best independent variables explaining spring maximum runoff especially. The most easily available of them, the altitude of the outlet (E<sub>o</sub>) was in most cases also the best one. An increase of 10 meters in the altitude (E<sub>o</sub>) resulted in an increase of 4·1 s<sup>-1</sup> km<sup>-2</sup> in spring maximum runoffs. The absolute increase almost equalled for various quantities of spring maximum runoff. Hence the relative influence of the altitude was greatest for MHq<sub>ω</sub>, which can also be seen from the correlation coefficients.

The altitude reduced the extremity of maximum runoffs. Especially the extremity of summer maxima decreased with the rise of the altitude. For the extremity and for the peaked tendency the maximum altitude was more effective than the altitude of the outlet.

The altitude has much the nature of an overall index: high altitudes generally mean in Finland a lot of snow (r = 0.82), a low percentage of cultivated land (r = -0.61) and fine soils (r = -0.55), and low annual temperature (r = -0.76).

The maximum variation in the altitude (E<sub>d</sub>) behaved in the same way as the altitude indices did. It explained, however, much less of the variances of the maximum runoffs than the altitudes and thus did not enter the best models. The increase in the altitude difference reduced the extremity and the peaked tendency similarly to the absolute altitude. It is explained mainly by the high correlation between the difference and the altitude (r = 0.88).

The mean slope of the basin (S<sub>m</sub>) increased the summer maxima, but decreased the spring maxima, according to the correlation coefficients. The mean slope did not prove to be as good an independent variable, as could be expected and did not come to the final equations. It was not effective in explaining the runoff ratios, either, although it increased the peaked tendency of exceptional summer maxima.

The slope index (s<sub>ω</sub>) increased the instantaneous summer maximum runoff, but was insignificant for the other runoff quantities. As far as the extremity and the peaked tendency of runoff is in concern, the slope index had an effect similar to the mean slope, but with much closer correlation (r = 0.75 and 0.71 for MHq<sub>ω</sub> and Hq<sub>ω</sub> 1/20 vs. MHq<sub>ω</sub> respectively). Especially was the peaked tendency of summer maximum runoff increased by the slope index.

The time of flow from the centre of gravity (t<sub>ω</sub>) appeared to be a significant variable for summer maxima, especially. It would have improved the degree of determination of those models, but it was not included due to its laborious calculation. The shortening in the time of flow increased the peaked tendency of the maximum runoffs, both for spring and summer.

The mean annual air temperature (T<sub>α</sub>) decreased the daily spring maximum by about 3·1 s<sup>-1</sup> km<sup>-2</sup> for 1°C. It was not as good as the altitude or snow cover and did not enter the best models. On the other hand the mean annual temperature remarkably increased the extremity and the peaked tendency of the maximum runoffs.

The mean annual precipitation (P<sub>α</sub>) entered some of the equations for summer maximum runoff. An increase of ten millimeters in P<sub>α</sub> caused an increase of about 3 to 4·1 s<sup>-1</sup> km<sup>-2</sup> in the summer maximum with return period of 20 years. The mean precipitation had no significant effect on the extremity of maximum runoffs, while it was in low positive correlation with the peaked tendency of summer maxima. The rather low correlation between precipitation and maximum runoff could be explained in two ways. First, the variation of mean annual precipitation is quite small in Finland and no especially rainy districts exist. Secondly, the high annual precipitation in the Finnish conditions does not necessarily mean heavy rainstorms, which are the basis for summer maximum runoffs. This conclusion can be drawn from the precipitation maps of Finland (Helimäki 1967, Lemmelä and Solantie 1977, Uppala 1978).

The water equivalent of snow (W<sub>ω</sub>, W<sub>α</sub>, W<sub>p</sub>) explained spring maximum runoff well, but not better than the altitude did. The influence of the average snowpack clearly decreased when moving from the daily mean maximum to the instantaneous and exceptional maximum runoff. There was no difference, practically speaking, between the various snowpack indices; therefore the average water equivalent of snow in 15 March, taken from the map, was mostly used. The water equivalent of snow also correlated with the summer maximum runoff (MHq<sub>ω</sub>) being in a way a general index for a northern location, high altitudes, a low percentage of cultivated land, and a moderate or high percentage of coarse soils.

