SYNTHESIS, PROCESSING AND DISPLAY OF COMPREHENSIVE HYDROLOGIC INFORMATION.

by

Lars Gottschalk and
Irina Krasovskaia

SMHI Rapporter
HYDROLOGI OCH OCEANOGRAFI

Nr RHO 22

SMHI

Sveriges meteorologiska och hydrologiska institut

SYNTHESIS, PROCESSING AND DISPLAY OF COMPREHENSIVE HYDROLOGIC INFORMATION.

by

Lars Gottschalk and
Irina Krasovskaia

SMHI Rapporter
HYDROLOGI OCH OCEANOGRAFI

Nr RHO 22

ISSN 0347 - 7827

SVERIGES METEOROLOGISKA OCH HYDROLOGISKA INSTITUT
Norrköping 1980

LIST OF CONTENTS

Foreword

Attitude to the water problem is changing. A number of products, which hydrologists found to be suitable in connection with water resources planning for many years, have exhausted their usefulness, others have come to replace them. We shall show our opinion about what hydrological information can be given in future, information which to a high degree is based on hydrological models of different types. This will give a back-ground to the application of the methodology presented in this report.

Need of hydrological information

The point of departure for all types of hydrological information are hydrological, climatological and ground water observation networks.

Processing and presentation of the information we get from these networks should be adapted to the way this information is going to be used.

A suitable division can be:

A. Comprehensive hydrological information, covering the whole country

B. Hydrological information at a regional level

C. Detailed hydrological information

The aim with the comprehensive information is first of all to identify the areas with similar conditions, both favourable and unfavourable. Here it is important that the presentation should be done in such a way that the comprehensive information easily can be combined with other general information.

Suitable computational element is the one applied by the FRP (Physical National Planning) data bank, - the economic map sheet (squares 5x5 km). The following hydrological and climatological parameters are necessary for a comprehensive evaluation of water resources supply and management:

1) precipitation
2) potential evaporation
3) calculated actual evaporation
4) runoff formation
5) ground water formation
6) flood risks

Any other type of information is obtained through multiprogramming with other data registers.

The management aspect is an important one at a regional level. The point is to suitably utilize and maintain the water resources within a region. Information should be related to actual points on rivers and lakes.

The element forming the basis of calculations, should necessarily be a catchment and not a more general unit, e g 5x5 km squares (the economic map) or administrative units. A suitable size for a catchment as a computational element is 50-200 km^2. Information necessary for water management planning at a regional level is the magnitude of different water balance elements; runoff, soil and ground water storage, precipitation and evaporation for each unit.

Detailed hydrological information, finally, is for production-preparing planning as a rule directly connected with a specific problem of design. The information that is necessary here is of different types: complete historic observation series of runoff, frequency of extreme events, particulars of precipitation, evaporation etc.

When discussing the need of hydrological information, we should further take into consideration two situations: an isolated planning situation and an operative situation. In the latter case quick reporting is desired partly in order to be able to describe the current conditions and also to give the basis for a forecast. Systems for quick reporting have been implemented for the weather service. There is a need of similar operative systems for hydrological information, both for information at a regional level and as detailed information for special water objectives. In some regions this demand appears only under critical conditions (flooding, drought). In others, on the contrary, with a more complex water utilization there can be a permanent need to know the current situation within a region together with a complementary forecast.

The planning situation also sets special requirements for information. In order to plan water management one should at the same time know water supply in a number of points within a region. In order to treat extreme situations in a correct way it is further necessary to work with complete observed or calculated runoff series.

Hydrologic observation network

SMHI's hydrological discharge observation network to-day comprises 328 stations, which corresponds to a station density of 1 station per 1400 km^2. The level of the hydrological bureau's ambitions is to increase the number to 640 (1 station per 700 km^2).

SMHI's climatological observation network gives important supplementary information for evaluation of water balance elements. This network was built up first of all for weather forecast purposes. In order to answer hydrological needs a denser network is required in space while time interval period as a rule can be shorted.

Hydrological models

Every formula or relationship, simple or complicated, which describes hydrological phenomena can be called a hydrological model.

There is no universal hydrological model which can be used in all situations. A strictly adjusted model is required for each field of application. Hydrological models can be built according to two different principles. The first is to apply only a statistical methodology to a given observation material. The other is to construct a model on the basis of physical relations. The best results are obtained as a rule by combination of these two principles.

In the comprehensive mapping the hydrological model's function is first of all to transmit information from observation points to the computational element (5x5 km squares). Hydrological and climatological phenomena are dependent on natural geographical conditions and these must be the point of departure for the model in this case. Statistical methods (regression analyses) are used in order to select the natural geographical conditions that have a significant effect. A water balance equation in its simplest form is used in order to give consistency among the various water balance elements.

The model assumes that the natural geographical conditions are known and that calculations can be done automatically by a computer. The National Land Survey of Sweden has today a certain digital map information, which we utilized. In future such information can be expected to increase in volume.

In order to give a basis for water management within a region a hydrological model should on one hand deliver information from the observation network and on the other give a possibility of estimation of the consequences (from the water balance point of view) of alternative utilizations. The consequences are evaluated from the standpoint of risks taking when choosing a certain alternative and its economy. In a planning situation one can choose to analyse a small number of realistic alternatives as a basis for a decision making or carry out a complete optimization considering all possible alternatives.

The principles for constructing a model are the same as for the comprehensive mapping. The differences are in the fact that the water balance equation should obtain somewhat more complicated forms and that calculations cannot be done element by element. They must be carried out simultaneously for a whole river basin in order to give consistency within it.

Many different types of information are gathered under the heading detailed information. A classic example is so-called design discharges, which are data forming the basis for the majority of hydrological design nowadays. These are calculated with the help of statistical relationships.

Under this heading we consider the models, used for discharge forecasts. The forecasts can today be made for points on the rivers where observation series of a certain length are available. The models are based on a generalized picture of the hydrological cycle. The determination of parameters is carried out with statistical methods.

A third type of models that we should like to mention here is flow models for rivers and channels. In this case it is a question of completely physical models. All values should be measured in the field. These models are first of all used for estimation of flood-risks zones.

The requirements for hydrological information, which have been sketched above, should be based on a well constructed observation network and on an effective utilization of hydrological models. The use of hydrological models cannot, of course, replace direct observations.

Each hydrological value calculated for a point with the help of a hydrological model involves uncertainty. With the increase of input data the uncertainty in the estimations can be expected to decrease. It is naturally least demanding of resources to have a relatively sparse observation network and utilize hydrological models to a high degree.

However, one should further consider the losses a community suffers through a greater uncertainty in the basis of water planning problems. It is a fact that today there is no basis for decision making what is an optimum balance among the density of the station observation network, use of hydrological models and acceptable accuracy in hydrological information. A concentration on hydrological models requires perhaps the least resources to satisfy many of the needs that exist.

1. Introduction

A map is a two-dimensional representation of an area. The map is a method for the reduction of very large-scale spatial relationships so that they can be easily perceived. Most maps are estimates of continuous functions, based on discrete observations at control points. One can use two approaches: contour maps (isolines) and cartograms (sampling cells). Contour lines can be produced in a variety of ways, ranging from subjective interpolation from the nearest observations by eye to estimates derived from numerical interpolation of all observations. Sampling cells for cartograms can be cartographic nets, administrative units, river basins, physiographic regions etc. Characteristics for each cell are derived by integrating or averaging over the cell and displayed by giving colours or shades to it.

Water balance maps

Water balance maps are as a rule based on the contour line principle. Isolines are drawn by hand with a subjective interpolation between the nearest observation stations. Corrections are made so that maps of different water balance elements are consistent i e that the water balance equation is satisfied. It is, of course, very difficult to use automatic methods for interpolation based purely on the observational data. Water balance elements are highly dependent on physiographic factors of a landscape. For climatic elements like precipitation and potential evaporation with a relatively dense observation network automatic methods such as trend surfaces, double Fourier series and Kriging give satisfactory results. Runoff is a more difficult element as it is derived as an integrated value for an area. This means that theoretically runoff cannot be displayed on a place if not the area is fixed. When using automatic methods for interpolation of each water balance element we still have the problem of consistency, to satisfy the water balance equation. It is too simple to avoid independent measurements of one of the elements (usually evaporation) so that this can be derived as the difference when the other are summed up.

Databank for nationwide physical planning

Within the framework of National Physical Planning lots of comprehensive data on the properties and use of national resources are collected. The analysis of such data on a national base demands a treatment that adapts the concepts and sampling units of National Physical Planning. One difficulty is that official statistics is attached to the sampling units, which as a rule are administrative. The National Land Survey of Sweden has developed methods and systems for a joint treatment and analysis of physical data.

The system is based on location coordinates and the information is referred to squares of different sizes. (Lantmäteriet, 1979). At present squares 5x5 km are taken as a basis. The aims of the system are:

- to give a joint and comparable description of certain areas i e counties, municipalities, geographical regions, river basins
- to show the tendencies in the development of natural resources and their use
- to illustrate and explain the connections between different factors
- to reveal critical areas with certain properties or combination of properties, i e places in the country with natural properties favourable for a certain exploitation
- to permit absolute and relative comparison between different areas or between an area and the national average.

The system is adapted to computer which allows different types of combinations and treatments of facts in the form of tables and in the form of automatically produced thematic maps.

Databank for water balance

In this report principles and methods for the development of a data bank for water balance elements based on a square grid technique are presented. The approach described avoids some of the existing drawbacks of water balance mapping and further allows automatic productions of such maps with the help of hydrological models. A data bank for water balance based on a square grid also corresponds to other attempts to set up data banks for properties and use of national resources in Sweden.

The project to develop the methodology has been carried out under the title "Spatial variation of hydrology and physiography" and was financially supported by the Swedish Natural Science Research Council (NFR). Two preliminary reports were published: I Krasovskaia (1978) and Gottschalk and Krasovskaia (1979). This is the final report on the project, where the essence of the two latter reports is reviewed and the methodology is completed and improved.

Water balance is highly dependent on physiography. Automatic interpolation must consider this fact and that is why the basic data includes meteorological, hydrological and also physiographic data. In fig 1.1 a flow chart shows the processing and transfer of basic data up to the final product - water balance for square grids.

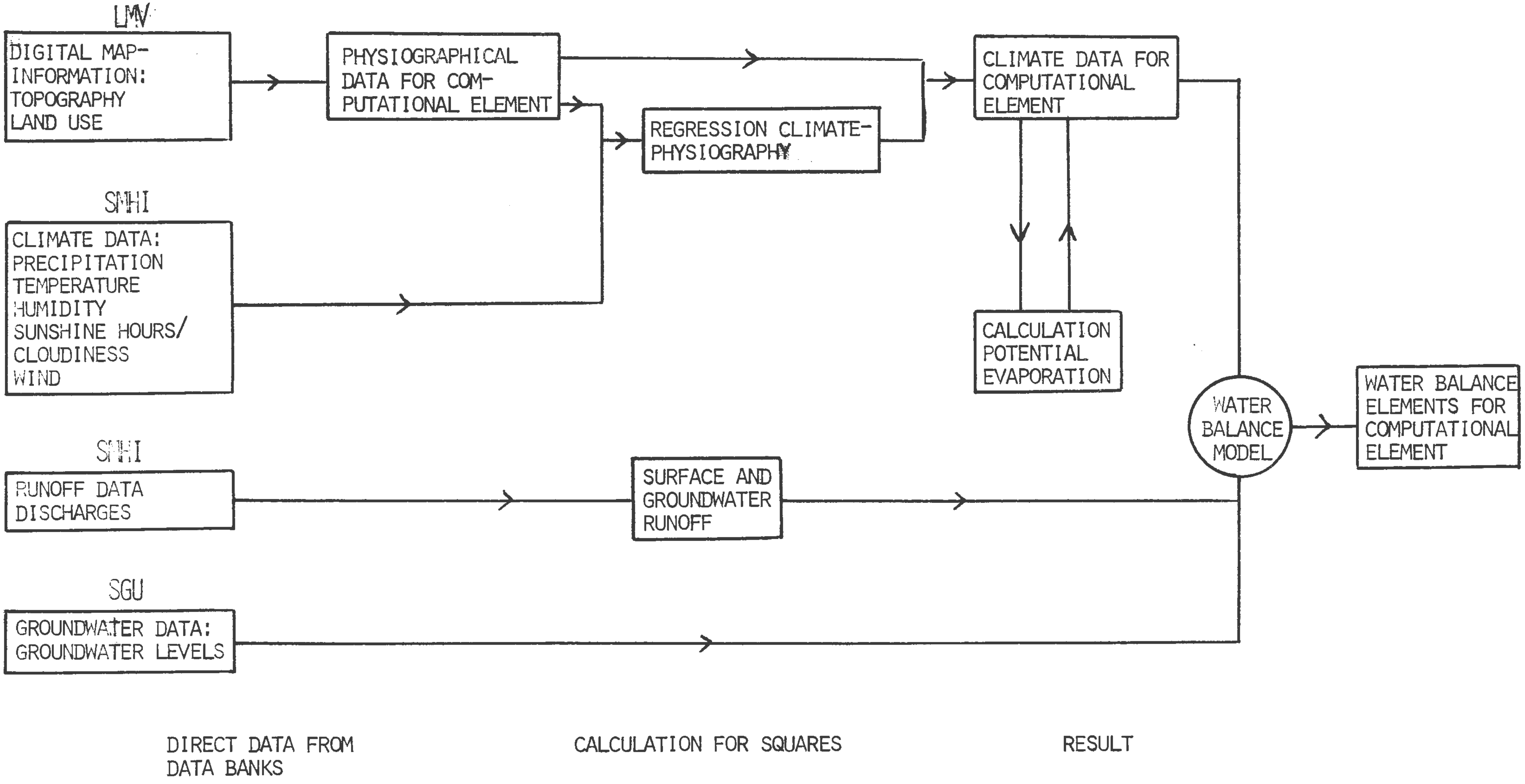


Fig 1.1 Processing and transfer of basic data to the final project

The same ideas in a more general form are illustrated in fig 1.2, where the elements of a data bank for Water Survey, Environment Canada (Solomon and Quereshi, 1972) are shown. The elements there are:

- The space-time reference system
- Data storage including data screening
- Data processing
- Information transfer techniques
- Information retrieval

The geo-hydrological reference system in this data bank consists of a square grid system corresponding to the UTM (Universal Transverse Mercator). The grid interval is uniform 10x10 km in northern and western Canada and 5x5 km in Ontario.

In this report we shall start with a description of the area chosen for the study. In the following basic data, data processing, information transfer to a square grid, retrieval of information and automatic production of maps are subjects that are developed and described in accordance with the flow charts, shown in figs 1.1 and 1.2.

