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The Watershed Influence on Storm Runoff in Small Norwegian Rivers

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A procedure to isolate and investigate the watershed influence on storm runoff is presented. It offers an opportunity to study also the change in influence of particular watershed characteristics by changing the input or soil moisture state of each catchment. Weighted lake area, area of bare rocks, main stream gradient, drainage density and basin area are found to be the most significant characteristics in affecting peak runoff and time of rise on storm hydrographs in small Norwegian rivers. The intercorrelation structure of the watershed properties is examined.

Introduction

Any watershed, small or large, may conceptually be looked upon as an *operator* in which a time-dependent input (rainfall, snowmelt, etc.) is re-arranged to form a hydrological response. Its internal structure is similar to a basin's response function by which effective runoff throughout the drainage basin is generated, transmitted and transformed before it reaches a water gauge and is recorded as, for example, a flood hydrograph.

The most simple »black-box« runoff models link input and output by only one or a few parameters – which do not describe any true response function. For the purpose of doing a proper study of the response function, it would be far more suitable to split a basin into its separate components in a »grey« or ultimately a »white-box« model. This may be done only if we are able to identify the internal function of a watershed and the composite nature of all those sub-processes and basin components that influence and participate in the total runoff response. It has, however, proved to be extremely difficult to obtain any acceptable solution. Even a study of the effect of one basin element only will be heavily complicated by its influence on several hydrological sub-processes or meteorological inputs and, particularly, by its interrelationship to other watershed characteristics.

To what extent the hydrological response of a watershed depends on its physiographical characteristics is, however, an old problem in hydrological science. That is true particularly in flood flow computations where it seems to have accompanied almost every approach being presented in order to do a prediction or design analysis (Sokolov et al. 1976). A prediction or design analysis implies, however, that a hydrologist has to consider not only the runoff event itself, but its return period as well. It will be necessary also to include local meteorological and climatic characteristics in order to attain a proper and generally accepted input-output relationship. Due to the composite and complex interconnections between climate, runoff and physiography, it turns out to be difficult to test the mere influence of the watershed itself.

An ultimate goal to know *»what is actually going on in a watershed«* has, however, not generally been any standard of whether engineering design or prediction procedures are successfull (Weyman 1975). A good prediction may, in fact, be made irrespective of having performed a correct description of the basin function. Most of the recent efforts in watershed modelling have therefore been made in favour of quick and practical solutions of the outputs of water, not of an examination of the watershed structure and its interconnections to runoff processes.

What appears to be an antagonism seems, however, about to be reduced. Model engineers do stress (Bergström 1974) the need to know what optimalized model parameters really stand for in a natural watershed. It is one thing to have a model that functions, another to have a model that is applicable on ungauged basins – or on environmental problem dealing with aspects of the water cycle other than predicting a correct output.

This paper presents a procedure which may be used to isolate just the influence of the watershed on storm runoff and to reveal some of the interrelationships between the watershed and selected flood response characteristics. Such a test ought to be best performed by a laboratory procedure. This has the advantage that one can isolate the effect of one element at a time and thereby study the influence of just this element on the rest of the system. Nature does, however, seldom or never give us two watersheds with identical characteristics except for the one we want to investigate. They should also be in a state of identical input and ground moisture. Otherwise, a comparison most probably will fail.

Presentation of the Procedure

The procedure presented here is an attempt to obtain some of the same advantages as would be attained by performing a »laboratory« test. This is achieved by a combination of a prediction analysis and a comparative statistical test on data collected from natural watersheds.

The first step relates different flood-hydrograph characteristics ($H_1, H_2, \ldots H_n$) to causative input parameters ($i_1, i_2, \ldots I_m$) on each of a group of small watersheds.

$$H_{xi} \equiv f_{xi}(I_1, I_2, \ldots, I_m) \quad (1)$$

Similar input-output relationships may, in fact, be approached by several hydrological procedures (Linsley 1967). In this study, however, the method itself is more or less unimportant since the approach has no practical prediction purposes on future floods. It must only give a reliable estimate of floodflow characteristics where both input and output are known. The relationships are therefore solved by multiple regression rather than unit hydrographs, conceptual models or some other technique, and the resulting equations are called prediction equations.

