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Hydrologic Regions in the Nordic Countries

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A reviewed report of a Nordic working group on Hydrologic regions is presented in this paper. The emphasis is mainly put on runoff regime patterns in the Nordic countries. Maps over runoff regimes, annual runoff and variations coefficient of runoff are presented. For Finland a more detailed regime map is given also.

Introduction

There exist large variations in the hydrological cycle for the world as a whole. Hydrological conditions can vary much even within the borders of a separate country. It should be one of the tasks for hydrologists to describe hydrological systems generally with respect to the basic relationships between individual components of the hydrological cycle. For this purpose classification and localization of the main variation pattern in the hydrological cycle are needed, i. e. distinguishing between hydrological regions.

Hydrological Regionalization

Some examples of hydrological regionalization in literature should be mentioned. Kuzin (1960) classifies the USSR with respect to the hydrological data observed in a great number of drainage basins and to climatic and topographical information, which defines hydrological regions. Toebes and Palmer (1969) review hydrological regionalization in New Zealand, based on information about precipitation, vegetation, topography, soiltypes and geology. Juncer (1971) shows an example of hydrological regionalization for the whole world. Frankdieter Grimm (1968) divided Europe into a large number of regions following an elaborate system of regimes and subregimes (totally 55). The regimes are defined by main cause (rain/snow) and season of high water, sub-regimes are based on annual height of runoff, and season and rate of low flow.

Hydrological regionalization in the Nordic countries. A number of authors have suggested hydrological regionalization of the Nordic countries. Kupriyanov (1960) performed a schematic division of the Scandinavian peninsula based upon how the rivers mainly are fed, e.g. from rain, snowmelt, ground water. Melin (1970) divides the Nordic countries on the basis of regime types, which follow the pattern by Pardé (1955). Kupriyanov's and Melin's division on the regime basis gives a very coarse division of the hydrological cycle's variation of the Nordic countries.

Melin (1970) divided the Nordic countries into hydrological regions by analysing trends in 30-year series of river runoff, runoff volumes and geographical situation. Nine regions have thus been obtained in the Nordic countries. Melin strictly follows the principle that region boundaries should not cut rivers. As a result some of Melin's regions include rivers with significantly different seasonal distribution of high and low water periods and with extremely varying mean runoff. Tollan (1975) uses a more detailed regime criterion, based on monthly runoff, and also information about relief, soil type and vegetation. Thus he gets a more detailed regionalization of the Nordic countries. These regions, unlike those given by Melin, are suitable for determination of hydrological representativity.

Physiographic Regionalization

Hydrological regionalization should be mainly based on physiographic regionalization (Toebes and Palmer 1969, Tollan 1975). Physiographic conditions are essential for formation of water balance elements, and they are mapped in greater detail than the hydrological ones. Comprehensive studies of the relationship between physiography and hydrology are necessary if one wants to use physiographic information in hydrology. Hydrological regionalization is a way to do this.

Physiographic conditions should be divided into types and classes to obtain the necessary simple and unified description of drainage basins. National atlases more and more often contain physiographic regions. These methods were used very early in Finland (Granö 1928 and 1952). But it is only now that physiographic regionalization has been carried out for all the Nordic countries after a decision made by the Nordic Ministers' Convent in 1974. A working group was established which made a physiographic regionalization of the Nordic countries (Physiographic regionalization of the Nordic countries 1977). The main aim of this regionalization is to give a unified basis for selection of natural conservation areas in the Nordic countries. The regionalization also facilitates estimation of the representativity of various regions. Vegetation zones have been the main regionalization criterion. Other factors were used to modify the regionalization especially in coastal regions, in fiord regions of western and northern Norway, and in Denmark. 60 regions have been distinguished (Fig. 1).