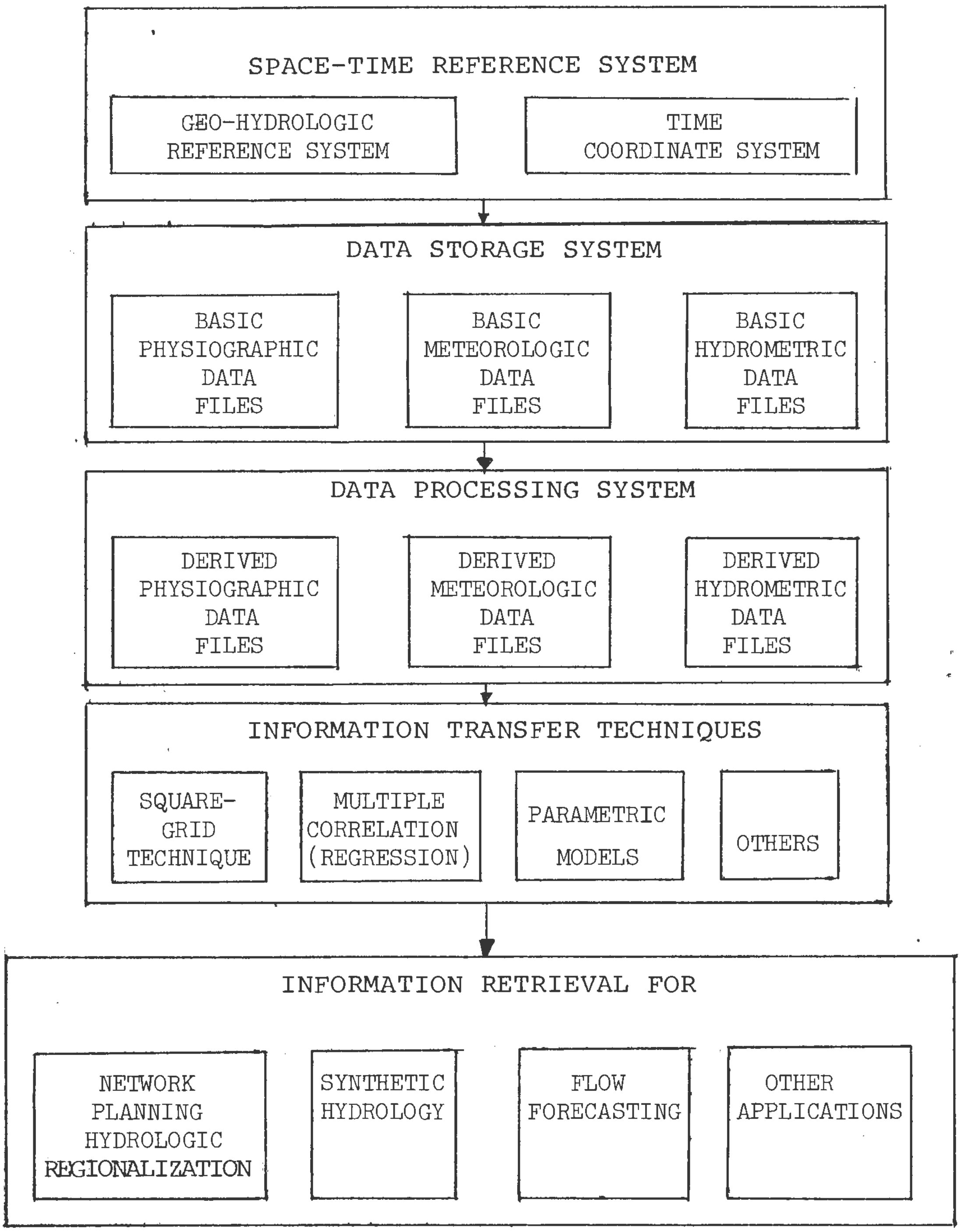


Fig 1.2 Basic layout of the physiographic land-use land-cover and hydrometeorological data bank (from Solomon and Querheri, 1972)

2. Geographical description of the test region

The region discussed in this study has been chosen rather voluntary. The only criterion was that the amount of input data enabled reliable conclusions. The region, thus, should be of a certain size to assure this.

The chosen region (fig 2.1) is covered by the topographic map, scale 1:50 000 (25 sheets), occupying a territory of approximately 12 100 km^2. It stretches from Söderköping-Motala in the south to Arboga-Eskilstuna in the north from Bråviken in the east to Vättern in the west.

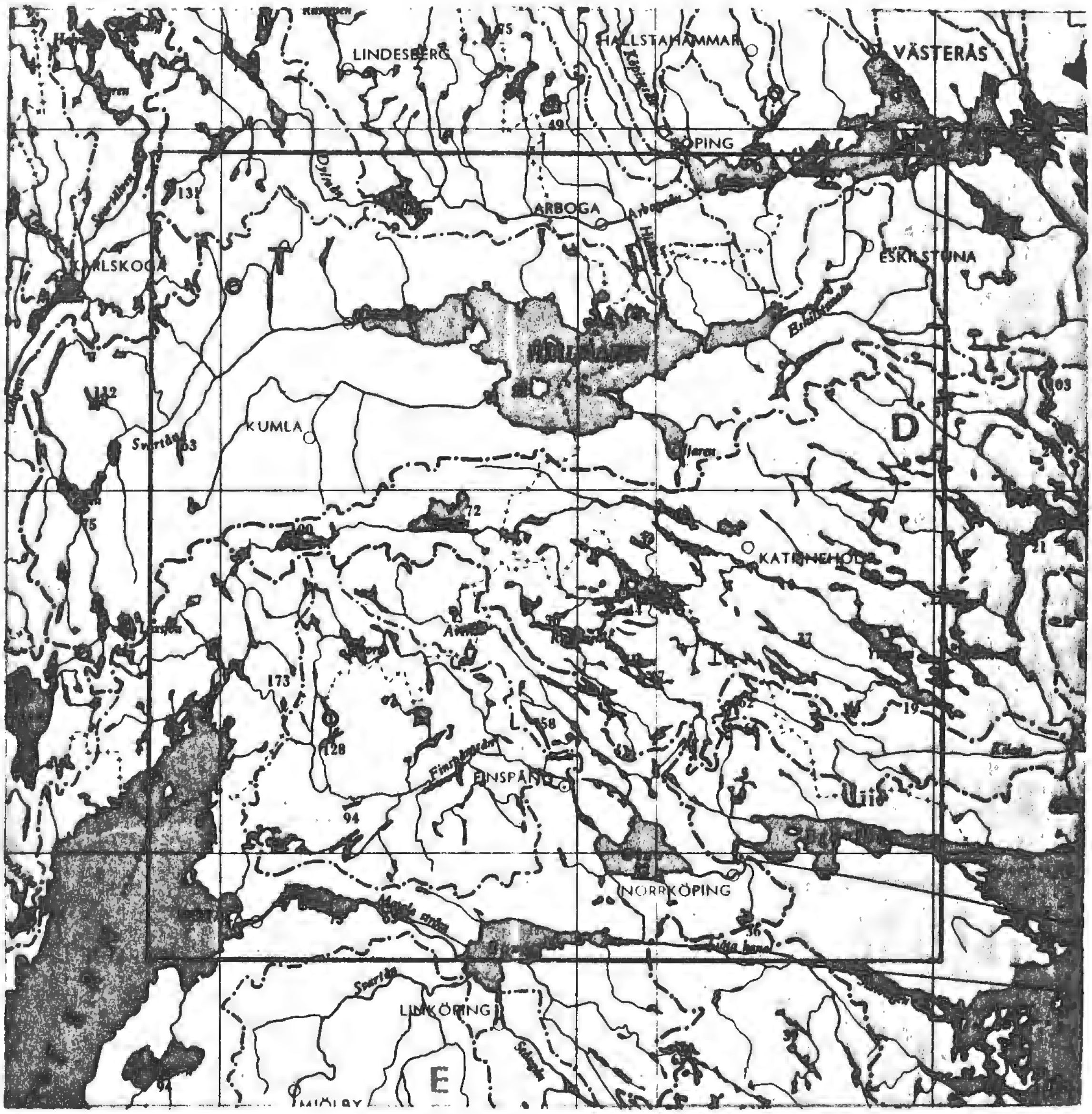


Fig. 2.1. The test area

The region covers approximately Hjälmaren's watershed and partly Vättern-Motala-ström's watershed.

The territory studied is subdivided into 4 physiographical regions, two of them, however, include only a boundary area (Physiographic regionalization of the Nordic countries, 1977).

The southern part corresponds roughly to the subregion "Östgötaslätten" in the region of "Central plains of Götaland". Plain is a dominant relief form and large areas in the region are cultivated. Fine grained sediments and moraine clays are widespread and brown soil is a dominant soil type. Natural vegetation is represented by a mixed and coniferous (mainly pine-tree) forest with spots of leaf forest (mainly oak) and meadows.

The central part of the territory corresponds to the region "Woodlands of Northern Götaland". The relief is of a fissure-valley type though with milder forms than more to the north. Moraine combined with exposed bedrocks are dominant. The brown soils are thinner and alternate with the podzols. Natural vegetation is represented by coniferous forest with spots of leaf forest (oak, asp). Bogs and swamps are widespread though unevenly distributed.

The northern part of the territory belongs to two regions "The fissure valley landscape of eastern Svealand" in the east and "Woodlands south of "limes norrlandicus" in the west. The first one is characterized by rather sharp relief forms - with valleys with clay material.
The role of exposed bedrocks is well pronounced in the landscape. Moraine is another common soil type. Vegetation is mainly represented by coniferous forests on the podzols with introduction of birch-forests. Small though numerous, swamps and bogs are concentrated to forest areas. In the second region the relief acquires plain forms and clay materials possess a significant rôle in the landscape. Natural vegetation is dominated by coniferous forest. Swamps and bogs, sometimes of a relatively big size, are common.

3. Reference system

The reference system used in this study is a square grid system which consists of a matrix of squares covering the area investigated and corresponding to the UTM reference system. The grid interval used is uniform 10x10 km squares (fig 3.1). The index number of the row and column of the square which is uniquely related to the UTM identification system provides the required information for the location of each square.

The Land Survey of Sweden uses the RAK* reference system instead of UTM and a square grid of 5x5 km^2. No principal differences of a methodological character arise from the fact that we use UTM instead of RAK. When the methodology developed here is applied in a larger scale for parts or the whole of Sweden the RAK reference system should be used to allow compatibility with other data banks. The size of the grid net must be chosen to give acceptable accuracy in the derived physiographic data. This is why squares 10x10 km^2 have been chosen instead of 5x5 km squares. For equal identification systems one can easily sum up four 5x5 km^2 squares to derive a 10x10 km^2 square.

---

* Gauss' conform projection on the Bessel ellipsoid with mean meridian equal to $15^{\circ}48'29''8$.

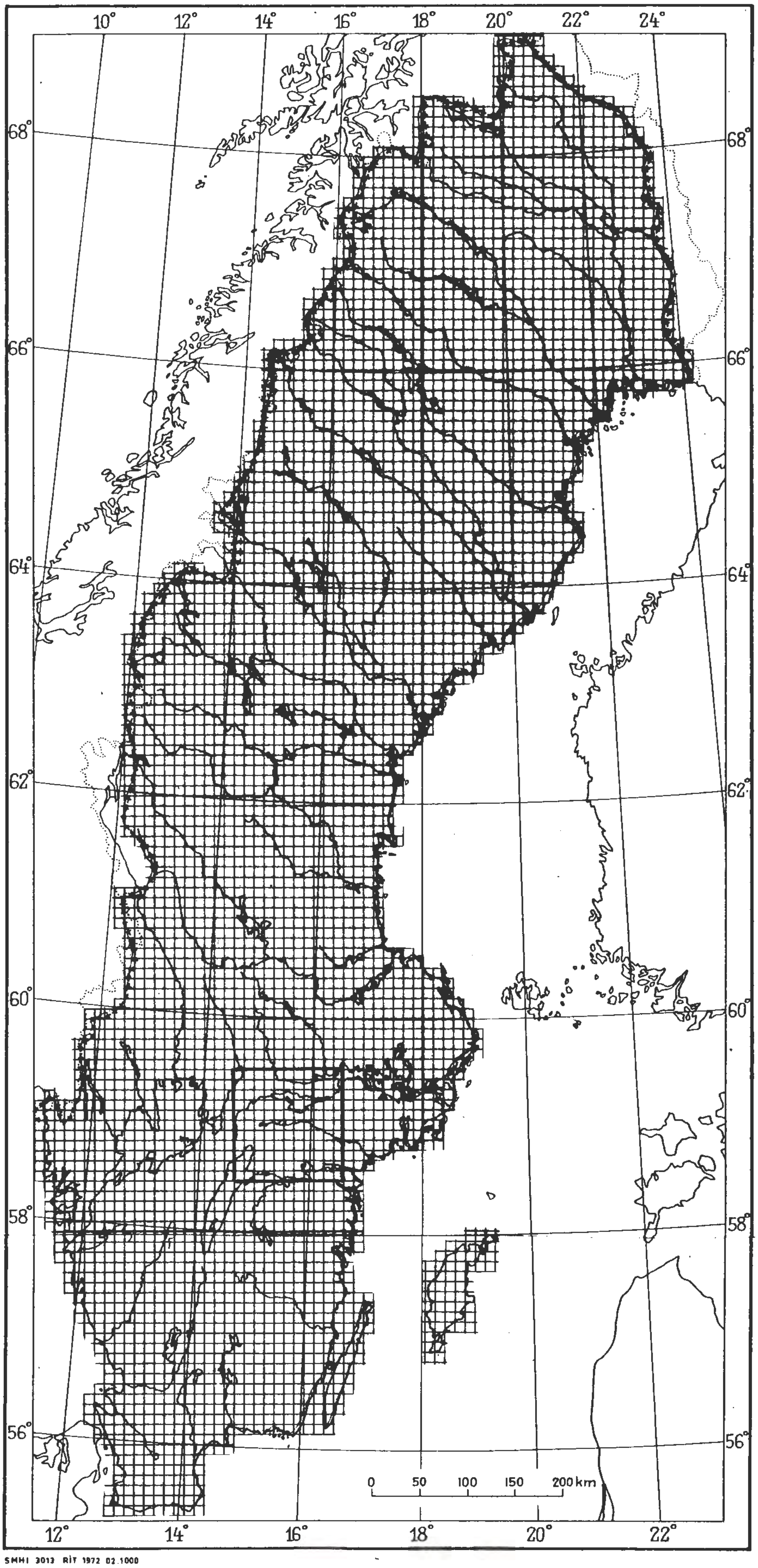


Fig 3.1 The reference 10x10 km grid net used.