In order to isolate the influence of a watershed, the rivers have to be compared for identical inputs. The second step therefore predicts a particular flood-hydrograph characteristics H_i on each river by inserting in Eq. (1) an identical set of relevant input parameters. We thus obtain one specific and comparable set of H_i's for all the watersheds. If the values of H_i are significantly different, the reason for the variance is postulated to be the differences in watershed characteristics.

The validity of such a postulate does first of all depend on the predictive power of Eq. (1). Its efficiency has to be tested before continuing the procedure to see whether some basins have to be omitted or not (Fig. 1). If the postulate may be maintained, the relationship between a particular flood-hydrograph characteristic and the watershed components is tested by stepwise multiple regression on a large sample of physiographical parameters. In this way those basin characteristics that influence storm runoff in the actual sample of watersheds are found.

A statistical procedure like this makes it possible to investigate whether the influence of one particular or a group of watershed characteristics remains stable or changes as a function of precipitation or soil moisture. The approach has thus some of the same advantages as those of a process-based runoff model.

On the other hand, the procedure heavily relies on whether or not multivariate correlation analyses are accepted in solving the composite and complex interrelationships between a watershed and its hydrological system. A success will, anyhow, depend on to what extent the criticisms against these methods have been accomodated. An uncritical attempt by applying multivariate analyses »to see into a darkness« and thereby take any statistically significant result for granted, is not at all any trustworthy way to go. We do expect, however, that the proposed

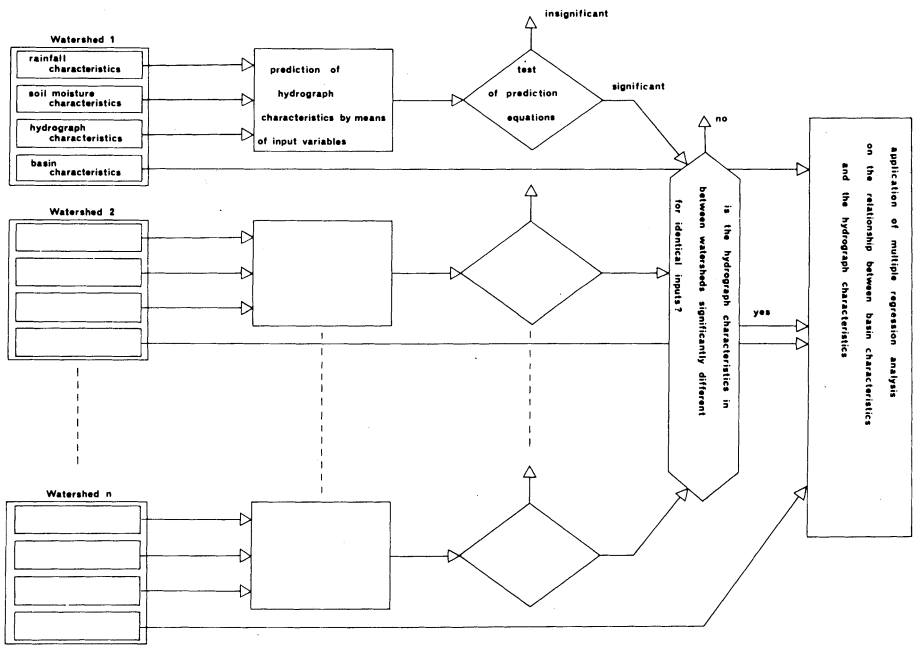
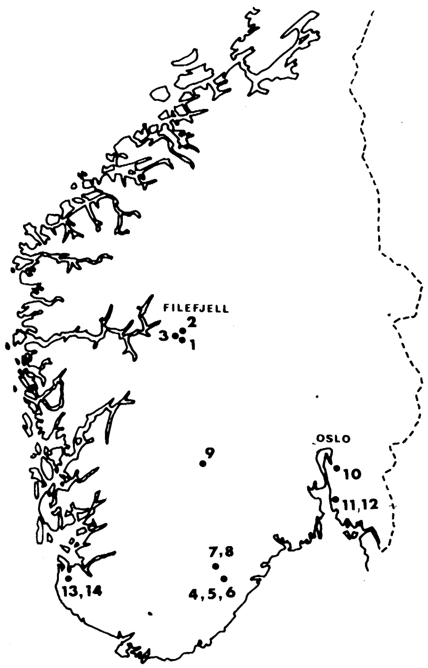


Fig. 1. Flow schedule of the proposed statistical procedure.

procedure may be a reply to some of the most severe objections (Amorocho and Hart 1964). This is achieved by first establishing the functional and independent prediction equations, and the results have to be accepted before any correlation analysis is performed to evaluate the watersheds' influence on the residuals. A similar procedure has also been applied on the low-water behaviour of the same rivers (Tjomsland, Ruud and Nordseth 1978).