The water equivalent of snow decreased the ratio of exceptional and average spring maximum runoffs, being in good agreement with an earlier study (Seuna 1977), which stated that the statistical distribution of snow cover for different years is much more uneven in southern and western Finland than in eastern and northern parts of the country. On the contrary, snow cover did not affect the peaked tendency of runoff, which can also be concluded from an earlier study (Mustonen 1965 c).

The average summer precipitation (P<sub>ω</sub>)
influenced quite parallelly with the annual precipitation. However, it was in a higher positive correlation with the spring maximum runoff than the annual precipitation. This again stems from low altitudes, high percentage of cultivated land, and vicinity of the coast, all of which are associated with low summer precipitation. The summer precipitation did not markedly affect the extremity or the peaked tendency of maximum runoffs.

7. DISCUSSION

The statistical characteristics of both spring and summer maximum runoff could be explained at a rather satisfactory level using only physiographic characteristics of the basins and some climatological factors, which are readily available beforehand. From a practical point of view this is important considering the design of hydraulic engineering works for unobserved basins.

The regression coefficients were, although dependent on the other parameters in the equations, generally rather stable. They grew logically with the increase in the variances of various dependent variables.

To ensure the applicability of the equations obtained, the residuals of the models were analysed (Figs. 14 and 15). On this basis and because of the skewness of some transformations of the independent variables, a number of equations were rejected. A considerable number of them fitted to the data better than respective equations presented here. It is still to be noted, however, that the independent variables should not be used for practical planning much beyond the range of the data base.

The peaked tendency and the extremity of the maximum runoff, i.e. ratios of the instantaneous to daily and the ratio of the exceptional to mean maximum were affected by many of the same factors. Those characteristics were especially promoted by fine soils (Gf, Gc), cultivated land (C), impervious surfaces (Id, Id, Dd), slope of the basin (Sc, Ss, Sm, s), and high annual mean temperature (Ta). On the other hand the extremity and the peaked tendency were decreased by the increases in drainage area (A, Lb, Lc, Lw), in coarse soils (Gr), in altitudes (E0, Ew, Ex), and in abundance of snow (Wm, Wh, Ws, Wp).

The most effective factors influencing the exceptional spring maximum, compared with mean maximum, were the amounts of snow and coarse soils, both of which tended to decrease this variation. An abundance of fine soils, drainage density and a small drainage area, respectively, were the most important factors in sharpening the peak of spring flood.

For summer the exceptional maximum as compared with the mean was most affected by the annual temperature and drainage density. Respectively the drainage area alone explained more than 85 per cent of the variance of the peaked tendency for

![Fig. 14. An example of a satisfactory distribution of the residuals. The equation $MHq_w = 0.018(C + I)^2 - 1.2(C + I) - 0.50F_s + 0.29E_0 + 126$, $R = 0.875$, has been used.](image1)

![Fig. 15. An example of an unsatisfactory distribution of the residuals. The equation $Hq_{\text{inst}}^{1/20} = 477A^{-1/2} + 5.6I_s^2 - 109S_w + 57$, $R = 0.944$, has not been accepted.](image2)
the summer flood.

In general the peaked tendency of flood could be much better explained than the relationship between exceptional maximum and mean maximum. This was the case both for spring and for summer.

Some of the characteristics evidently have a nature of a multiple coefficient. Such is e.g. drainage area, as shown in literature (e.g. Kaitera 1939, Renqvist 1933). In this context multiple combinations were not used, however, because the significance of the individual independent variables was wanted to be compared. The polynomial models used in this study are not necessarily physically-based, but they can be considered acceptable for practical purposes and for giving good suggestions for further research. In later studies multiple combinations should be tested.

Restrictions of regression analysis have been widely discussed in literature (e.g. Mustonen 1965c, Yevjevich 1972, Daniel and Wood 1980). Especially have the difficulties risen by intercorrelations of the independent variables been pointed out. Strictly speaking regression analysis should not be employed in such a case at all, if mathematical orthodoxy is followed. In hydrological phenomena, however, the intercorrelations are inevitable, and no practical solution exists to produce useful combinations of parameters, i.e. design models, except for regression analysis. On the other hand, the main purpose, also in this study, is to obtain combinations of readily available variables to explain satisfactorily the variation of a certain runoff quantity, but not that much to investigate the physical relationships. For these reasons the use of regression analysis can be considered justified.