4. Basic data

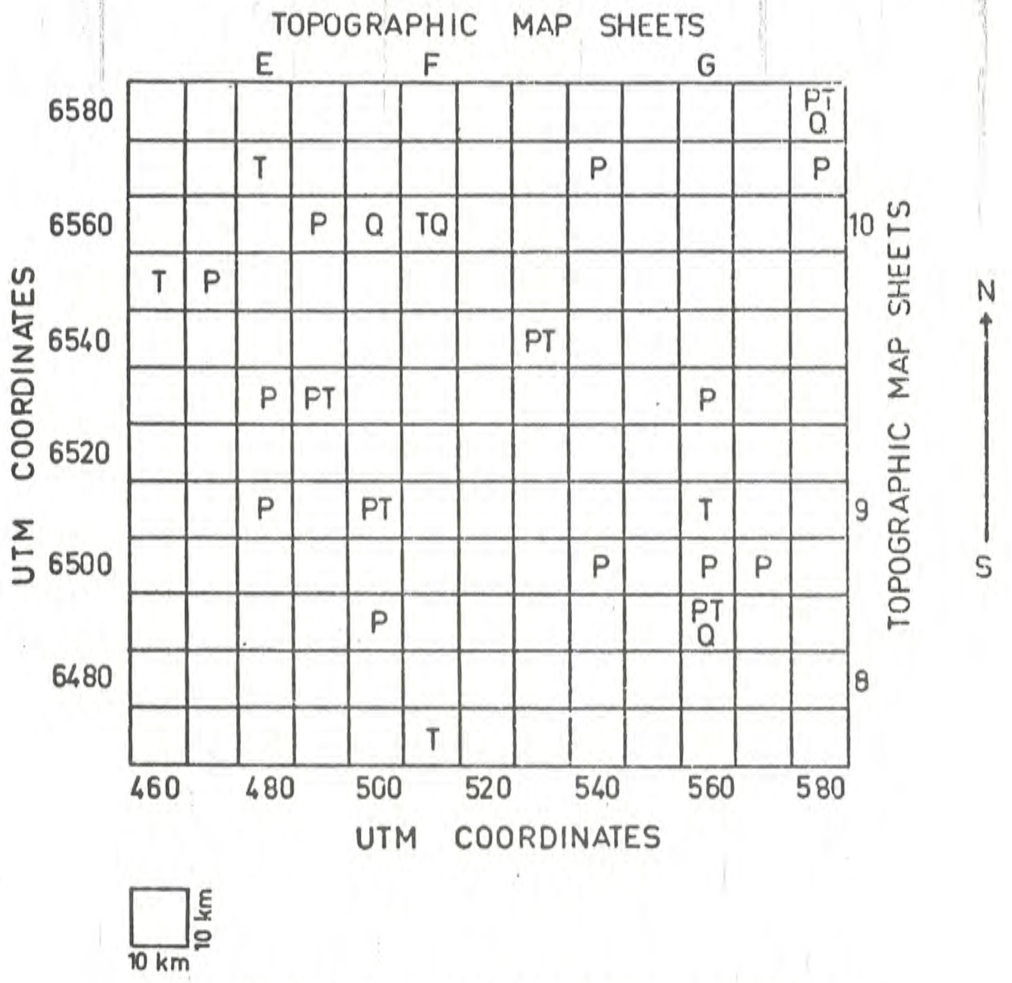
Basic data are of two principal types: digital map data and observational data from meteorological and hydrological observation stations. The digital map data cover the studied territory in a square grid net, with an interval of 500m. Hydrological and meteorological data are in the form of time series at points scattered irregularily over the territory.

General data storage systems do not exist today neither for digital map data nor for hydrological and meteorological data. Most data are available and data files were set up for this study covering the test area.

The data for elevations (as point values for heights) and presence and absence of forest are available from the Land Survey of Sweden (LMV) on magnetic tape. Information about lake and swamp presence on the map was obtained by manual digitization of a topographic map (1:50000) with the help of set-functions: when the presence of an element was marked by "1" and its absence by "0".

Climatological data utilized in the study include, first of all, 20 years' long series of monthly temperatures for 10 stations, monthly precipitation values for 17 precipitation stations, situated in the region investigated or close to it (see fig 4.1 and table 4.1). Data were specially punched on cards for this study. Monthly values of the mean relative humidity, wind velocity and the number of sunshine hours were taken from the "Meteorological Observations in Sweden" part 2.2 for 20 years for the station Örebro-Ekeby, as differences in these figures proved to be small for the stations of the region.

Finally monthly runoff data from the four gauging stations of the region were taken from the SMHI data file of water levels and discharges.



T-TEMPERATURE OBSERVATIONS AVAILABLE

P-PRECIPITATION OBSERVATIONS AVAILABLE

Q-DISCHARGE OBSERVATIONS AVAILABLE

Fig 4.1 Situation of observation stations in the region.

Table 4.1 List of observation stations used

N	Name	Coordinates UTM	Parameter measured
8449	Sörbytorp	480/6510	P
8458	Snavlunda	490/6530	P,T
8460	Törntorp	480/6530	P
8522	Öjebro	510/6470	T
8533	Motala kraftverk	500/6490	P
8543	Finspång	540/6500	P
8545	Godegård	500/6510	P,T
8636	Norrköping	570/6500	P
8637	Norrköping-S	560/6490	P,T
8641	Hult	560/6500	P
8647	Simonstorp	560/6510	T
8659	Katrineholm	560/6530	P
9405	Åtorp	460/6550	T
9407	Svartå	470/6550	P
9414	Degerfors	460/6560	P
9415	Leckeberga	490/6560	P
9417	Villingsberg	480/6570	T
9502	Högsjö	530/6540	P,T
9516	Örebro-Ekeby	510/6560	T*
9520	Sickelsjö	540/6570	P
9620	Hyndevad	580/6570	P
9623	Eskilstuna	580/6580	P,T
61-742	Torshälla invalln.	510/6560	Q
61-1158	Södra Bro	500/6560	Q
61-138	Övre Hyndevad	580/6580	Q
67-1216	Hällerstad	560/6490	Q

* wind, humidity, sunshine hours

The basic data files thus include the following elements:

Table 4.2	Basic data files	
Physiographic data	Meteorological data	Hydrometric data
elevation forest lake swamp	temperature precipitation relative humidity wind velocity sunshine hours	discharge
Point values for 500x500 m grid	Time series of monthly values	Time series of monthly values

4.1 Data sufficiency and computational accuracy

To check sufficiency of the basic physiographic data we applied the theory of confidence intervals. For data in the form of set functions the percentage of landsurface covered by a certain element p is calculated as the relation frequency of "ones" within a square, p = n/N (n number of "ones" and N total number of grid data). The confidence interval is calculated from (Cramer, 1948):

$$\frac{n}{n+\lambda_{\varepsilon}^{2}}(p^{*} + \frac{\lambda_{\varepsilon}^{2}}{2n} \pm \lambda_{\varepsilon}\sqrt{\frac{p^{*}q^{*}}{n} + \frac{\lambda_{\varepsilon}^{2}}{4n^{2}}}) \qquad (4.1)$$

where n = the number of observation points,
q = 1 - p,
p^{*} = empirical probability,
ε = confidence level,
λ_{ε} = ε% value (from the tables of "Normal distribution").

From here we can determine the value of n, that is necessary to provide a desired accuracy of estimation of p:

$$n = \lambda_{\varepsilon}^{2}\left[\frac{2p^{*}q^{*}}{\delta^{2}} - 1 \pm \sqrt{(\frac{2p^{*}q^{*}}{\delta^{2}} - 1)^{2} + \frac{1}{\delta^{2}} - 1}\right] \qquad (4.2)$$

where δ = length of confidence interval, the other symbols are the same as in (4.1).

Using this expression, we have determined n for different "δ", "ε" and "p" values. The results of estimation are given in table 4.3.

Table 4.3. Dependence of "n" on different values of "δ", "ε", "p".

δ	ε%	p				
		0.1 (0.9)	0.2 (0.8)	0.3 (0.7)	0.4 (0.6)	0.5
0.05	33	145	256	335	383	399
	25	191	338	443	507	528
	10	392	691	907	1036	1080
	5	556	982	1288	1471	1533
0.02	33	901	1600	2099	2399	2499
	25	1192	2116	2778	3174	3307
	10	2437	4328	5680	6491	6791
	5	3460	6145	8064	9216	9600
0.01	33	3601	6400	8399	9599	9999
	25	4764	8464	11114	12701	12231
	10	9743	17315	22726	25972	27054
	5	13833	24585	32266	36876	38412

For the case when we deal with continuous data (heights), the following equation was used:

$$n = 4\alpha^2 \cdot \lambda_{\varepsilon}^2 k^2/\delta^2 \qquad (4.3)*$$

where α = standard deviation,

δ = length of confidence interval,

k = coefficient, which gives us the mean, when

k = 1 and when k = 1.7094 - 10% percentiles;

(see Kendall, M.G. and Stuart, A., 1958).

We, similarly to the first case, performed estimation for different values of "ε" and "δ". The results of this procedure are given in table 4.4.

Table 4.4 Dependence of "n" on different values of "σ", "δ", "ε".

		σ(m)					
		20		40		60	
δ(m)	ε%	Mean	10% percentile	Mean	10% percentile	Mean	10% percentile
0.5	33	6400	18701	25600	74803	57600	168307
	25	7362	21511	29448	86046	66257	193604
	10	10527	30761	42109	123044	94746	276848
	5	12544	36654	50176	146614	112896	329882
1.0	33	1600	4675	6400	18701	14400	42077
	25	1840	5378	7362	21512	16564	48401
	10	1632	7690	10527	30761	23687	69212
	5	3136	9163	12544	36654	28224	82470
2.0	33	400	11691	1600	4675	3600	10519
	25	460	1344	5378	5378	4141	12100
	10	658	1923	2632	7690	5922	17303
	5	784	2291	3136	9163	7056	20618
5.0	33	64	187	256	748	576	1683
	25	74	215	294	860	663	1936
	10	105	308	421	1230	947	2768
	5	125	366	502	1466	1129	3299

---

* Normally distributed data are assumed.

With the help of these tables it is easy to see that in case of 5x5 km squares with 100 figures per element the accuracy will not be satisfactory. The computational element was, for this reason, chosen as squares of the size 10x10 km. This indicated that there is a need for denser digital map data in the form of grid nets, than the one that can be obtained today if one wants to use 5x5 km squares as a unit. An alternative is to use digital polygon data (instead of grid net) from a topographic map. The latter type of map data is being developed by the Land Survey of Sweden and will be available in future.

4.2 Landscape scales

As it was already mentioned we worked with the grid density of 500 m. However, in order to make clear if such grid density is suitable to describe all landscape forms we tested even other grid densities 100 m and 1 km on a limited number of maps, covering different nature conditions in Östergötland, Halland, Skåne and Jämtland). The purpose was to get a numerical description of landscape forms, to see whether these were different for different regions and finally, to check whether they can be described with the chosen grid densities.

We tried to get numerical descriptions of landscapes studied by analyzing autocorrelation function for rows (east-west direction) and columns (north-south direction) of matrices for the elements studied: heights, presence of forest, lakes or swamps. For this purpose a "landscape scale" was used, definition of which was borrowed from the theory of turbulency:

$$S = \int_{0}^{\infty} \rho(\tau)d\tau \qquad (4.4)$$

where S - scale
ρ - autocorrelation function
τ - integration parameter

This can be illustrated graphically (see fig 4.2). We get the scale by integrating the autocorrelation curve.

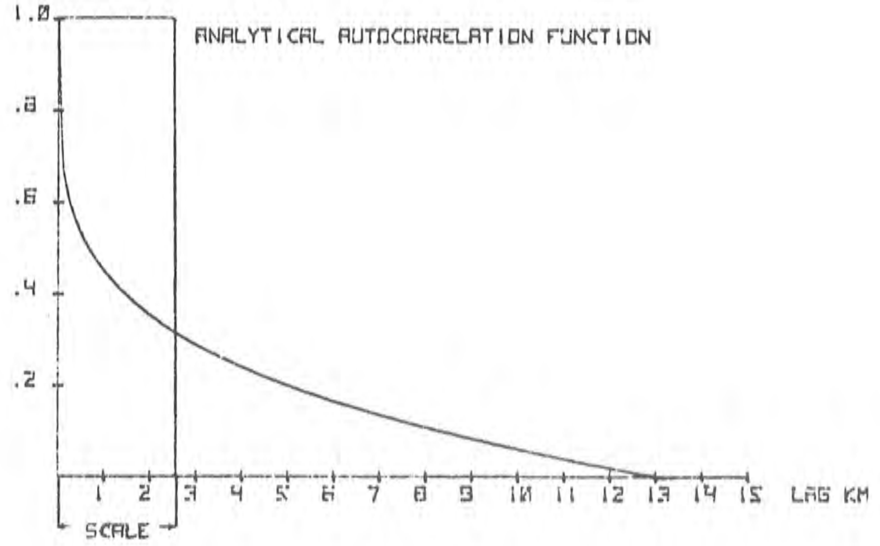


Fig 4.2 Definition of scale from the correlation function

If we then draw a rectangular with the same area, then its side on abscissa gives us the "scale".

We used the definition given above and got the landscape scales for the four regions studied. We did the analyses with and without removing of trend from the data for heights. Besides similar analysis was performed even for empirical probability curves for a number of cases, the results of which are also given in table 4.5.

Table 4.5 Landscape scales (km)

Region	Grid density	Element	Estimated from analytical expressions for autocorrelation				Estimated from conditional probabilities	
			with trend		trend removed			
		Direction	E-W	N-S	E-W	N-S	E-W	N-S
Öster-götland	100 m	height	-	-	-	-	-	-
		forest	0.13	0.08	-	-	-	-
		swamp	0.1	0.1	-	-	-	-
		lake	-	-	-	-	-	-
Öster-götland	500 m	height	5.1	1.25	2.0	1.7	-	-
		forest	2.0	0.3	-	-	9	9
		swamp	0.3	0.3	-	-	<1	<1
		lake	0.8	0.5	-	-	<1	<1
Öster-götland	1000 m	height	1.3	3.7	1.1	1.0	-	-
		forest	0.9	0.3	-	-	9	9
		swamp	0.5	-	-	-	<1	<1
		lake	0.9	0.4	-	-	<1	<1
Jämt-land	1000 m	height	3	2	≈1	≈1	-	-
		forest	0.4	0.4	-	-	10	10
		swamp	0.2	0.8	-	-	<1	<1
		lake	1.0	0.7	-	-	<2	<2
Hal-land	1000 m	height	2.5	7	0.8	1.5	-	-
		forest	0.3	1.1	-	-	9	9
		swamp	0.7	0.6	-	-	<1	<1
		lake	25-21	251-53	-	-	1	1

It can be seen from the table that the scales of different elements of landscapes for all the regions proved to be less than 1 km in the majority of cases. This justifies a direct rejection of 1000 m grid density. Even 500 m grid density proved to be too inadequate to describe such elements as forest, lake and swamp. The best grid density of those tested is thus 100 m. This is the grid density that should be used even in case one chooses 5x5 km as a computational element to get a desired accuracy, as it has been mentioned before.