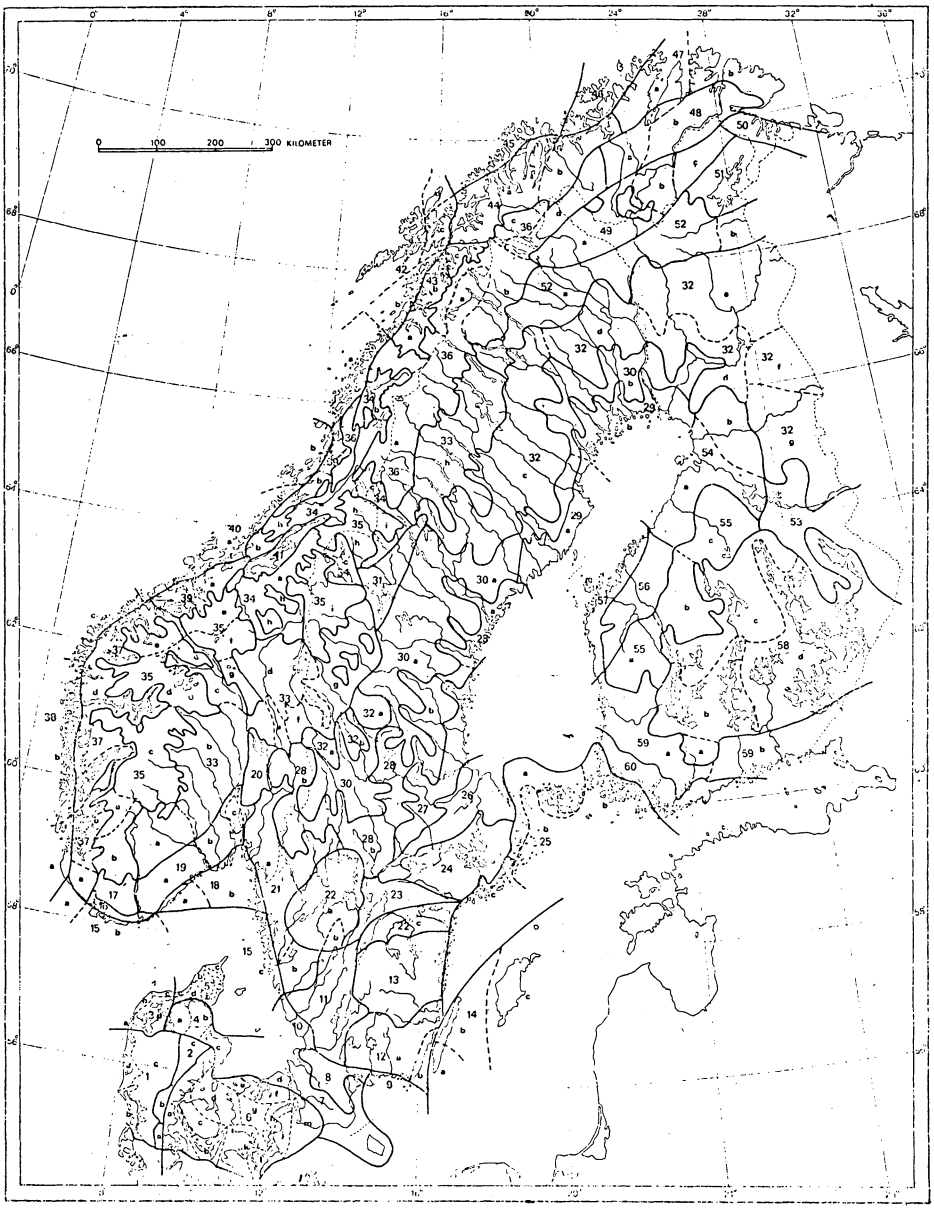

Fig. 1. Physiographic regions of the Nordic countries (from Naturgeografisk regionindelning av Norden NU B 1977:34 Stockholm, 1977).

Classification and Regionalization

Geographers have used and developed techniques for regionalization and grouping of geographical data for a long time. Grigg (1965, 1967) gives three purposes for the application of such techniques:

1) to give names to things
2) to enable information transfer
3) to enable development of generalizations

Grigg also stresses the importance of clearly formulating the purpose of grouping and regionalization, and excludes classifications on general principles.