Basic Input-Ouput Data

The procedure was tested on 14 small watersheds in South Norway (Fig. 2) with basin areas ranging from 0.6 to 29.3 km^2. The selection of small watersheds only is made in accordance with the acknowledgement that they generally are more physiographically homogeneous than large ones. Their characteristics differ, however, from dissected high-mountain rivers to low-land forested catchments. The areal share of bare rocks differs from 0 to 51% and the forested area from 0 to 86%. Natural vegetation is primarily coniferous forest on medium to lower site classes in which a thin cover of podzolic till is a dominant soil type. The cultivated area is small, and open lakes and swamps constitute 0-8% respectively 0-12% of



1. Sula
2. Frostdøla
3. Valdresdøla
4. Stigvassåna I
5. Stigvassåna II
6. Stigvassåna III
7. Raudåna I
8. Raudåna II
9. Grosetbekken
10. Sagstubekken
11. Trolldalen
12. Nordødegård
13. Gramstad
14. Rovik

Fig. 2. Watershed applied in establishing prediction equations.

the basin area. For a more thorough description of each catchment, we refer to Ruud (1974) and Tjomsland (1976). A list of the characteristics of the basin was presented in a previous paper (Tjomsland, Ruud and Nordseth 1978).

Except for Stigvassåna II and III and Raudåna II where the instrumentation and measurements were performed especially for this study, the catchments are selected from the official networks of the Norwegian Water and Electricity Board (NVE) and the Norwegian Meteorological Institute (MI). There is at least one automatical rain gauge in each basin, and the runoff was computed from an automatical water stage recorder in connection with a sharp-crest weir.

Only rainfall floods have been examined. That is because meltwater floods are more strongly influenced by climatic inputs which particularly in high-mountain basins are too laborious to evaluate in order to establish any significant prediction equations. Two parameters are applied in a description of the storm hydrographs (Fig. 3) since the recession limb has been studied before (Tjomsland, Ruud and Nordseth 1978)

H_1: q_{max} Specific peak runoff (l/sec/km^2)
H_2: T_r Time of rise (hours)

Their relevance in floodflow hydrology has been fully documented in previous

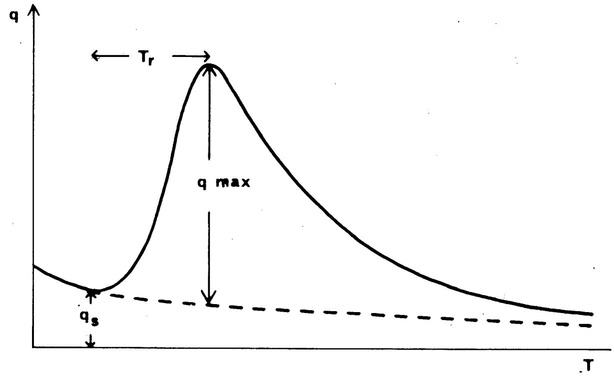


Fig. 3. Selected characteristics on a flood hydrograph.

prediction and design analyses (Sokolov et al. 1976). However, a corresponding T_r has most often been defined as a »lag«-parameter, i.e. the time interval between the centre of gravity of the graph of effective rainfall and the hydrograph peak. Time of rise was selected instead because of its more simple and applicable definition as it does not rely on a more or less unknown storm duration or spatial variation in rainfall intensity. Its relevance has been tested among others by Gray (1961), Renard and Keppel (1966), Bell and Kar (1969) and Schultz et al. (1971).

Originally, hydrograph skewness and peakedness were also tested as well as two optimalized model parameters in Prasad's (1967) nonlinear runoff model. In most of the watersheds they were, however, not significantly related to any of the precipitation or soil moisture parameters (Ruud 1974, Tjomsland 1976). They have therefore not been further discussed.