To get an idea about the character of distribution periodical or random of different landscape elements two-dimensional Fourier-analysis was applied to the data matrices. Even in this case the grid density of 100 m gave more reliable results. Minimal wave lengths were often omitted when 500 m and 1000 m grids were used (for more detailed information about the analyses mentioned,see Krasovskaia, I., 1978).

5. Data processing and information transfer

Data processing and information transfer include calculation of physiographic characteristics to describe relief, distribution of vegetation, lakes, swamps, soil types and drainage density, techniques for the interpolation of meteorological variables and models for water balance.

5.1 Derived physiographic data

Derived physiographic data are obtained in the basis of the basic data with the technique described below.

5.1.1 Relief

The relief in each square needs to be described more completely than by using elevations only. For this purpose 8 indirect parameters have been estimated: mean, maximal and minimal elevations and standard deviation from the mean, local relief, mean and maximal slope and elevation-relief ratio. The first three are quite obvious and the four latter will be commented below.

Standard deviation of elevations provides a more stable measure of the vertical variability in a region than only maximal and minimal elevation.

Local relief was determined as the difference of the maximal and minimal elevation in each square. This parameter is important as it illustrates vividly variations in elevations within a square and is closely related to the slope (see for example, D Mark, 1975).

Slope is actually a parameter defined at every point, unlike many of relief parameters. However, in practice one deals often with average slope, calculated for some finite area. The procedure of slope calculation in this study is described below. First, we determined slope in three directions (see fig 5.1) for each point and took the maximal value of these three. The mean slope for each square was determined as the mean over these maxima.

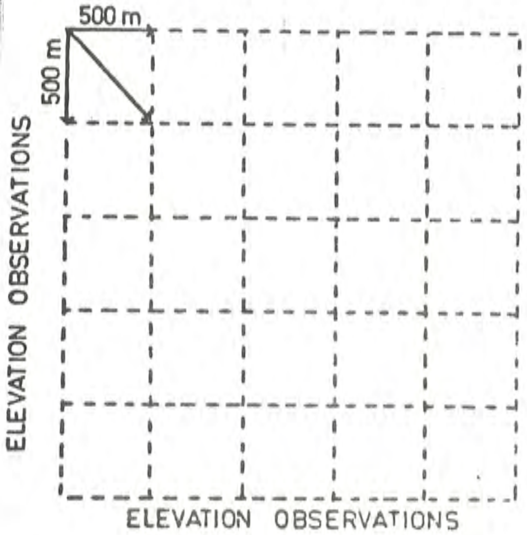


Fig 5.1 Calculation of slope.

Elevation relief ratio was determined as:

$$E = \frac{\overline{H}-H_{max}}{H_{max}-H_{min}}, \qquad (5.1)$$

where $\overline{H}$ - mean elevation

H_{max} - maximal elevation

H_{min} - minimal elevation

Elevation relief ratio describes hypsometry of the region. This value is mathematically equal to a hypsometric integral (see Pike and Wilson, 1971) and thus - the area under the relative hypsometric curve, though it is much easier to determine, than the hypsometric integral.

5.1.2 Vegetation, lakes and swamps

Knowledge about the presence and distribution of lakes and swamps as well as the forests is essential for any hydrological study, as their influence on runoff is significant. That is why this information should be included in the basic data. In this study the following three elements: presence of forests, swamps and lakes were described with the help of "set functions" and it is meaningless to speak of maximal and minimal values in this case. However, the mean values and standard deviations, in our opinion, should be taken into account as they describe variation of elements within each square.

5.1.3 Soils

Soil is another element of landscape which is closely connected to hydrological phenomena.

Estimation of evaporation in a water balance model requires knowledge about soils' active zone. In order to evaluate the active zone for each soil type present in a square, reports of soil water studies in the representative basins in Sweden have been used. We chose the data that had been obtained in Sweden, for landscapes more or less similar to those studied.

We have accepted the following figures, describing an average active zone for different soil types, 120 cm for sand, 250 cm for clay, 150 cm for moraine, 100 cm for swamps (turf), 0 cm for exposed bedrocks. The values are approximate, of course, though quite acceptable in this study. These figures have been weighted together with repect to the area, which each particular soil type occupies in each square. Thus one value, characterizing an active soil zone in each square was obtained.

In order to take into account a lag-time of ground water response, we included in our data list for each square one more characteristic, which corresponds to the lag-time among the lag-times for all soiltypes present in a particular square. The values of lag-time were taken from another study (Gottschalk, Nordberg, 1977), performed for Swedish conditions. (0.5 was taken as the minimal value of lag-time and 1.83 as the maximal, depending on a soil type).

Soil types' distribution was calculated in percent for each square directly from the "Soil types map of Sweden", (Karta över Sveriges jordarter, 1958, scale 1:1 000 000). The types, distinguished on this map and correspondingly in this study are: sand, clay (incl moraine clay), fluvioglacial deposits, swamps, moraine, exposed bedrocks.

5.1.4 Drainage density

Drainage density is a characteristic which is a combined product of a number of others: climatologic, hydrologic, geomorphologic and pedologic (see Krasovskaia, I., 1979). That is why knowledge of drainage density is valuable when describing a landscape for hydrological purposes.

Drainage density is determined by dividing the stream length in a basin (square) by its area. This is quite a simple procedure when digital topographic maps are available. However, in practice this is not the case yet, and area and stream length measurements are done manually, which is both labour and time-consuming.

We chose to use an indirect simple method (line intersection) for drainage density estimations, developed by Carston & Langbein (1960). The main idea of the method is based on the relationship of the drainage density as the reciprocal of the mean distance between the channels. If one draws a straight line of the length L through the basin and count the number of streams that were crossed by it (N), then the mean normal distance between the channels will be expressed as:

$$\sin 45^{\circ} L/N \qquad (5.2)$$

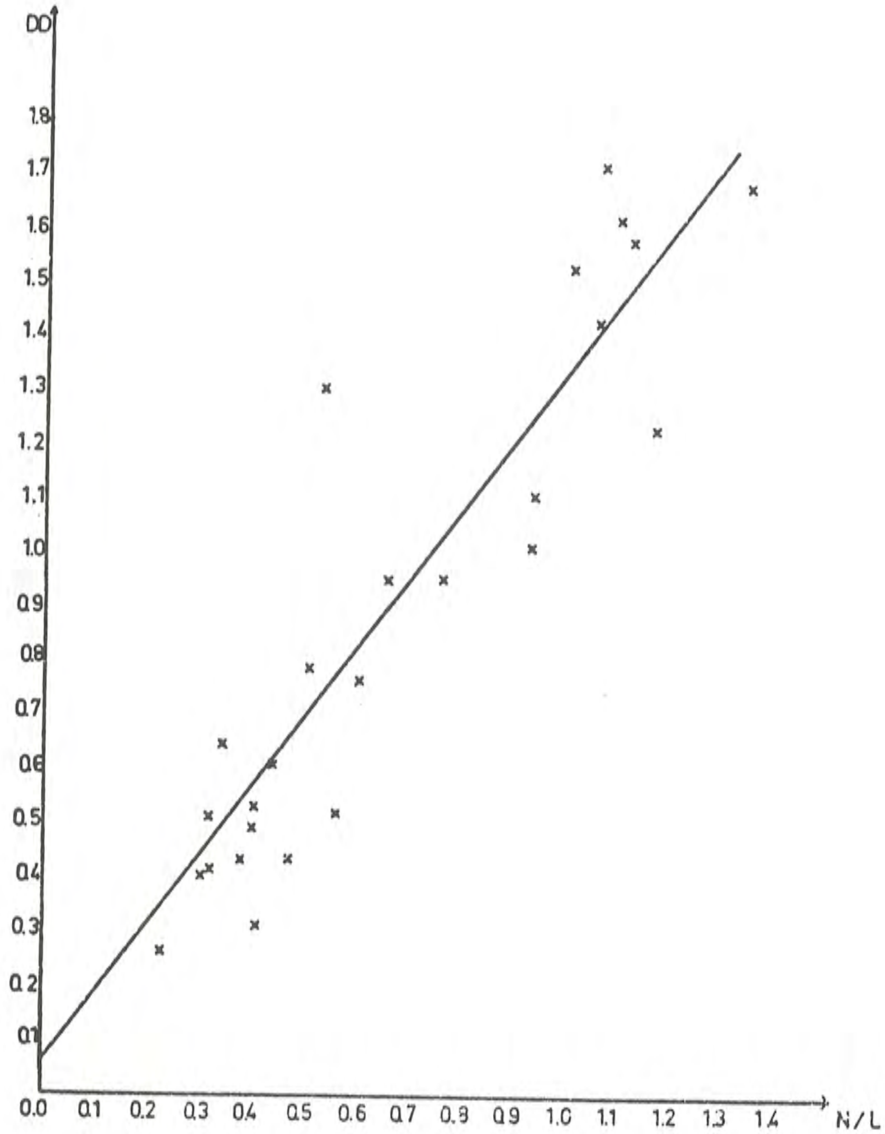
where 45° is an average angle of intersection from 0°-90°. The reciprocal of expression (5.2) gives an approximation of drainage density.

We used a random pattern of lines to determine drainage densities for the squares studied. The number of intersections was in all cases more than 50 to achieve the desired accuracy (see McCoy, R., 1971). We used regression analysis to get the relationship between drainage density and number of channel crossings per km of a line and got the following equation (see fig 5.2):

$$DD = 0.05 + 1.28\,(N/L) \qquad (5.3)$$

where DD = drainage density and
N/L = number of channel crossings per km of line

Correlation coefficient between DD and N/L was found to be equal to 0.92. The equation and correlation coefficient's value were obtained on the basis of the data from 26 squares and basins in Sweden, where drainage density was measured both by conventional and line intersection methods.



<u>Fig 5.2</u> Relation between line intersections per km (N/L) and drainage density (DD).

The physiographic parameters used in the study are given in table 5.1.

Table 5.1 Physiographic parameters used in the study

Element	Parameter
1 Coordinates	x,y-coordinates
2 Relief	mean elevation maximal elevation minimal elevation standard deviation of elevation local relief elevation relief ratio maximal slope average slope standard deviation of slope
3 Land use	percentage of forest standard deviation of the value above percentage of lakes standard deviation of the value above percentage of swamps standard deviation of the value above
4 Drainage density	number of intersections per km of line
5 Soil	active zone response lag-time

5.2 Derived meteorological and hydrological data

Meteorological and hydrological observations are derived as point values. To transfer the information derived at these points to each square two different approaches were used. Meteorological observations were transferred by statistical methods to get indirectly calculated parameters for each square. From these parameters potential evaporation was estimated. Surface and groundwater runoff on the other hand were calculated with the help of water balance models with meteorological parameters as an input. Model parameters were determined by hydrograph analyses.

5.2.1 Temperature and precipitation

The space distribution of temperature and precipitation is considered to be described by the following formula:

$$y_i(t) = D_i(t) + P_i(t) \qquad (5.4)$$

where y_i stands for temperature and precipitation, respectively, for a square with index i, D_i is a deterministic part dependent on the physiographic charactetistics of this square and P_i is a purely probabilistic part.

It is also assumed that observations within a certain square are valid for all the squares and influenced by the physiographic conditions in this square.

As it has been mentioned above we used the data for 17 precipitation and 10 temperature observation points to get temperature and precipitation for each square (see fig 4.1 and table 4.1). This was done by setting regression equations for dependence of precipitation (or temperature) on 18 physiographic parameters (see table 5.1). In order to reduce the number of regression equations (12 - one for each month) principal component analysis has been used.

We use the following model:

$$y_i(t) = m_i + \sum_{k=1}^{n} h_{ik} v_k(t), \quad i = 1,.., M \qquad (5.5)$$

h_{ik} are weights, $v_k(t)$-amplitude functions, m_i-mean value of y_i, M-number of observation stations and n-a number less or equal M. The weights and amplitudes are determined from the correlation matrix of the basic data. It should be noticed that the amplitudes $v_k(t)$ do not depend on i and therefore are common for all stations. The expansion (5.5) thus determines the extent to which precipitation and temperature, respectively, at different locations are covariant.

5.2.2 Precipitation

The precipitation series for 17 stations were decomposed into 17 orthogonal components. The first three amplitide functions for them are shown in fig 5.3.