If the goals for grouping of a population or set of units are clearly formulated, then grouping and regionalization are subject to hypothesis-test methods. The assumption is that a population consists of units with common features of certain characteristics of these units. On the basis of these common features, groups can be formed giving a general picture of spatial distribution of the units.

Hypotheses that we can test are:

1) There are distinctly defined groups in the population.
2) These groups show similarity in respect to some dependent variables.

In a discussion of the hydrological representativity, Gottschalk and Krasovskaia (1975) give these alternative definitions:

I. – a hydrologic parameter value, obtained at one point, can be assumed to be valid for a larger region. This can never be fulfilled exactly, because we always have a lack of information and therefore are forced to make modifications, that with a certain accuracy makes the obtained value valid for the region. The possible minimum error in this statement, is that of pure randomness.

II. – a certain set of physiographic characteristics is represented. With a proper choice of characteristics, representativity in the first sense can also be reached. Further research is, however, usually needed to clarify the relation between hydrologic parameters and physiographic factors.

III. – the information content, reached at one point or for one watershed, can give fundamental knowledge of how a larger area reacts hydrologically. We condense this information in a mathematical model. It is obvious that a model can be more or less complex and thereby also represents a smaller or larger area.

Definitions II and III can be compared to geographically homogeneous regions and model homogeneous regions as suggested by Solomon (1976).

Let us discuss the two hypotheses 1) and 2) on the basis of these three definitions.

In the first definition (Def. I) we study one parameter and it is meaningless to speak about a dependent variable.

A hydrological parameter varies over an area due to its dependence on physiography. Variability depending on uncertainty in parameter determination from observation should be added to it. We can say that a hydrologic parameter has a uniform distribution over an area when its variability caused by a physiographic variability, can be neglected.

The hypotheses that there are significant differences between different regions can be tested statistically.

In the second definition (Def. II) the situation can be compared to that of stratified sampling. We perform stratification into distinctly defined groups with respect to physiography. Our dependent variable is a certain hydrologic parameter.

The hypotheses that we have put forward mean that even for the hydrologic parameter there exist distinctly defined groups which coincide with those for physiography, and that parameters have more resemblance within these groups than among them.

One of the aims of hydrological studies in representative and experimental basins in the Nordic countries is to investigate the dependence of hydrology on physiography. We can test this dependence under the condition that experimental and representative basins are chosen in such a way that there is at least one basin in each physiographic region. Regionalization in this case will also be a method for network planning.

According to the third definition the meaning of the hypotheses is that a hydrological model can be developed for an area and that this model can then be used for the whole region. Application can have two different aspects.

1) A model structure is common for the whole region, but the model parameters should be determined in each case, e.g. conceptual runoff models;
2) A model structure and model parameters are common for the whole region, e.g. regression models for determination of runoff parameters.

For the latter type of models a region can be defined so that an interpolation error within it has a uniform distribution (Salomon 1976).

We shall here modify the first definition of representativity by stating that a hydrological relationship for a region is valid within certain accuracy limits, with an error which has a uniform distribution.

On the basis of present knowledge about relationships between hydrology and physiography it is difficult to make conclusions about the way physiographically homogeneous and model homogeneous regions are related to each other.

The aim of investigation of hydrological regions is to find principles for regionalization which makes physiographic regions coincide with model homogeneous region for various types of hydrological models.

Physiographic Factors

Using modern system analysis terminology, we can regard a catchment as a hydrologic system, where climatological input variables are influenced by drainage basin physiography (topography, geology, vegetation). Systems response in the form of runoff depends on the physiographic factors and the input climatological variables. Regionalization can be performed for each of these three variables, climate, physiography and runoff.

We have already stressed the necessity of a defined goal for regionalization. From a hydrological point of view we can see two important goals. The first one is the planning of observation networks in connection with representative and experimental basins. One of the purposes for use of representative and experimental basins in the Nordic countries is »to identify the influence of landforms, soil types, vegetation and landuse on hydrological and hydrochemical elements«. This corresponds to our hypothesis in the previous part, when we regionalize with respect to climate and physiography, runoff being a dependent variable. Another important purpose is to distinguish a region, where a certain type of model can be applied (model homogeneous region). This cannot be done without studying how the models, and particularly model errors, behave over a large area.