The use of regression analysis also presupposes other requirements, such as the normality of the distribution of the variables and the residuals. An independent variable should also have a range wide enough in order to be meaningful in the regression equations. Due to these requirements a number of transformations and equations had to be rejected. Totally some 1500 different combinations of variables were tested.

ACKNOWLEDGEMENTS

This study has been based on the data provided by the National Board of Agriculture and by the National Board of Waters in Finland. The local observers — about 200 in all — have been important in producing the data. The construction and the maintenance of the measuring weirs have been carried out mainly by the local Water Districts' Offices and their predecessors.

A number of persons have contributed to the study. Among them I especially wish to thank Mr. Teppo Järvi for carrying out the computational tasks, Mr. Timo Nieminen and Mr. Heikki Susimaa for assisting in the collection and the processing of data and Mr. Veikko Salmipuro and Mr. Tapio Saarenketo for a remarkable assistance in the maintenance of the network.

The manuscript was commented by Prof. Seppo E. Mustonen, for which I express my gratitude.

Finally I want to thank Ms. Eeva-Liisa Alanne for typing the manuscript, Ms. Terttu Halme for drawing the figures and Ms. Raili Malinen for making the layout.

Tuusula December 1982

Pertti Seuna

TIIVISTELMÄ


Valitut ylivalumien tunnuksut on ollut yleensä mahdollista selittää käytännön tarpeisiin riittävällä tarkkuudella käyttämällä 2–4 muuttujaa. Hetkelisten huippujen ja vuorokausiarvojen suhde on selittynyt selvästi paremmin kuin kerran 20 vuodessa sattuvien ylivalumien suhde keskimääräisiin.

Parhaita selittäjäryhmät ovat olleet maaperäteki jät, alueen sijainti ja korkeusasema sekä puusto. Hienot maalajit ovat selittäneet erityisesti kesäyl-
Valumia kun taas avoimet alueet, lähintä peltojen osuus, ovat selittäneet paremmin kevätylivalumia. Valuma-alueen korkeusasema, yleensä ilmaistuna alimman pisteen korkeutena, on osoittautunut erittäin hyväksi kevätylivaluman selittäjäksi, mutta se on selittänyt hyvin myös kesäylivalumia. Korkeusasemaa on pidettävä eräänlaisena yleisindeksiä; sen suuri arvo merkitsee samalla pohjoista si-jaintia, runsasta lumen määrää \( r = 0.82 \), vähäistä pellon \( r = -0.61 \) ja hienojen maalajien osuutta \( r = -0.55 \) sekä matalaa vuoden keskilämpötilaa \( r = -0.76 \). Valuma-alueen ala on selittänyt voimakkasti kesäylivalumia ja ylivalumien huipun, samoin on tehnyt uomatohiyyes, vaikka se on jäänyt yleensä alan rinnalla poiss malleista. Alueen topografiaa ei ole ollut — eikä geometrisilla tekijöillä — merkittävä vaikutusta selittäviin muutujiin, joskin kaltevuuden lisääntyminen on lisännyt ylivaluman äärevyyttä, erityisesti kesähuipun peltojen osalta. Ilmastotekijöistä pitkän jakson lämpötila, sadanta ja lumen vesiarvo ovat olleet tärkeät ylivaluman selittäjä.


**LIST OF SYMBOLS**

- \( MHq_w \) = mean value of spring maximum runoff \( 1 \text{ s}^{-1} \text{ km}^{-2} \)
- \( MHq_s \) = mean value of summer maximum runoff \( 1 \text{ s}^{-1} \text{ km}^{-2} \)
- \( MHq_w_{inst} \) = mean value of instantaneous spring maximum runoff \( 1 \text{ s}^{-1} \text{ km}^{-2} \)
- \( Hq_w^{1/20} \) = spring maximum runoff with return period of 20 years \( 1 \text{ s}^{-1} \text{ km}^{-2} \)
- \( Hq_s^{1/20} \) = summer maximum runoff with return period of 20 years \( 1 \text{ s}^{-1} \text{ km}^{-2} \)
- \( Hq_w^{inst\,1/20} \) = instantaneous spring maximum runoff with return period of 20 years \( 1 \text{ s}^{-1} \text{ km}^{-2} \)
- \( Hq_s^{inst\,1/20} \) = instantaneous summer maximum runoff with return period of 20 years \( 1 \text{ s}^{-1} \text{ km}^{-2} \)