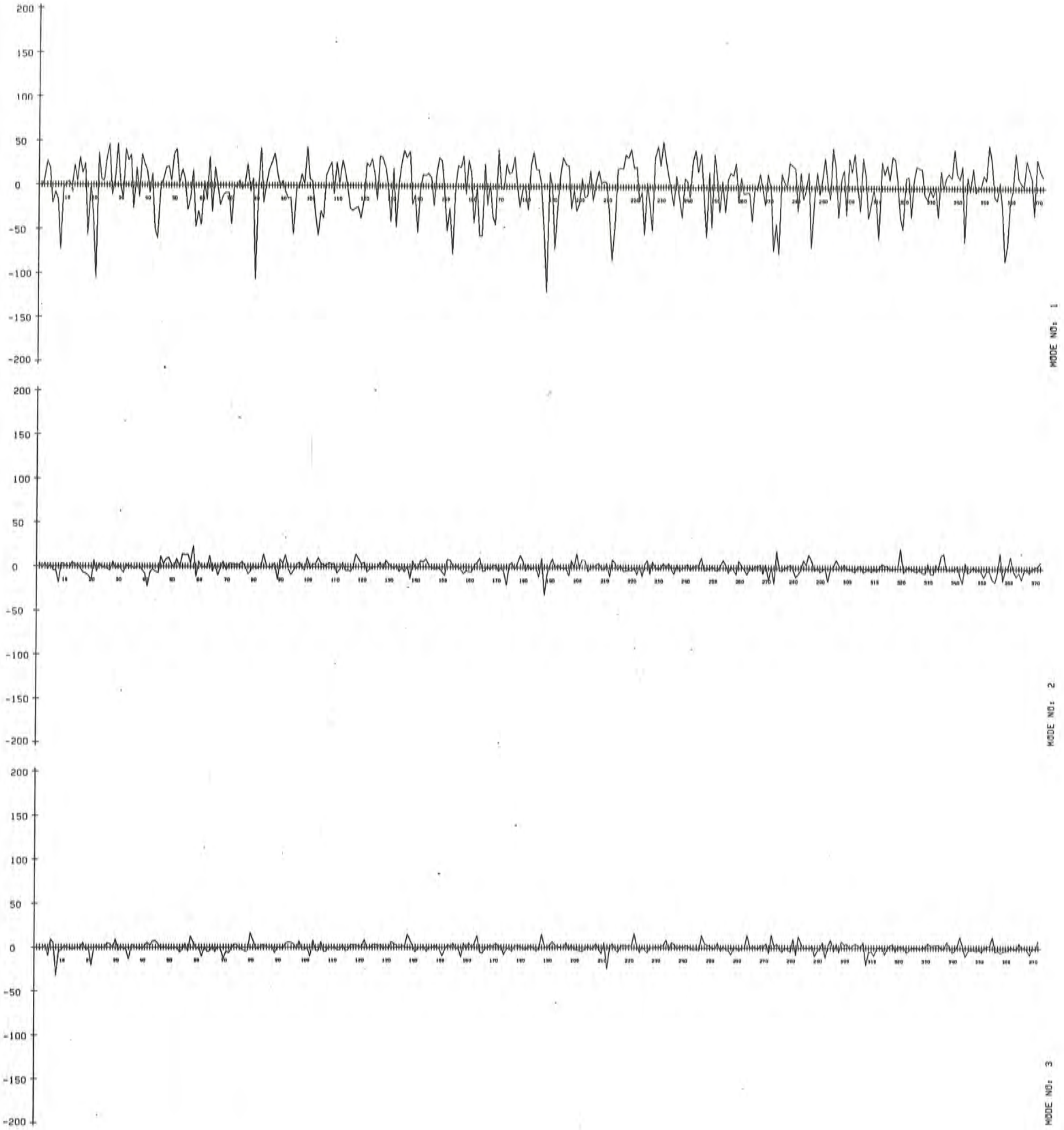


Fig. 5.3 The first three amplitude functions for precipitation (17 precipitation stations).

It can be seen from the graph that the greater part of variations in the monthly means for precipitations can be traced in the first component. This one can be associated with a dependence on the distance from the sea. Even weak periodicity can also be noticed. The other two amplitude functions on the graph answer for much smaller part of variation, which can be attributed to the influence of the local physiography. Alltogether the first 3 components stand for the 91.8% of the total variation of the monthly means of precipitation (see table 5.2).

Table 5.2 Cumulated variance for principal components, precipitation

Component's number	Cumulative variance
1	0.844
2	0.889
3	0.918
4	0.933
5	0.942
6	0.951
7	0.058
8	0.964
9	0.970

In order to find out which of the physiographic parameters influence these 9 components and the means we used a multiple regression analysis. The results of this analysis are given on table 5.3, where for each of 9 components and the mean,physiographic parameters influencing them are given, as well as the multiple correlation coefficients, R_m, describing the percentage of variation explained by them.

Table 5.3 Results of the multiple regression analysis with 17 precipitation stations

Principal component	Physiographic parameter	R_m
mean	y-coordinate mean lake percentage	0.906
1	y-coordinate mean lake percentage	0.837
2	y-coordinate x-coordinate mean lake percentage	0.992
3	y-coordinate x-coordinate elevation-relief ratio	0.983
4	maximal slope drainage density	0.713
5	mean lake percentage	0.538
6	no	-
7	no	-
8	no	-
9	mean swamp percentage	0.488

It can be seen from the table that for the mean and the first 4 components the physiographic parameters chosen explain a considerable part of their total variation.

y-coordinate (east-west direction)*, for example, which turned out to be important for the mean, describes the distance from the sea, which supports our previous assumption.

Our next step was to test which one of the physiographic parameters, that are enlisted in table 5.3, came in by occasion. For this purpose 3 of the precipitation stations were removed and the multiple regression test was carried out again. Only parameters common for all the stations should remain after this procedure, while those peculiar for individual stations should fall out. The results of this analysis are given in table 5.4.

*Notice. In the UTM system the x-axis is in the north-south direction and the y-axis in the east-west one.

Table 5.4 Results of the multiple regression analysis with 14 precipitation stations

Principal component	Physiographic parameter	R_m
mean	y-coordinate mean lake percentage	0.924
1	y-coordinate mean lake percentage standard deviation of slope	0.941
2	y-coordinate x-coordinate minimal elevation mean lake percentage	0.996
3	y-coordinate x-coordinate	0.940
4	drainage density	0.513
6-9	no	-

If we compare the two tables with the results of the multiple regression analyses we can see that the most important physiographic parameters are those common for both tables. They are: y-coordinate, x-coordinate, mean lake percentage, drainage density and parameters characterizing slope and elevation. The conclusion can be that these should be included into the regression equation to determine precipitation for each square.

It is interesting to notice, that the amplitude functions for 14 stations do not differ much from these for 17 stations - see fig 5.4.

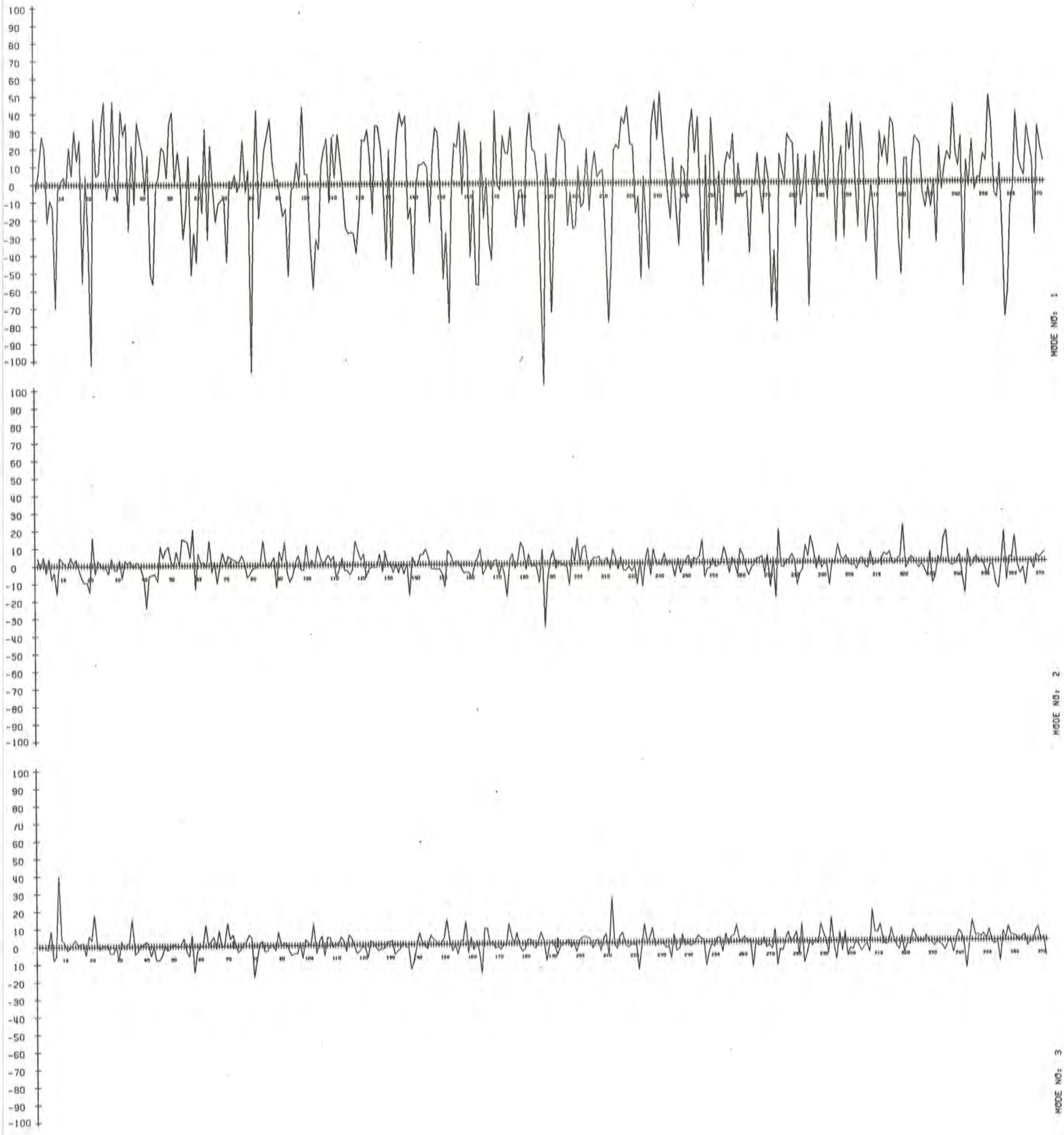


Fig. 5.4 3 first amplitude functions for 14 precipitation stations

Now with the help of the knowledge about the mean and the principal components and physiographic factors, explaining their variation,we can try to calculate the precipitation values for each square with the help of regression.

In order to test how well we can do it we removed observations from three stations, made a forecast for them and compared the obtained values to the actual ones by studying the error (difference between the actual and measured value).

The error functions for 6 stations can be seen in fig 5.4 where the "independent" stations (those removed in tests) are specially marked.