Two parameters were found significantly representative to function as independent rainfall variables in a prediction analysis:

I_1: P_e Effective basin rainfall (mm)
I_2: I_e Storm intensity (mm/hour)

A true basin rainfall is always difficult to determine particularly in watersheds with a high relief and dissected topography. To avoid that problem, P_e has been defined as the depth of rainfall equivalent to the volume of storm runoff (Fig. 3). This is done according to a traditional hydrograph separation technique in which baseflow is separated by an extrapolation of the recession curve (Wilson 1974). P_e should therefore represent effective basin rainfall of each storm. Its definition, however, makes it difficult to perform a prediction analysis based on rainfall records alone.

Dawdy and Bergmann (1969) have shown that peak runoff in high-mountain basins in California cannot be better estimated than within ± 20-25% if the rainfall estimate is based on an averaged value according to some areal extrapolation technique. In our watersheds the rain gauge network did not permit any investigation of the areal variation. Storms with a highly diverging areal pattern should therefore be rejected, and this is done by testing the relationship between P_e, recorded rainfall P_p and an antecedent rainfall index API for each storm in every watershed;

$$P'_e = k_1 P_p + k_2 API + k_3 \qquad (2)$$

Step by step the storm with the greatest divergence between P_e and P'_e was omitted and new regression equations were established. Thereby, the total sample of storms was reduced by about 25% by demanding

$$\frac{100(P_e - P'_e)}{P_e} < 15$$

This elimination technique seems to function satisfactorily based on a case study in Stigvassåna and Raudåna (Tjomsland 1976) in which the areal variability of rainfall was examined by a network of »Pluvius« rain gauges having a density of 1.0 respectively 1.4 gauges per km^2.

Due to a more or less unknown representativeness of the rainfall records, I_e has been assumed constant during each storm. It is therefore defined as the ratio between P_e and the storm duration as actually recorded on the rain gauge. Consequently, it has not been necessary to apply storm duration as an additional input parameter. However, storms with a large variation in recorded intensity have been omitted. According to Chow (1962) and Henderson (1966) peak runoff may vary within ± 15% solely due to a non-uniform rainfall intensity. It is, however, to be expected that a corresponding error in our watersheds will be much smaller particularly in lake-fed streams.

Soil moisture are often claimed to play an important part in flood flow hydrology. This study, however, lack quantitative information on both soil water content and fluctations in groundwater level, or they have been too discontinuously recorded to be of any value in a storm runoff analysis. Therefore, the soil moisture state prior to a storm has been described by the following parameters:

I_3: API Antecedent rainfall index (mm)
I_4: q_s Specific start runoff ($1/sec/km^2$)

The API-index has been defined according to Eq. (3) (Linsley, Kohler and Paulhus 1949, 414).

$$API = K(API_{i-1} + P_{i-1}) \qquad (3)$$

P_{i-1} is recorded rainfall on day i-1, and K is a reduction constant. *API's* relevance to actually recorded soil water content was shown by neutron probe measurements in Trolldalen (ref. Tjomsland 1976) where K was found equal to 0.87 and the start-*API* to 50 mm. These values were applied on the rest of the watersheds despite the fact that they most probably have a restricted benefit anywhere else than just close to the plot where the recording took place. The basal terms are also expected not to be the same during the summer season.

Nevertheless, a parameter describing the day number of the year did not prove to add any significancy in the prediction equations.

q_s generally proved to be more significant than *API* in explaining the variance in flood-hydrograph characteristics. *API* did not either explain a significant part of the resulting restvariance, and it has therefore been excluded from the prediction equations. Start runoff q_s is thus the only soil moisture parameter applied. According to Andersen (1972) it is anyway a representative parameter for the groundwater level in the Filefjell Representative Basin. However, q_s may also be looked upon as a specific recession discharge, and as such it is related to the hydraulic transmissibility within the stream channel network as well as the swamp and lake storage. (Tjomsland, Ruud and Nordseth 1978). In this way a q_s-parameter exerts some of the same influence on a river's flood-flow behaviour as some of the watershed characteristics.

The final prediction equations are best described by the following relationships:

$$q_{max} = k_1 \, P_e^a \, I_e^b \, q_s^c \tag{4}$$

$$T_r = k_2 \, P_e^d \, I_e^e \, q_s^f \tag{5}$$

The regression coefficients are shown in Tables 1 and 2 together with separate r^2-values for each input variable, the multiple correlation coefficients of the equations (r_m), standard error (s) and number of storms (N) applied for each watershed.