\( A \) = drainage area \( \text{km}^2 \)
\( C \) = cultivated land \% of area
\( C_s \) = sub-drained cultivated land \% of area
\( F \) = forest \% of area
\( B \) = swampland \% of area
\( B_0 \) = open bog \% of area
\( B_d \) = forestry drainage \% of area
\( d_i \) = index of forestry drainage

\( d_1 = \sum \frac{d_i}{t_i} \)

\( t_i \) = time in years from each drainage
\( I_s \) = paved surfaces and open bedrock \% of area
\( D_d \) = drainage density of main ditches \( \text{km}^{-1} \)
\( F_s \) = volume of growing stock in total drainage area \( \text{m}^3 \text{ ha}^{-1} \)
\( F_c \) = coverage of tree stand \% of area

\( G_f \) = percentage coarse soils (gravel, coarse to fine sands, coarse silt and respective moraines) \% of area
\( G_r \) = percentage fine soils (clay, fine and medium silts and respective moraines) \% of area
\( L_b \) = length of basin along main channel \( \text{km} \)
\( k_e \) = elongation ratio = \( A / (L_b)^2 \)
<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
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<tbody>
<tr>
<td>k_c</td>
<td>circularity of basin = A / A_p</td>
</tr>
<tr>
<td>A_p</td>
<td>area of a circle with equal perimeter km^2</td>
</tr>
<tr>
<td>L_c</td>
<td>length of main channel km</td>
</tr>
<tr>
<td>S_c</td>
<td>mean slope of main channel %</td>
</tr>
<tr>
<td>L_w</td>
<td>distance from outlet to the centre of gravity km</td>
</tr>
<tr>
<td>S_w</td>
<td>slope from centre of gravity to outlet %</td>
</tr>
<tr>
<td>E_w</td>
<td>altitude of centre of gravity m a.s.l.</td>
</tr>
<tr>
<td>E_o</td>
<td>altitude of outlet m a.s.l.</td>
</tr>
<tr>
<td>E_p</td>
<td>maximum altitude of basin m a.s.l.</td>
</tr>
<tr>
<td>E_d</td>
<td>maximum difference in altitude m</td>
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<tr>
<td>S_m</td>
<td>mean slope of basin %</td>
</tr>
<tr>
<td>s_i</td>
<td>slope index = relief ratio</td>
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<tr>
<td>tw</td>
<td>ratio between mean altitude of the water divide referred to outlet and divided by basin length m km^{-1}</td>
</tr>
<tr>
<td>T_a</td>
<td>mean annual air temperature °C</td>
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<tr>
<td>Q_n</td>
<td>the Manning coefficient</td>
</tr>
<tr>
<td>P_a</td>
<td>mean annual precipitation (corrected) mm</td>
</tr>
<tr>
<td>P_s</td>
<td>average precipitation of June to August mm</td>
</tr>
<tr>
<td>W_m</td>
<td>water equivalent of snow on 15 March as long-term average mm</td>
</tr>
<tr>
<td>W_h</td>
<td>water equivalent of snow on average during study period on 15 March mm</td>
</tr>
<tr>
<td>W_e</td>
<td>water equivalent of snow on average during study period on 31 March mm</td>
</tr>
<tr>
<td>W_p</td>
<td>maximum water equivalent of snow on average during study period mm</td>
</tr>
<tr>
<td>s_y</td>
<td>standard deviation mm</td>
</tr>
<tr>
<td>s_e</td>
<td>standard error of estimate mm</td>
</tr>
</tbody>
</table>

**REFERENCES**


Niinivaara, K. 1961. Ylivalumien todennäköisestä vaihtelusta Suomen päävesistöjen alueilla. (Statistical variation of maximum runoff in the main