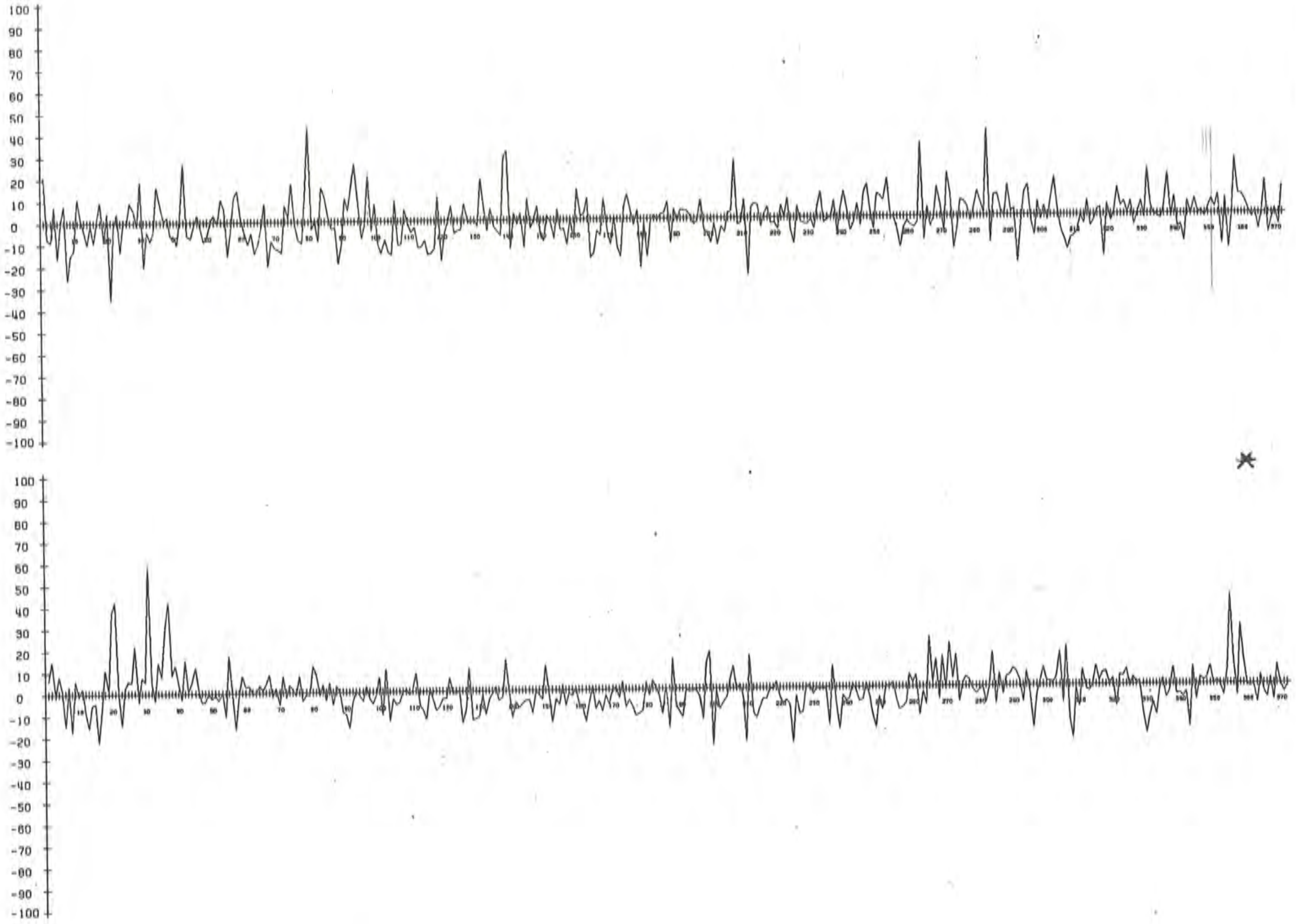
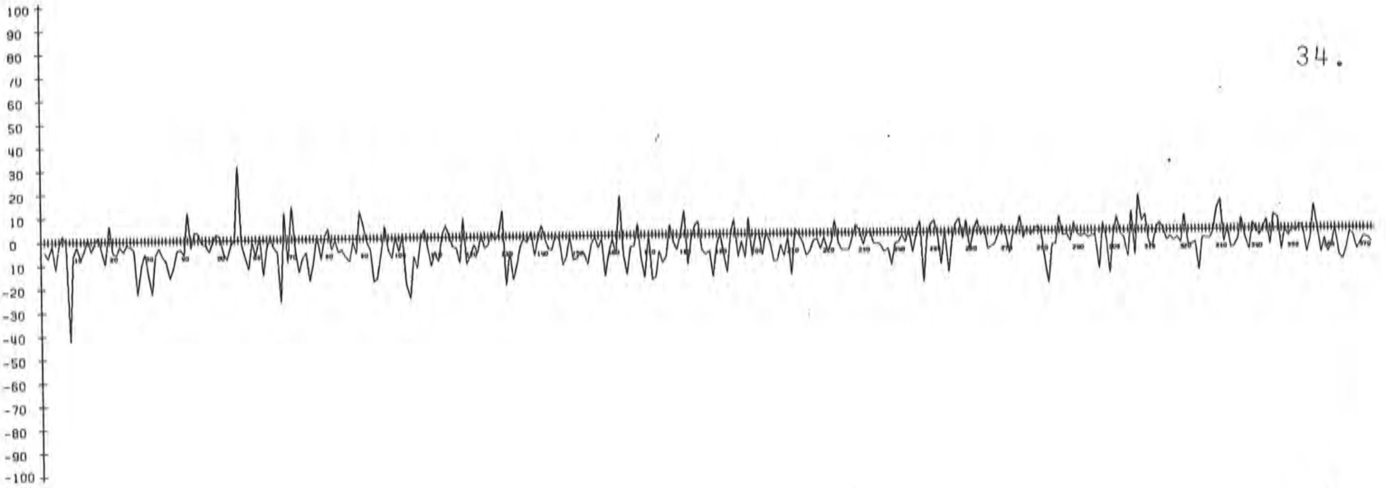
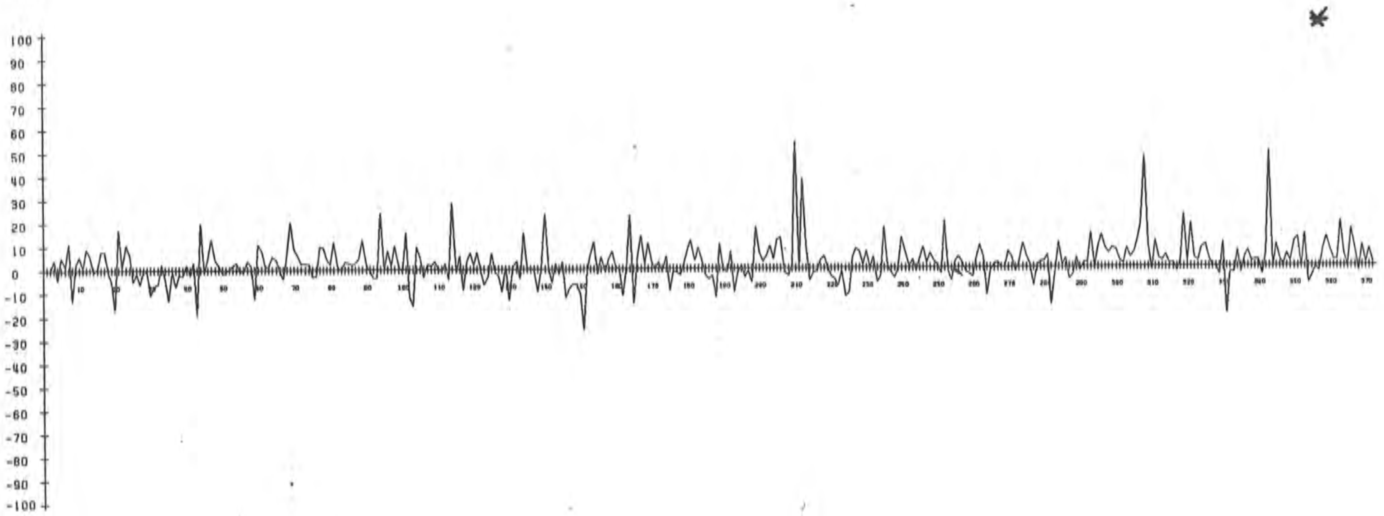
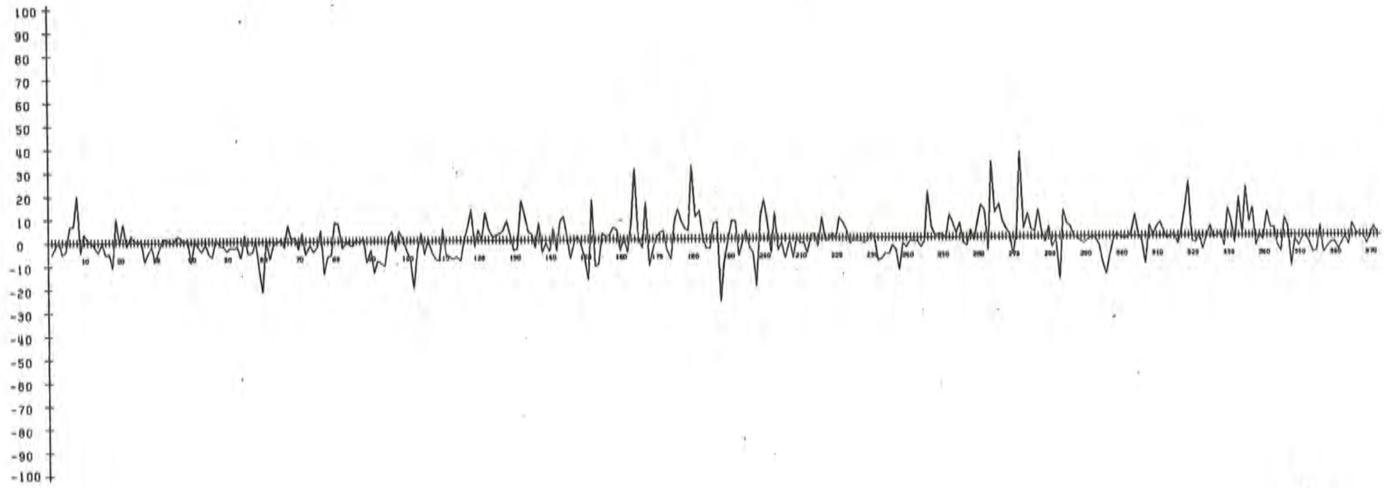
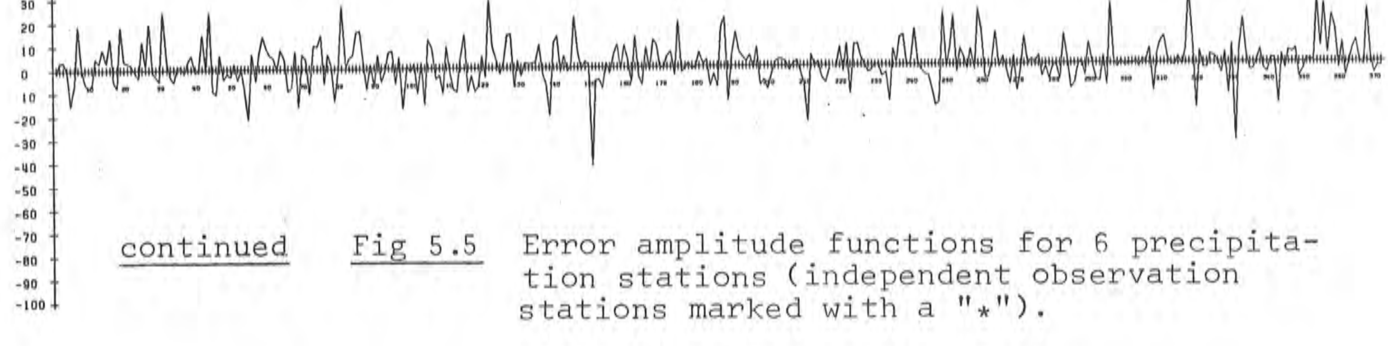


Fig 5.5 Error amplitude functions for 6 precipitation stations (independent observation stations marked with a "*").
(continued next page)









<u>continued</u> <u>Fig 5.5</u> Error amplitude functions for 6 precipitation stations (independent observation stations marked with a "*").

The first thing we were interested in was whether this error was random or not. For this purpose we plotted the graph of the empirical correlation function for error (see fig 5.6). It is interesting to compare it to the graph of the empirical correlation function for precipitation values themselves, which are highly correlated (see fig 5.7).

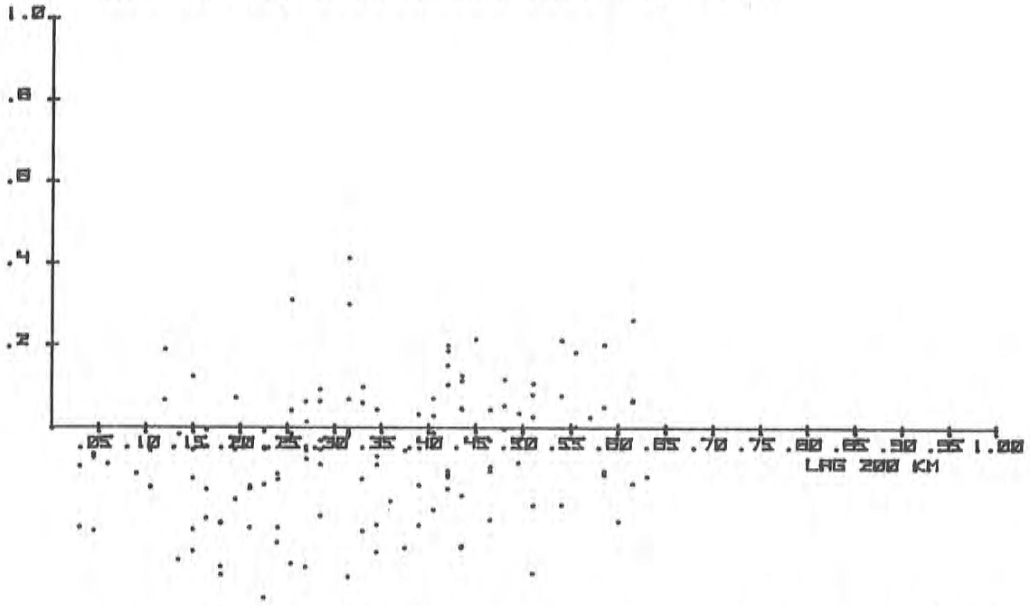


Fig 5.6 Empirical spatial correlation-precipitation residuals.

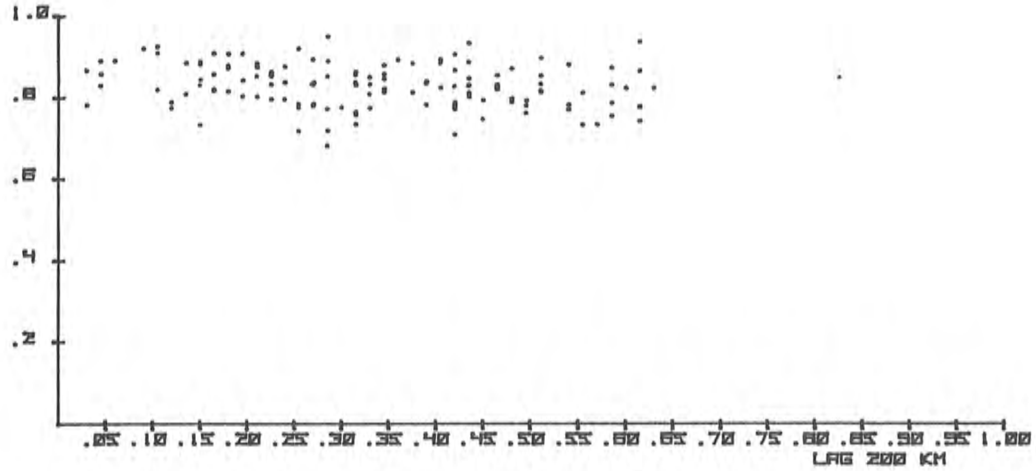


Fig 5.7 Empirical spatial correlation-precipitation.

It can be seen from the figure that there is no correlation in the error values and we can consider it to have a random character. We have, thus, fully described the spatial variation of precipitation.

Another problem that we were interested in was the optimal number of principal components used which gave us the minimal error. We tested a different number of components in our equation (from 1 to 6) and plotted the standardized error against the number of components used, see fig 5.8. In this figure graphs no 5, 9 and 14 stand for independent stations (those removed).