All equations for q_{max} are significant at the 0.01-level of confidence. Similar results are also attained for the T_r-equations except for five watersheds. In Raudåna II the significancy level is even above 0.05. It has therefore been rejected from the procedure.

In Eq. (4) all input variables have positive signs. Accordingly, an increase in effective basin rainfall, rainfall intensity or start runoff all bring about an increase in peak runoff. Time of rise T_r does also increase with basin rainfall, while an increase in rainfall intensity has an opposite effect. In those watersheds where the start runoff contributes significantly, q_s has an negative effect too. Effective basin rainfall P_e is by far the most important variable in a prediction of q_{max}, while P_e and I_e have about the same effect in a reliable prediction of time of rise. All the results seem physically reasonable.

Table 1 – Regression coefficient in the prediction equation $q_{max} = k_1 \cdot P_e^a \cdot I_e^b \cdot q_s^c$

Watershed	Regression coefficients				100·r^2			r_m	s	N
	k_1	a	b	c	P_e	I_e	q_s			
Sula	1.22	1.159	0.141	0.075	91	5	1	0.985	0.10	9
Frostdalen	1.43	1.210	0.020	0.198	66	1	3	0.835	0.35	16
Valdresdalen	1.55	1.300	0.202	0.030	83	2	0	0.919	0.32	14
Stigvassåna I	3.38	0.938	0.268	0.127	86	3	1	0.946	0.41	12
Stigvassåna II	3.88	1.126	0.137	0.047	94	1	0	0.975	0.28	16
Stigvassåna III	4.47	0.740	0.874	0.131	92	7	0	0.995	0.18	9
Raudåna I	3.82	1.205	0.155	0.077	97	2	0	0.994	0.20	10
Raudåna II	2.03	1.058	0.489	0.358	47	20	23	0.949	0.32	9
Grosetbekken	1.12	1.115	0.296	0.199	91	3	1	0.974	0.38	13
Sagstubekken	2.25	1.230	0.217	0.160	87	1	1	0.946	0.34	21
Trolldalen	2.61	0.964	0.361	0.450	56	2	18	0.870	0.38	17
Nordødegård	11.05	0.795	0.126	0.087	74	8	4	0.922	0.22	20
Gramstad	7.53	1.118	0.423	0.171	85	4	3	0.964	0.23	26
Rovik	2.57	1.119	0.508	0.239	77	7	5	0.946	0.34	18

Table 2 – Regression coefficient in the prediction equation $T_r = k_2 \cdot P_e^d \cdot I_e^e \cdot q_s^f$

Watershed	Regression coefficients				100·r^2			r_m	s	N
	k_2	d	e	f	P_e	I_e	q_s			
Sula	8.06	0.437	–0.352	0.014	8	50	1	0.765	0.17	9
Frostdalen	6.90	0.592	–0.232	–0.251	25	26	9	0.775	0.28	16
Valdresdalen	4.33	0.647	–0.533	–0.112	67	30	1	0.991	0.07	14
Stigvassåna I	3.05	0.744	–0.582	0.017	43	26	0	0.835	0.30	12
Stigvassåna II	2.76	0.755	–0.696	0.004	30	50	0	0.890	0.33	16
Stigvassåna III	2.79	1.025	–0.635	–0.321	15	65	10	0.945	0.19	9
Raudåna I	13.99	0.271	–0.233	–0.166	0	74	15	0.945	0.15	10
Raudåna II	–	–	–	–	–	–	–	–	–	–
Grosetbekken	4.38	0.488	–0.449	0.071	45	39	1	0.922	0.19	13
Sagstubekken	4.24	0.537	–0.449	–0.056	17	60	1	0.855	0.17	21
Trolldalen	3.95	0.399	–0.830	–0.081	10	66	1	0.874	0.33	17
Nordødegård	2.59	0.579	–0.150	–0.062	49	15	4	0.825	0.26	20
Gramstad	2.17	0.620	–0.544	–0.060	42	23	1	0.811	0.28	26
Rovik	2.39	0.649	–0.513	–0.319	42	28	6	0.869	0.28	18

The Influence of the Watershed

One of the most severe criticisms raised against correlation analyses in hydrology (Amorocho and Hart 1964) is that one is never sure to find any true functional relationship at all. By inserting e.g. mutually dependent variables in a multivariate analysis we may have to do with both logical and illogical correlations. Therefore subjective judgement often has to be exercised to search for a true cause-and-effect relationship.