More intuitively, we can divide a region on the basis of the runoff regimes, taking into account the processes which dominate runoff formation. However, this kind of division cannot be very detailed. Climatological and physiographic factors which are believed to be essential for the hydrological regime are presented below.

Climate

The climate of a region is the mean weather for a long period of time. Weather could be described by a large number of elements, such as temperature, humidity, cloudiness, sunshine, rain, wind etc. Each of these elements can be characterized by figures, but it is very difficult to combine these figures in order to describe weather or climate. Even if we concentrate on the most important elements: temperature and precipitation, it is impossible to combine data to a general evaluation of climate without defining the goal of such an evaluation. Köppen's classification system for climate (see for example, Petterssen 1958) is widely used for classification of climates for the whole world.

From a hydrological point of view, temperature and precipitation as well as radiation, air humidity and wind which influence on evaporation are the most important climatic factors.

Physiography

Vegetation, soil type and topography are physiographic factors which have a significant influence on the formation of the waterbalance elements.

The influence from these factors is difficult to separate from climatic influence.

For example, vegetation is closely connected to climate, which means, that regionalization with respect to climate can very well coincide with one for vegetation. In hydrological studies vegetation is often characterized only by the forest covered part of the area.

Soil type and geology are in general important for runoff, water permeability and water storage capacity.

Quantifying these characteristics for hydrological purposes can be complicated. A simple division can be as follows: bare rocks, soil with low permeability, soil with high permeability.

Topography can be characterized in many ways. Relative relief (i. e. slope height) is important for precipitation formation and thus influences the runoff process. Other physiographic factors, such as amount and area of lakes and swamps, as well as drainage basin morphometry and hydraulic geometry – are factors which also have a great influence upon the hydrological relationships. The influence of lakes is often taken into account in hydrologic investigations in the Nordic countries. The role of other factors is unsufficiently studied, however.

Glaciers are locally of great importance for runoff in parts of Norway and Northern Sweden.

Regime

The runoff regime of a river can be defined as time variation in its flow. This variation is governed by climate and physiography, as discussed above.

The regime is usually classified on the basis of seasonal variations, i. e. when periods of low and high flows occur. Such classification is further based on the main sources of recharge. Lvovich (1971) distinguishes rain, snow, glacier and groundwater recharge sources, while e.g. Pardé (1955) distinguishes glacial regime, oceanic and tropic rain regime and nival regime. Tollan (1975) presents a simple regime classification system only based on low water and high water periods.

Regionalization of Regime

Tollan's (1975) classification has been chosen for regionalization in respect to regime. It takes into account only mean seasonal variations and is simple to apply. It is believed that the regime classification satisfies the purpose stated above. In order to illustrate runoff variations, the regional regime figure has been supplemented by a combined map of variation coefficients of annual runoff. A map of mean annual runoff in Norden is reproduced as Fig. 2.

Classification criteria. The basis for the regionalization is a determination of boundaries between areas with the following characteristics.