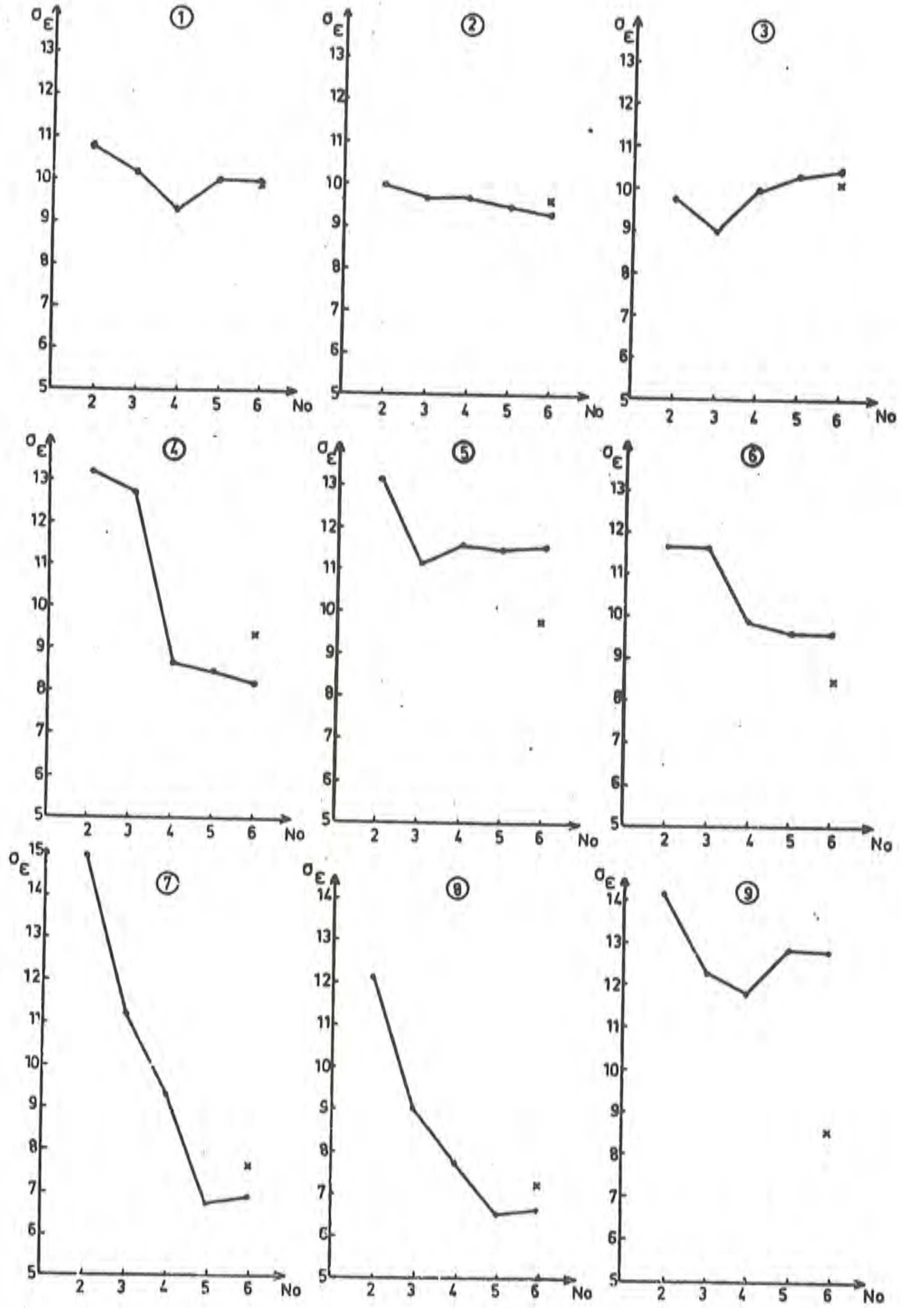
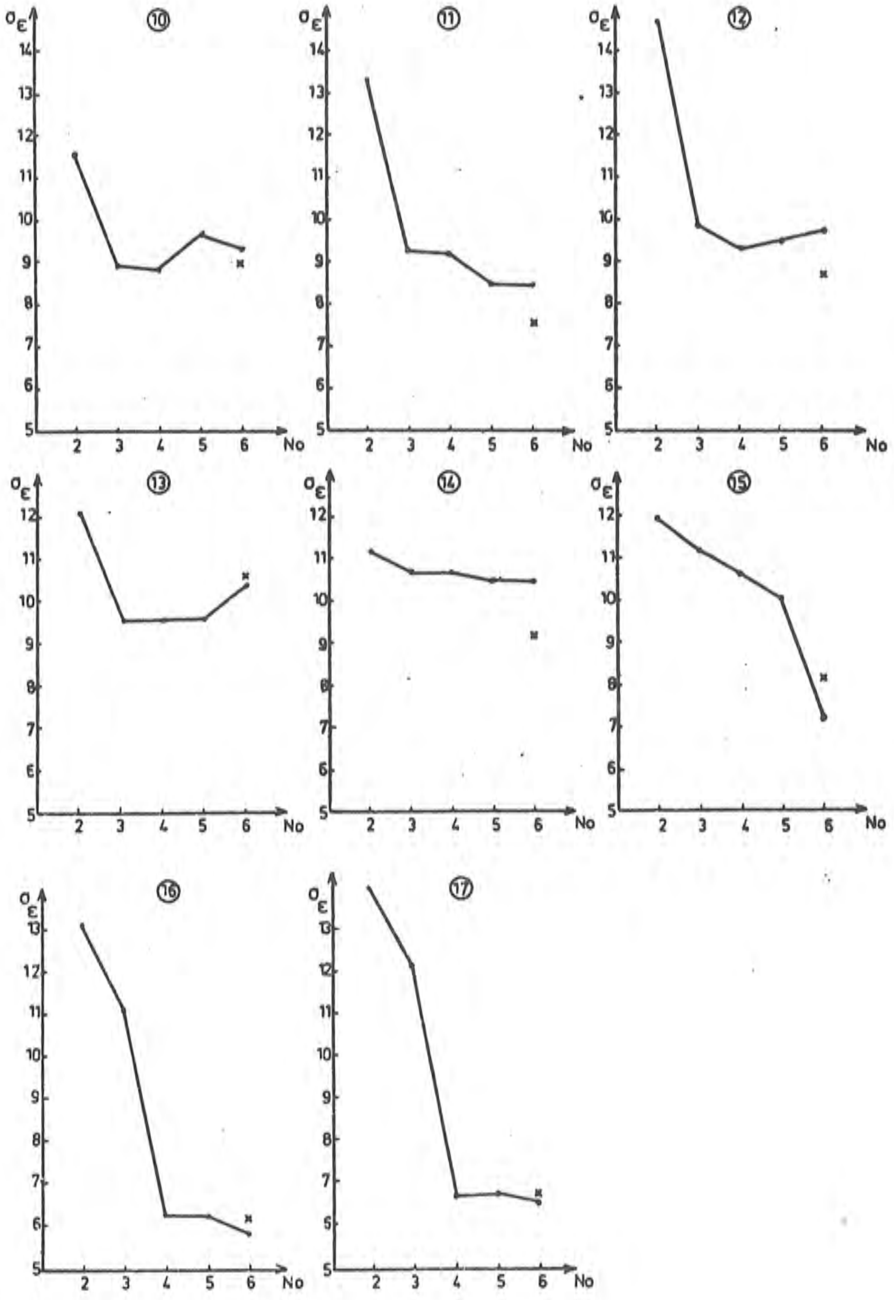


Fig 5.8 Calculated error at each observation station as a function of the number of used components in the prediction equation. "x" marks the error when all 17 stations are used and regression on the mean and 5 components.



continued

Fig 5.8 Calculated error at each observation station as a function of the number of used components in the prediction equation.

After studying the plots it was impossible to give a unique answer on this question about the best number of components, though it was obvious that 4 or 5 gave the minimal error in the forecast.

Finally, we could proceed to calculate the values of precipitation for each square by using the mean and the weights for 5 principal components in the regression equation with the physiographic parameters chosen.

5.2.3 Temperature

With the same methodics we get 10 orthogonal components for the temperature series.

The amplitude functions for the first 3 of them are shown on fig 5.9.

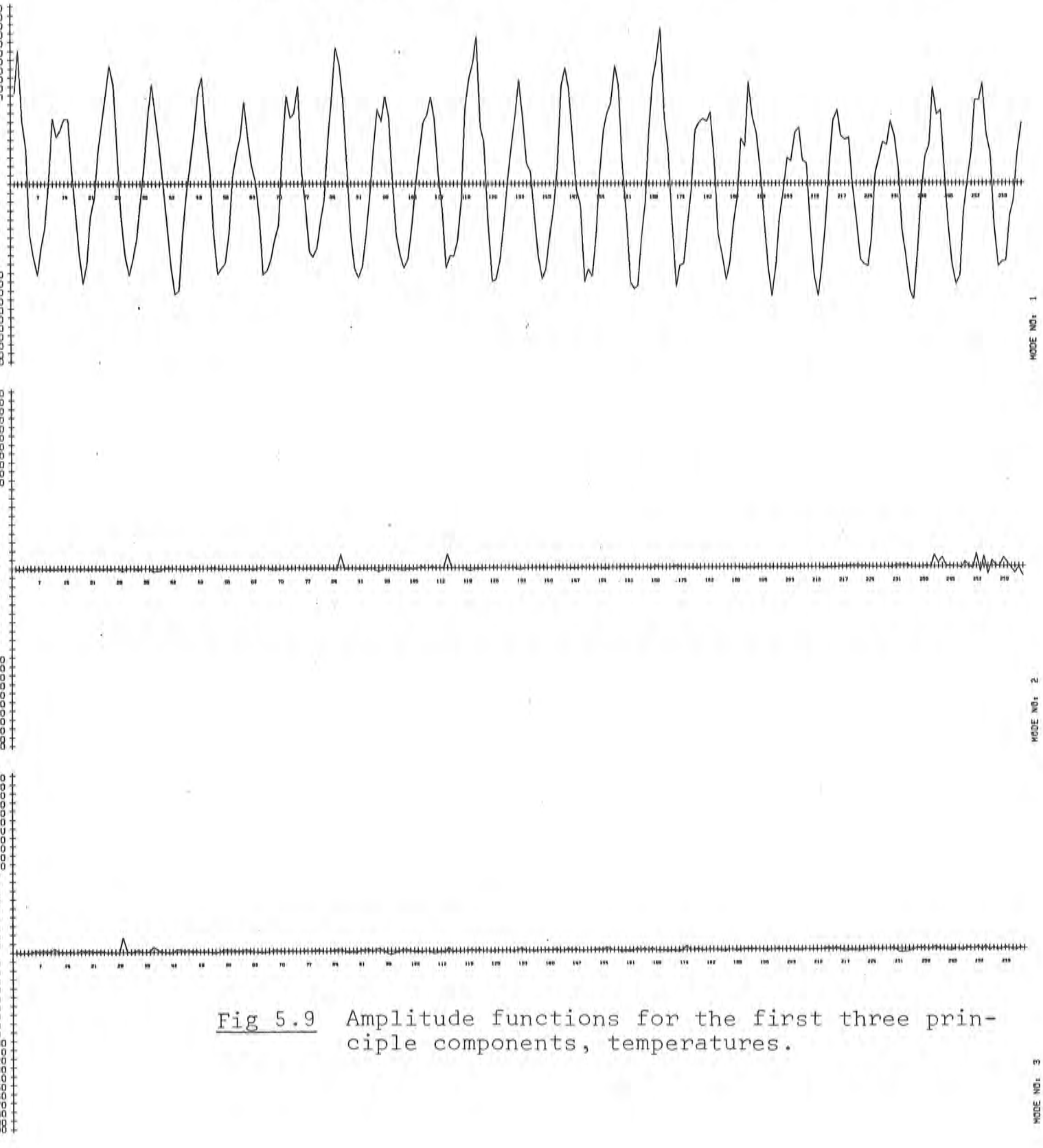


Fig 5.9 Amplitude functions for the first three principle components, temperatures.

In this case, periodicity is very vivid, with a period of 12 months. It is also obvious that the first component is responsible for the dominant part of variations in the monthly values.

The same can be seen from the figures of the accumulated variance for 6 principal components (see Table 5.5), where the three first of them explain 99.9% of the variation.

Table 5.5 Accumulated variance for principal components, temperature

Component's number	Accumulative variance
1	0.997
2	0.998
3	0.999
4	0.999
5	0.999
6	1.000

It can also be seen from the table that already 6 components explain the total temperature variations. We limited ourselves to the use of one component.

Similarly to the case with precipitation we tried to select those of the physiographic parameters, which influence the mean and the first component by means of the multiple regression. The results of this analysis for temperature are given in table 5.6.

Table 5.6 Results of the multiple regression analysis with 10 temperature stations

Principal component	Physiographic parameter	R_m
mean	x-coordinate minimal elevation standard deviation of slope	0.979
1	x-coordinate	0.870

In case of temperatures, the most important factor was x-coordinate (latitude), followed by the two relief parameters, characterizing slope and elevation. This is in a good agreement with our previous assumption that climatic zonality is reflected at least by the mean. The terms of the regression equation turned out to be that few that it was meaningless to test them as in the case of precipitation.

However, the problem of how well we can predict the temperature values was studied even in this case.

This was done again by the comparison of predicted and observed values. The error correlation function is shown in fig 5.10. The correlation structure of the temperature series themselves is shown in fig 5.11. It can be seen that the temperature values for the stations are highly correlated.

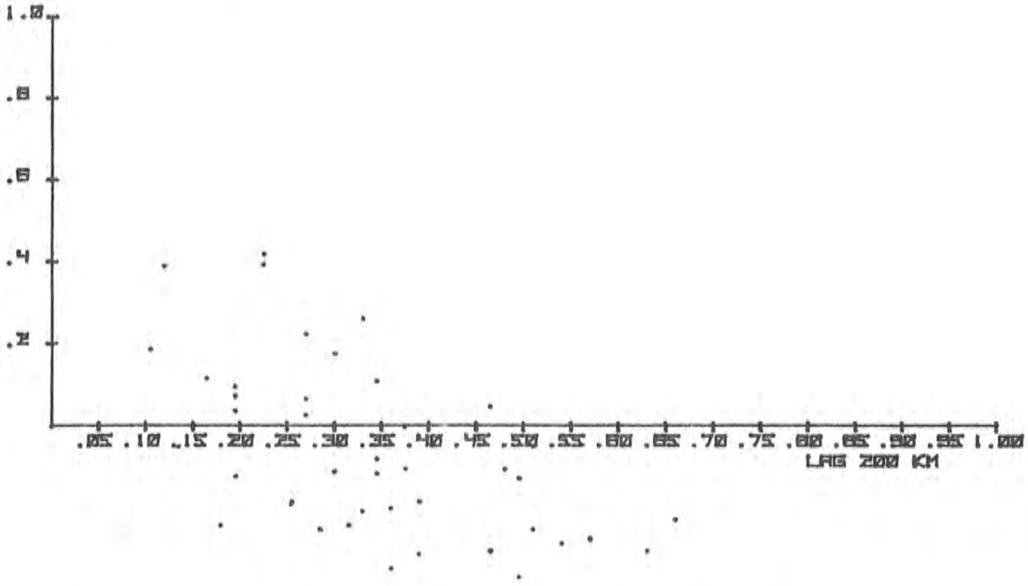


Fig 5.10 Empirical spatial correlation temperature residuals.

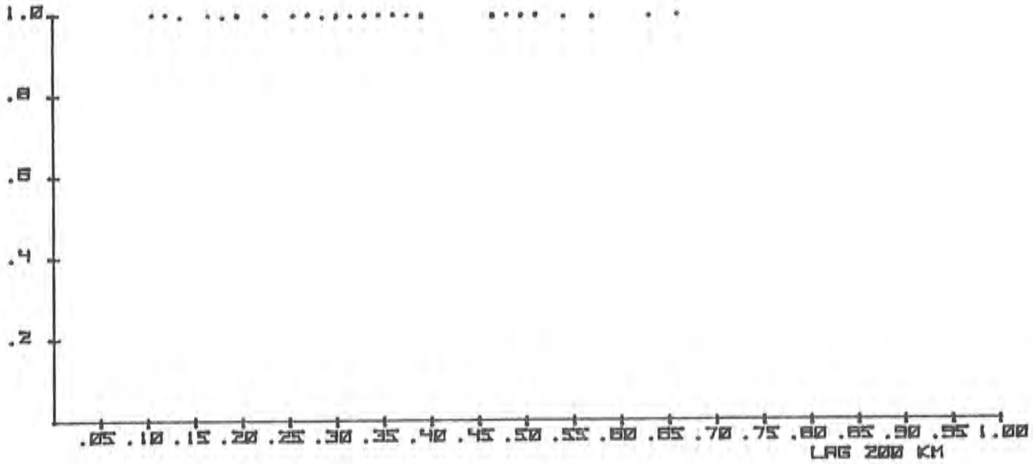


Fig 5.11 Empirical spatial correlation temperature.

As far as the character of the error is concerned it can be regarded to be random.

With the help of the knowledge about the mean and the first principal components for temperature and physiographic parameters from Table 5.6 we could calculate the temperature values for every square.

5.2.4 Potential evaporation

Potential evaporation was calculated using the Penman formula (Lindeberg, 1973)

$$E_p = \frac{\Delta((s(1-r)+\sigma T_2(0.53+0.65\sqrt{e-1})-\Delta L)\cdot(0.1+0.9^{n}/N)+G)}{L\cdot(\gamma+\Delta)} + \frac{0.26(0.5+0.54v_2)(e_s-e)\gamma}{\gamma+\Delta} \qquad (5.6)$$

where

Δ	is the psycrometric constant
s	incoming solar radiation
r	albedo
σ	Stefan-Bolzmann's constant
T_2	temperature at 2 meters height
e	damp pressure
e_s	saturated damp pressure
ΔL	$= \sigma(T_o^4-T_2^4)$ i e the difference in longwave radiation at 2 meters height and surface, values of ΔL are given in Aslyng and Jensen, 1967
n	is actual number of sunshine hours
N	maximal number of sunshine hours
G	change in heat storage in the soil or water body
L	latent heat of water
γ	constant to keep units consistent (≈ 0.61)
v_2	wind velocity at two meters height

The incoming solar radiation s was calculated with an astronomical formula and reduced according to Wallén (1966) by the quotient-actual to maximum sunshine hours.