The mere selection of watershed characteristics is probably the most difficult task of all the sub-routines in the entire procedure (Nordseth 1978). The true fact is that one has to foresee the result before the procedure has even started! A huge sample of quantitative characteristics is already available in hydrological and geomorphological literature. Most of them ought perhaps to be included in an approach like this one as each characteristic may in fact represent a functional property in the hydrological response of a watershed whether its significancy is based on intuition, a qualitative experience or it has been found relevant in previous investigations. Nevertheless, there does not yet exist any statistical correlation technique that gives any necessary quarantee to find the most functional solution. A qualified judgement is still necessary – and is probably more important than ever.

It is difficult to see any safe way out. We have tried, however, to meet some of the objections, even though it is not a particular effective way of doing it, by including as many groups of watershed characteristics as possible. Further, only parameters have been applied that are defined according to functional or meaningfull properties of the basins, i.e. properties that make sense in their relation to the flood-flow response of a watershed.

The influence of the watershed on the flood-flow behaviour is approached by predicting q_{max} and T_r in each catchment for all combinations of P_e = 5, 10, 15, 20 and 25 mm, I_e = 1, 3 and 5 mm/hour and q_s = 10, 35 and 60 l/sec km². For each set of input variables the corresponding set of flood hydrograph characteristics is then related to a total sample of 28 different watershed characteristics. (Their definitions and values for each catchment are presented in a previous paper (Tjomsland, Ruud and Nordseth 1978, App.I and II). Both exponential and linear relationships were tested, and the best fit was attained by a linear equation like Eq. (6) and (7).

$$q_{max} = -\underset{25-50}{b_1\, a_{se}} + \underset{20-30}{b_2\, a_f} + \underset{2-30}{b_3\, S_{60}} \mp \underset{1-10}{b_4\, A} \tag{6}$$

$$T_r = -\underset{30-70}{c_1\, a_{se}} - \underset{5-25}{c_2\, D} \tag{7}$$

a_{se} is weighted percentual lake area (%), a_f area of bare rocks (%), S_{60} slope (m/km) of the central segment of the main stream, A basin area (km^2) and D drainage density (km^{-1}). Each of the parameters' significancy in explaning the variance of q_{max} and T_r is shown by their coefficients of determination ($100r$). Eq. (6) is significant at the 0.01-level of confidence as far as 90% of the equation is concerned. A corresponding share for Eq. (7) is 75%, and only one equation shows a level of confidence above 0.05.

Interpretation and Discussion

A large number of flood-flow design or prediction analyses pay attention to the influence of basin size or main stream length in affecting the flood-flow behaviour of a river. Eqs. (6) and (7) reveal that this is not the result of this investigation. Storage capacities of each watershed seem far more important. This is expressed through the significancy of the percentual lake area and the position of the lakes within the drainage system (a_{se}). Such a result is in agreement with a previous flood-flow analysis of Norwegian rivers (Søgnen 1942) although their quantitative role more seldomly has been properly appraised.

It may also be possible that the significancy of basin area is »lost« due to the intercorrelation structure of different groups of watershed characteristics. Such a system does exist in every watershed no matter how homogeneuous they are. One ought to remember that there is in fact no contradiction between results which prove the significancy of one parameter instead of another if these watershed characteristics are highly intercorrelated. In studies like this one, however, not all the interconnections have a functional meaning (Nordseth 1978). Some of them may turn out to be statistically false partly because their high degree of correlation only relies on a functional relationship to another characteristic which at worst have not even been included in the procedure. By detecting the true relationship, the original correlation may disappear or even change sign. Another »false« intercorrelation may appear due to a restricted sample of watersheds which by accident gives a high correlation between watershed characteristics, i.e. correlations that does not make sense at all.