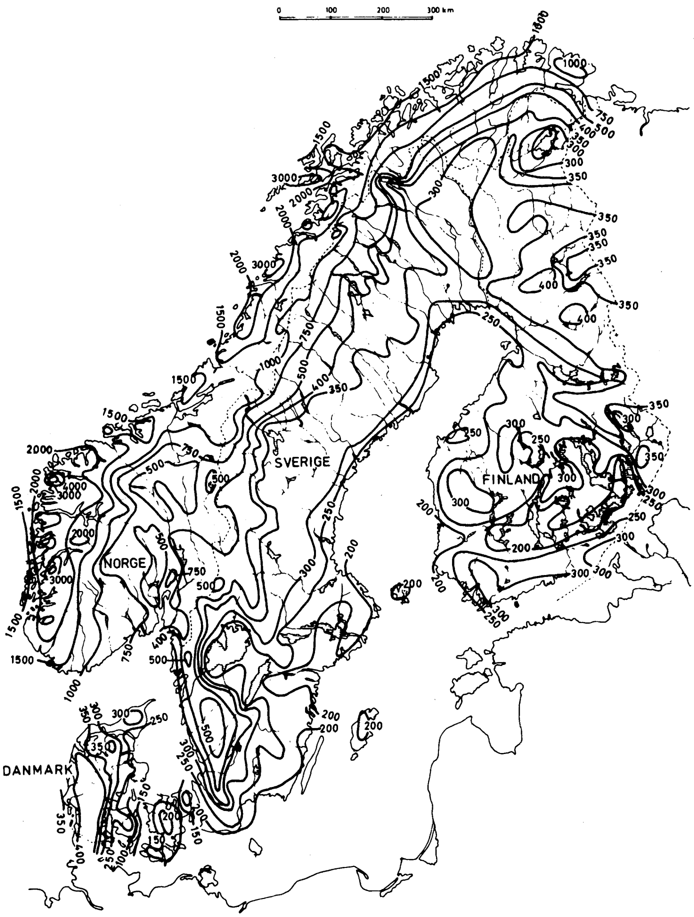

Fig. 2. Map of annual runoff in the Nordic countries.

High water

H_1: Dominant snowmelt high water. An area is classified as H_1 if the three months with the highest average runoff belong to spring or early summer (typically May-July).

H_2: Transition to secondary rain high water. An area is classified as H_2 when the second highest or third highest monthly runoff takes place in autumn (typically: October, November, on the Scandinavian peninsula – early in the west and late in the east and vice versa in Finland).

H_3: Dominant rain highwater. An area is classified as H_3 when the highest monthly runoff takes place in autumn or early winter (typically November-December).

Low water

L_1: Dominant low water flow in winter, caused by snow accumulation. An area is classified as L_1 when the two months with the lowest runoff both belong to winter or early spring (typically: February-March).

L_2: Transition zone, when the two months with the lowest runoff do not belong to the same time of the year (typically: February and July).

L_3: Dominant summer low water caused by high evapotranspiration and/or low precipitation when the two months with the lowest runoff belong to summer or early autumn (typically: June-August).

Data Basis

Data for production of maps of regional regimes and annual runoff variability were taken from stations selected to have at least 30-years observation series, catchment areas less than 2,000 km^2 and low lake percentage. The following number of stations were used: Denmark 15, Finland 50, Norway 50 and Sweden 50. In regions with few stations, data series less than 30 years had to be used.

Map of Runoff Regions in the Nordic Countries

Five main combinations of regimes can be distinguished in the Nordic countries (see Fig. 3):

H_1 L_1 Inner and northeast parts of Norway, Sweden and Finland.

H_2 L_1 Fiord area along Norway's western coast, forest and costal area to the west of the Gulf of Bothnia, Finland except southwestern parts and northern Lapland.

H_2 L_2' (H_3 L_2) Inlands in Østlandet (Norway), Vermland, Dalecarlia and Gestrikland (Sweden) and the western and southern coast of Finland.

H_2 L_3 Parts of Møre-Trøndelag (Norway), southeastern Sweden, southwestern coast and the archipelago of Finland.

H_3 L_3 Frontier coastal regions of Norway, southwestern Sweden and Denmark.

Special regime types such as glacial (extreme H_1 L_1) and the lindá-regime in strongly permeable soils in Iceland might be added to the ones mentioned.

At the Norwegian west coast there is a rapid, but gradual change of the regime when one moves inland (eastwards). At the very coast there is H_3 L_3 and further inland a transition zone of regime types H_2 L_3, H_2 L_2 and H_2 L_1 to H_1 L_1 in the mountainous regions. The transition zone is, however, so narrow that one cannot distinguish all regime types on the basis of available observation stations. Only those regimes that have been verified have been marked on the regime map.