In our sample of 14 watersheds all parameters describing basin size and lake area are, in fact, so much interrelated that they have to be grouped together (Fig. 4) despite the fact that some of the interconnections are physically unreasonable. For instance, weighted lake area a_{se} and basin area A are correlated to each other with an r-value as high as + 0.78. This makes it difficult to evaluate the separate influence of each of them. In order to investigate A's real effect, 8 watersheds with none or an only insignificant lake storage were selected from the original sample, and the whole procedure was repeated. The following equation resulted:

$$q_{max} = \pm \underset{0-10}{b_1' a_{se}} + \underset{60-80}{b_2' a_f} + \underset{5-20}{b_3' S_{60}} - \underset{0-10}{b_4' A} \qquad (8)$$

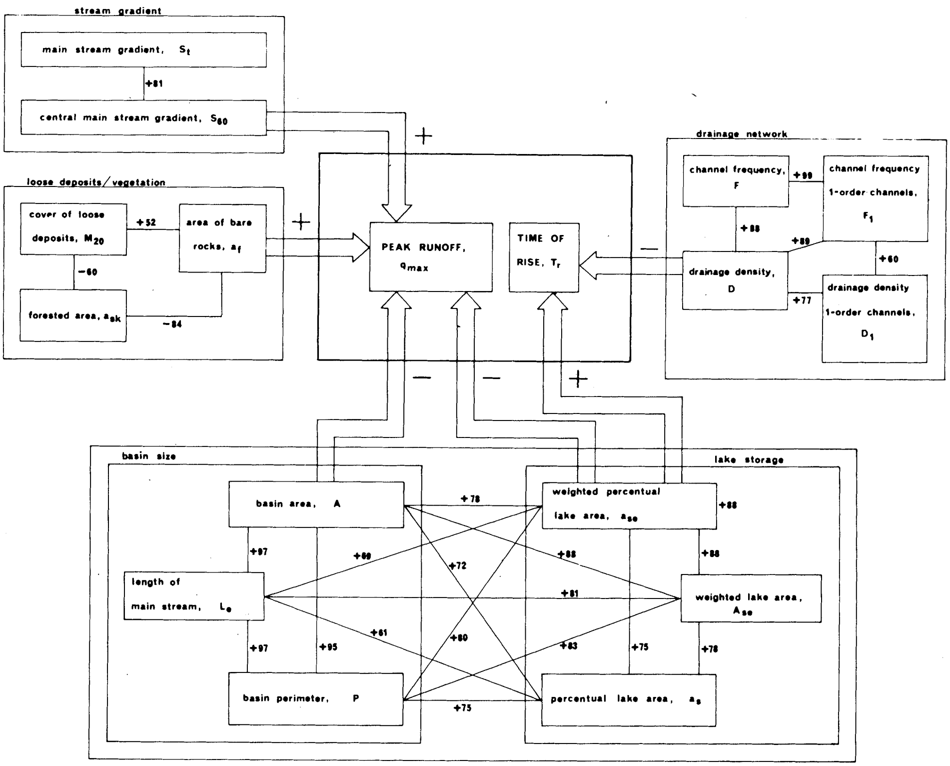


Fig. 4. The correlation structure (100·r) between watershed characteristics and their relevance to floodflow hydrology.

The result shows that the influence of A, or some other characteristic highly correlated to A, has not been increased. It has, in fact, remained the same as before, and the slightly modulating effect of the basin area on peak runoff in small watersheds has apparently been confirmed.

Another important group of watershed characteristics comprises the properties describing vegetation cover of the basin and the cover of loose deposits. That concerns particularly the percentual area of bare rocks a_f which shows a high positive contribution to the variance in q_{max} especially in lake-free rivers. That seems physically reasonable due to very low storage capacity of most Norwegian bedrock surfaces. On the other hand, a small area of bare rocks is almost identical to a large forested area which by experience is associated with a thicker cover of loose deposits. A dense tree-stand decreases the runoff intensity due to interception particularly during the first sequence of a storm, and a cover of well-textured forest soil encourages infiltration and interflow. Forest thereby generally retards the runoff processes.

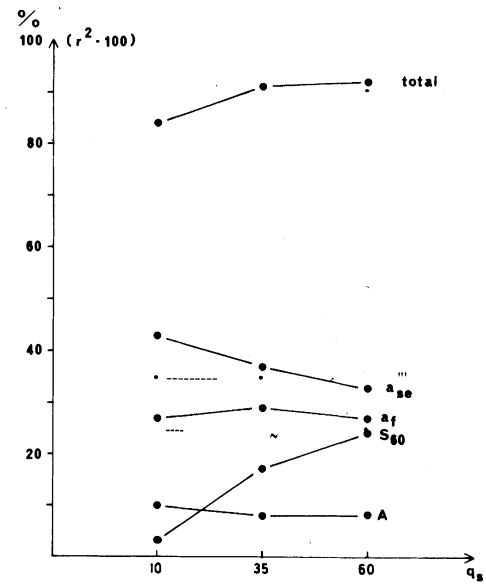


Fig. 5. Change in the watershed characteristics' contribution to peak runoff q_{max} as a function of start runoff q_s while basin rainfall P_e and rainfall intensity I_e are held constant like 15 mm respectively 3 mm/hour.

The main stream gradient S_{60} does also contribute positively to q_{max}. Its quantitative influence relies, however, on the state of a watershed described by its antecedent soil moisture prior to a storm (Fig. 5). S_{60}has an increasing positive effect on peak runoff the more q_s increases. This may be explained by stream channel roughness which exerts its greatest influence on stream velocity during low-water or small storm runoff. At a larger »base«-flow, the relative roughness decreases, and the stream gradient becomes more and more important in determining the transit-time of water within the stream-channel network.

A somewhat similar result has also been found concerning the influence exerted by drainage density D and channel frequency F. Although drainage density has an effect on time of rise, it has an insignificant influence on q_{max}, while it plays an essential part in explaing the differences in the low-water behaviour of the basins (Tjomsland, Ruud and Nordseth 1978). Drainage density D is a parameter for the dissection or texture of a basin. A low value means a long distance of travel across and within undissected slopes before the runoff reaches the much more effectively drained stream channels. Its negative influence on time of rise T_r seems therefore reasonable.

The reason for its insignificant influence on q_{max} is, however, not that obvious. A simplified description of a hydrological system may imply a division into two subsystems, i.e. a slope system dominated by slow runoff processes such as infiltration, percolation, interflow and groundwater seepage, and second the rapid transmission through the open channel system. Whereas the slope subsystem seems to be of prime interest during low-water, the drainage network not only emerges backwards on a state of high soil moisture, it also reactivates streamlets that otherwise are dried up. According to the conception of a dynamic response area (Weyman 1975) a gradually increasing part of the lower hillslopes adjacent to a channel also contribute in runoff response nearly as quick as the channel system itself.

Drainage density was, in fact, shown to exert its greatest effect on the low-water behaviour of a river during a very low recession runoff (Tjomsland, Ruud and Nordseth 1978), and the effect decreases the more the antecedent moisture of the basin increases. In predicting runoff characteristics ranging from low-water to floodflow the connection of these results implies that drainage density gradually looses its significancy and is replaced by properties describing the transmissibility of the stream channel network, i.e. channel roughness and finally main stream gradient. It is obvious that if one is able to solve all the interconnections between the structure and function of a basin, its hydrological system and different input conditions, it should also be possible to make the model equations far more functional.

It has not been the purpose of this work to develop any design or prediction analysis for direct application on ungauged watersheds or future floods. For that purpose it would have been more suitable to apply runoff characteristics with identical frequencies. A peak discharge with a fixed recurrence interval does, however, depend as well on basin characteristics as on local climatic conditions. A regression equation based on that premise has therefore also to include a set of significant climatic parameters, and it becomes far more difficult to isolate the influence of the watershed because of the necessity of first having tested the even more composite interrelationships between climate, runoff, and basin physiography. The proposed procedure has the advantage of being applicable without concern to local climate. It gives an opportunity to establish functional relationships between runoff response and basin structure, and to understand the hydrological response function of a watershed.

The »laboratory« power of the procedure to show an increasing, decreasing, or stable influence of each watershed component on one and the same runoff characteristic by changing input or the state of soil moisture of the watershed, is important in runoff analyses. The relevance of one particular watershed component may change, and even the whole sample of relevant basin characteristics may be re-arranged or some parameters replaced by other. Such an acknowledgement is essential in flood-flow analyses dealing with runoff magnitudes of different return periods. The influence of the watershed on processes that generate for instance an average flood runoff is to all appearance not the same as the influence exerted on a 50-year or 200-year flood.

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