Areas with glacial influence are in reality a variant of H_1 L_1, where maximal water flow can be observed as late as in July-August. Glacial areas are not marked especially on the regime map. However, all of them are situated within the H_1 L_1-area.

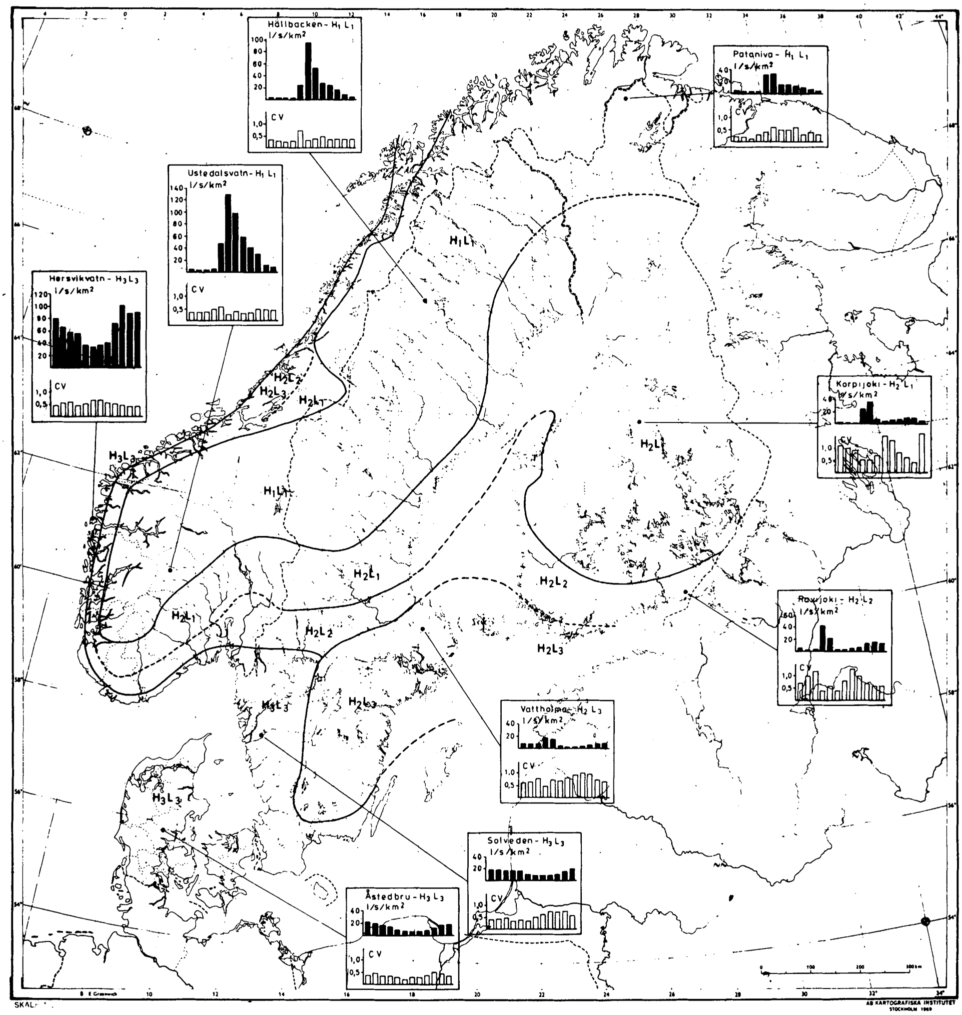

Fig. 3. Map op runoff regions in the Nordic countries.

The following names have been suggested for the five main regime types.

H_1 L_1	mountain regime	H_2 L_3	Baltic regime
H_2 L_1	inland regime	H_3 L_3	Atlantic regime
H_2 L_2, H_3 L_2	transition regime		

These names have been chosen in order to relate region types to geographical terms and names which are easy to remember. This does not imply a strict boundary – setting in the distribution of regions discussed.

Maps of Annual Runoff, Mean and Variation Coefficients

There are significant differences in the specific annual runoff and runoff variability in the Nordic countries. This could be utilized for more precise classification than the one made only on the basis of regime, as above.

A map of specific runoff for the Nordic countries was compiled by A. Forsman (1976) in cooperation with the central Nordic hydrological institutes (Fig. 2).

Runoff variability is shown by means of the variation coefficient $Cv = s/Q$, where Q is the average annual runoff and s the standard deviation for annual runoff. The coefficient of variation has been used for characterization of runoff condition in the Nordic countries by Kupriyanov 1960, and Tollan 1972. Fig. 4 shows the variation coefficient, based on the same stations as the regime map.

Variation in Cv can be interpreted from runoff regimes and climate. Typically the variability is low (0.10-0.25) in humid marine parts of the Nordic countries. High variability (0.35-0.45) characterizes areas with a more continental climate, usually with low precipitation and high evapotranspiration. A map of Cv cannot be detailed as this parameter does not have a smooth distribution over a large area (Gottschalk and Krasovskaia 1975).

Possibilities of Detailing

There exist still more possibilities for detailing of hydrological regions when taking into account physiography in addition to regime, average annual runoff values and variation coefficients. This has not been done for all the Nordic countries. R. Solantie (1975) has made a detailed regional map (Fig. 5) for Finland showing 6 sub-regions by taking into account also variations in vegetation. A suggestion for their names is:

H_2 L_1: Inland lake region
East-Bothnian region
Maanselkä region
North-Bothnian region
H_1 L_1: Lapland region
Kilpisjärvi region

Even if the whole of Denmark is obviously situated within region H_3 L_3, there are variations in annual runoff within the country. Both the annual mean and the ratio of highest to lowest months vary significantly due to variations in precipitation and geology.

The occurrence of high water in winter and low water in summer is, however, a common feature which clearly places Denmark in region H_3 L_3, and a description of variation of runoff characteristics within the country is beyond the scope of the present study.

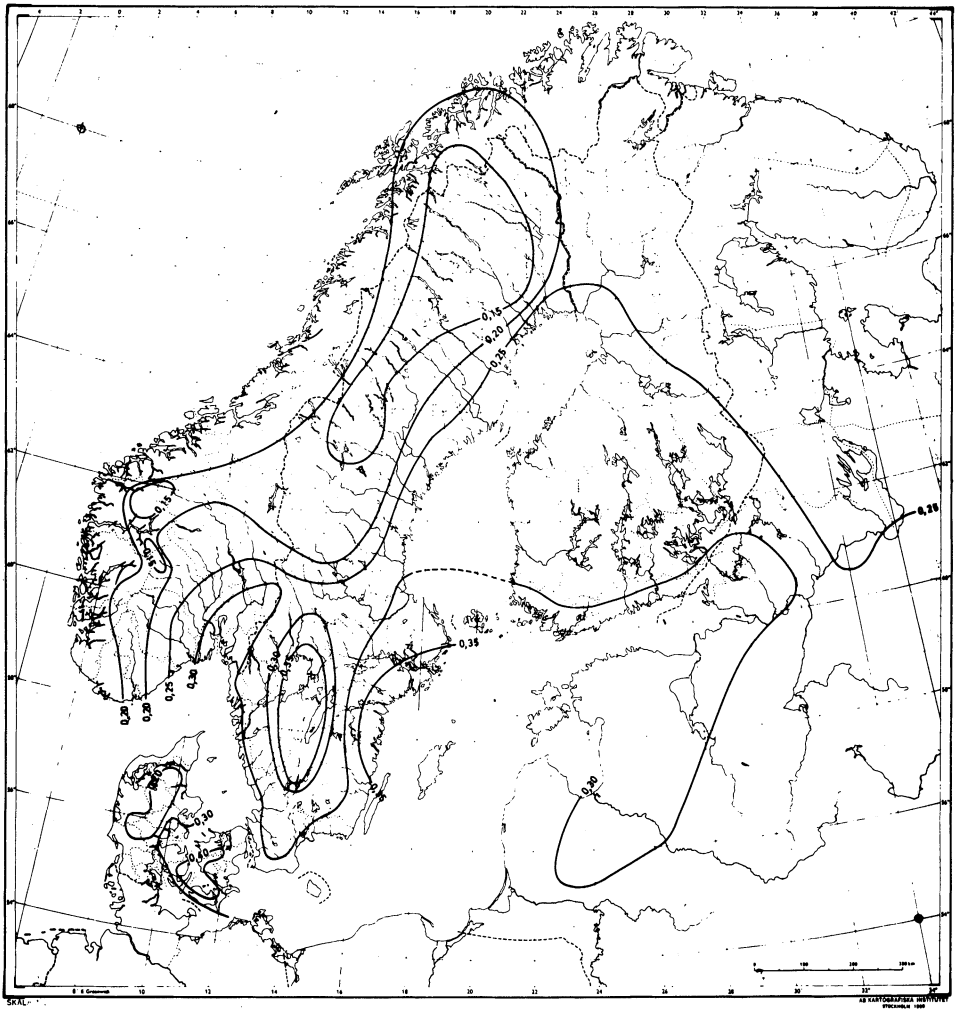

Fig. 4. Map of variation coefficient of annual runoff in the Nordic countries.

Conclusions

It is believed that the simple hydrological regionalization presented in this paper could be useful in practical hydrology, e.g. within network planning and generalization of results from representative and experimental basins. It is not intended to be a final definition of hydrological regions in the Nordic hydrology. Important tasks of defining homogeneous hydrological regions are still unsolved. New methods should be sought for more objective methods of classification and regionalization.

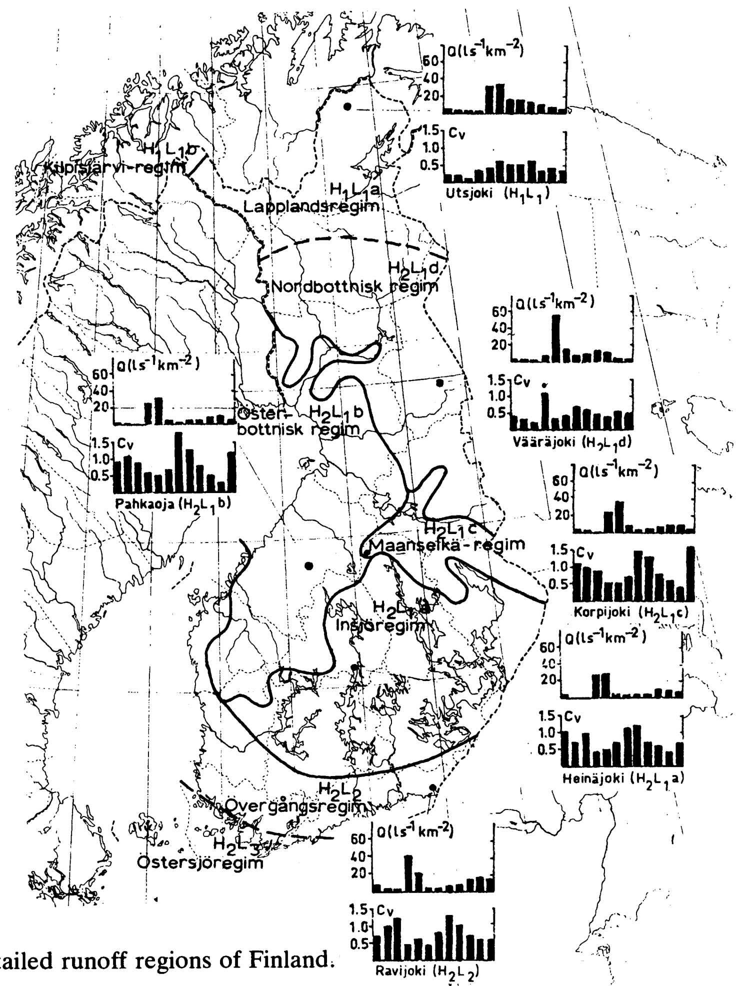

Fig. 5. Detailed runoff regions of Finland.

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