Albedo values for different land and water surfaces were taken from a table published in Sellers (1965):

forest	0.12
meadow	0.10
snow	0.50
water in winter	0.21
water in summer	0.07

Temperature values were calculated according to the methodology described in section 5.2.3. Actual damp pressure, wind at 2 meters height and actual sunshine hours have monthly mean values that differ very little within the studied territory. These factors further have relatively low influence on the calculated potential evaporation (Lindeberg, 1973). This is the reason why they were taken for the station Örebro-Ekeby and set equal for all squares.

Potential evaporation was calculated separately for land and water surfaces. For land surfaces the albedo for snow was used if snow cover was present and in other cases a weighted value was estimated considering the proportion of forest and meadow within a square. For water surfaces the winter value was used if temperature was below zero for the months, January to April and in other cases the summer value.

Changes in heat storage in soil and water bodies were approximated by a following expression:

$$G = A \cdot (\sin(2 \cdot \Pi \cdot (M+1)/12) - \sin(2 \Pi M/12) \qquad (5.7)$$

where M is the month number, A was given the value $0.5 \sim 10^6$ Ws(M^2 day) for soil and $1.0 \cdot 10^6$ Ws/(M^2 day) for lakes. Further research is needed to give better values to this coefficient. For lakes this coefficient is dependent on characteristics of a certain lake - mainly the water depth.

5.2.5 Actual evaporation and runoff

Two different models have been tested to calculate monthly water balance elements i e actual evaporation and surface runoff from precipitation and potential evaporation. The principle for the calculation for both models is shown in fig 5.12. Both models are described in Korzoun et al (1974). The first of the models has earlier been used by Gottschalk (1973) for water balance calculation to simulate urban influence.

The water balance equation can be written down as

$$Ps_i = E_i + Q_i + \Delta W; \quad i=1, \ldots, 12 \qquad (5.8)$$

where

Ps_i is rain and snow melt for month i
E_i actual evaporation for month i
Q_i total runoff for month i
and $\Delta W_i = W_{i+1} - W_i$ the difference in water content in unsaturated zone between the end and beginning of month i

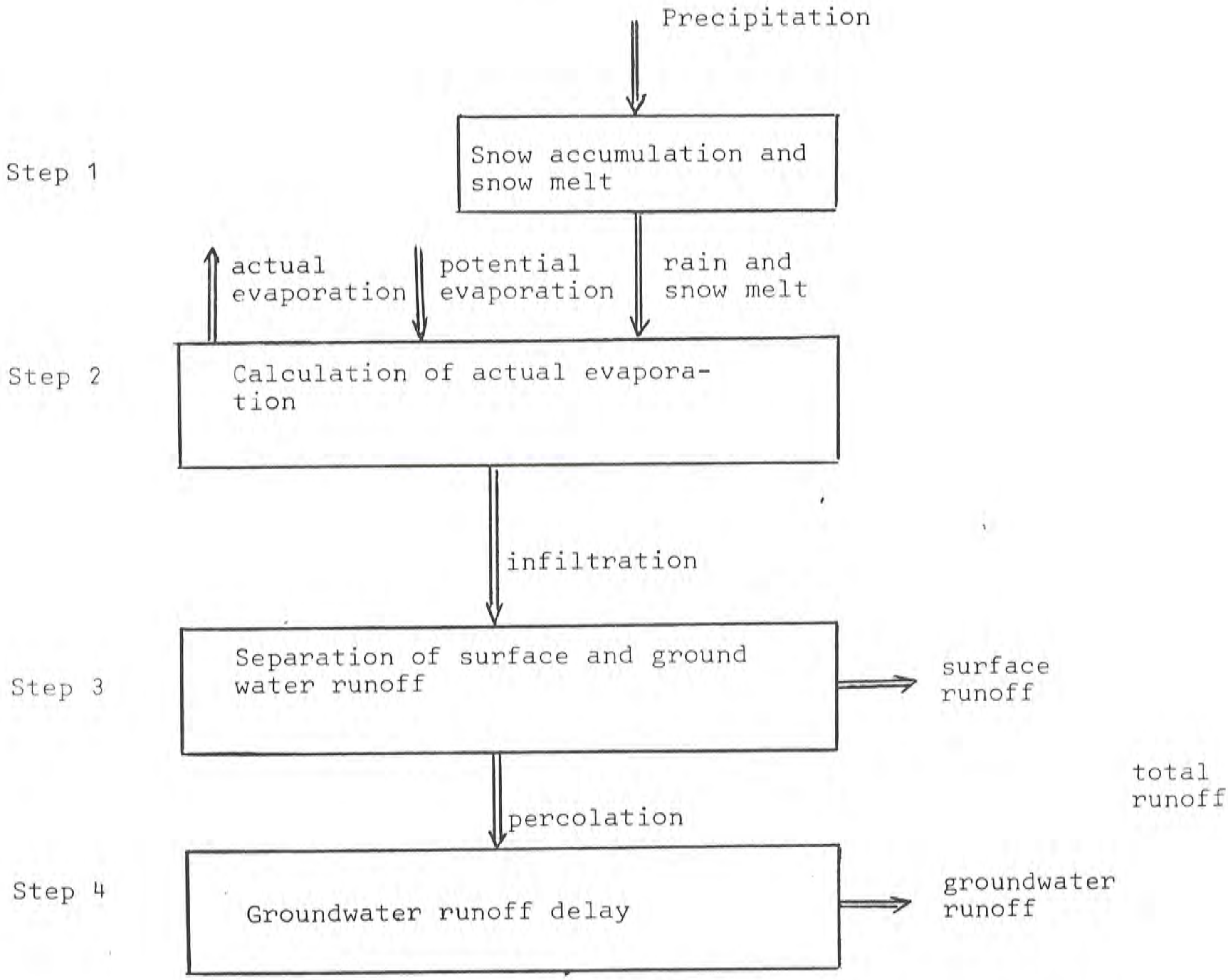


Fig 5.12 Flow chart for water balance calculations for each square.

Equation (5.8) is fundamental in both models.

Water balance step 1

Calculation of snow accumulation and snow runoff has a common procedure. Snow is accumulated when monthly average temperature is below zero. Snow is melted when monthly average temperature is above zero in accordance with the formula

$$Ps_i = T_i\ 30 \quad \text{for forest} \tag{5.9a}$$

$$Ps_i = T_i\ 50 \quad \text{for meadow} \tag{5.9b}$$

Water balance step 2

Step 2 (see fig 5.12) is different for the two models.

Model A:
Actual evaporation is calculated from the potential evaporation by the following formula:

$$E_i = Ep_i \quad \text{if } \overline{W}_i > W_o \tag{5.10a}$$

$$E_i = Ep_i \frac{\overline{W}_i}{W_o} \quad \text{if } \overline{W}_i < W_o \tag{5.10b}$$

where $W_i = (W_i + W_{i+1})/2$ and W_o is the active zone volume, a parameter given in the data sets for each square. Inserting these equations in (5.8) we get an expression to calculate W_{i+1} when W_i is known:

$$W_{i+1} = \frac{1}{1 + \frac{Ep_i}{2W_o}} \left[W_i \left(1 - \frac{Ep_i}{2W_o}\right) + Ps_i - Q_i \right] \tag{5.11a}$$

if $W < W_o$, and

$$W_{i+1} = W_i + Ps_i - Q_i - Ep_i \tag{5.11b}$$

if $\overline{W}_i > W_o$

The calculation is started with $W_1 = W_o$. Q_i is calculated from the condition that $\overline{W}_i$ cannot be larger than W_o. For months when $\overline{W}_i$ is less than W_o, Q_i is zero. When W_1 and W_{i+1} are known E_i is estimated from equations 5.10a and b.

Model B

Total runoff is calculated by the following formulas

$$Q_i = \gamma Ps_i \frac{\overline{W}_i}{W_o} \qquad (5.12)$$

where γ is a coefficient with the minimum value $\gamma = \gamma_o$ if $p_i < Ep_i$ and

$$\gamma = \sqrt{\gamma_o^2 \left[1 - \left(1 - \frac{Ep_i}{Ps_i}\right)^2\right] + \left(1 - \frac{Ep_i}{Ps_i}\right)^2} \qquad (5.13)$$

if $Ps_i > Ep_i$.

γ as a function of Ep/Ps for γ_o equals to 0.20 and 0.30 are shown in fig 5.13. Inserting 5.12 and 5.13 in the water balance equation (5.8) and solving it for W_{i+1} gives us the following equation:

$Ps_i < Ep_i$; $0 < \overline{W}_i < W_o$

$$W_{i+1} = \frac{Ps_i - W_i\left(\frac{Ep_i}{2W_o} + \frac{\gamma_o Ps_i}{2W_o}\right)}{\left(\frac{Ep_i}{2W_o} + \frac{\gamma_o Ps_i}{2W_o} + 1\right)} \qquad (5.14a)$$

$Ps_i < Ep_i$; $\overline{W}_i > W_o$

$$W_{i+1} = \frac{Ps_i - Ep_i - W_i\left(\frac{\gamma_o Ps_i}{2W_o} - 1\right)}{\left(\frac{\gamma_o Ps_i}{2W_o} + 1\right)} \qquad (5.14b)$$

$Ps_i > Ep_i$; $0 < W_i < W_o$.

$$W_{i+1} = \frac{Ps_i - W_i\left(\frac{Ep_i}{2W_o} + \frac{Ps_i}{2W_o}\sqrt{\gamma^2\left[1-\left(1-\frac{Ep_i}{Ps_i}\right)^2\right]+\left(1-\frac{Ep_i}{Ps_i}\right)^2} - 1\right)}{\left[\frac{Ep_i}{2W_o} + \frac{Ps_i}{2W_o}\sqrt{\gamma_o^2\left[1-\left(1-\frac{Ep_i}{Ps_i}\right)^2\right]+\left(1-\frac{Ep_i}{Ps_i}\right)^2} + 1\right]} \qquad (5.14c)$$

$Ps_i > Ep_i$; $\overline{W}_i > W_o$

$$W_{i+1} = \frac{Ps_i - W_i\left(1 - \frac{Ps_i}{2W_o}\sqrt{\gamma^2\left[1-\left(1-\frac{Ep_i}{Ps_i}\right)^2\right]+\left(1-\frac{Ep_i}{Ps_i}\right)^2}\right)}{\left[1 + \frac{Ps_i}{2W_o}\sqrt{\gamma_o^2\left[1-\left(1-\frac{Ep_i}{Ps_i}\right)^2\right]+\left(1-\frac{Ep_i}{Ps_i}\right)^2}\right]} \qquad (5.14d)$$

For this case the calculations are started with $W_1=W_o$, and then W_{i+1} is successively calculated from W_i.

Q_i is determined from eq (5.12) as W_i is known. E_i is estimated from eq (5.8) as all other parameters in this equation now are known.

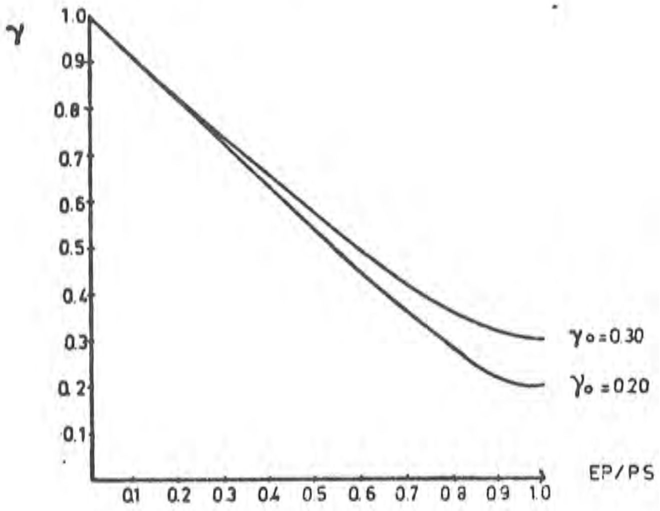


Fig 5.13 Coefficient γ as a function of EP/PS

Water balance step 3

For the separation of groundwater and surface runoff hydrographs from the four hydrologic observation stations without regulation within the test area were used. Dissection was done by the simplest methods (see Luchsheva, 1976). An example is given in fig 5.14. For each station one dry, one wet and two normal years have been analyzed. No regional differences could be traced. The maximal groundwater fed runoff of the total was 27%, the minimal 19% and the average 23%.

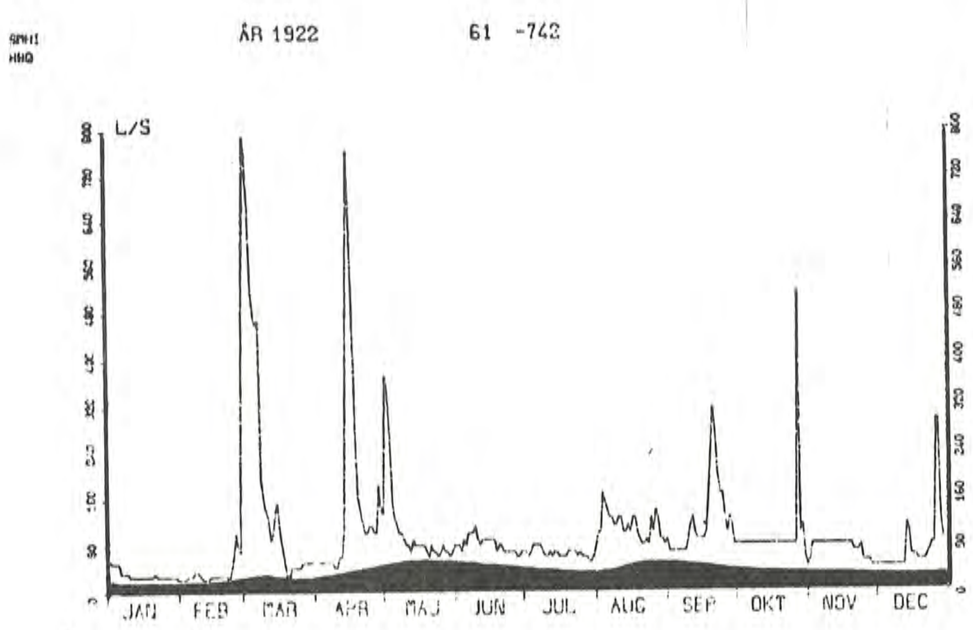
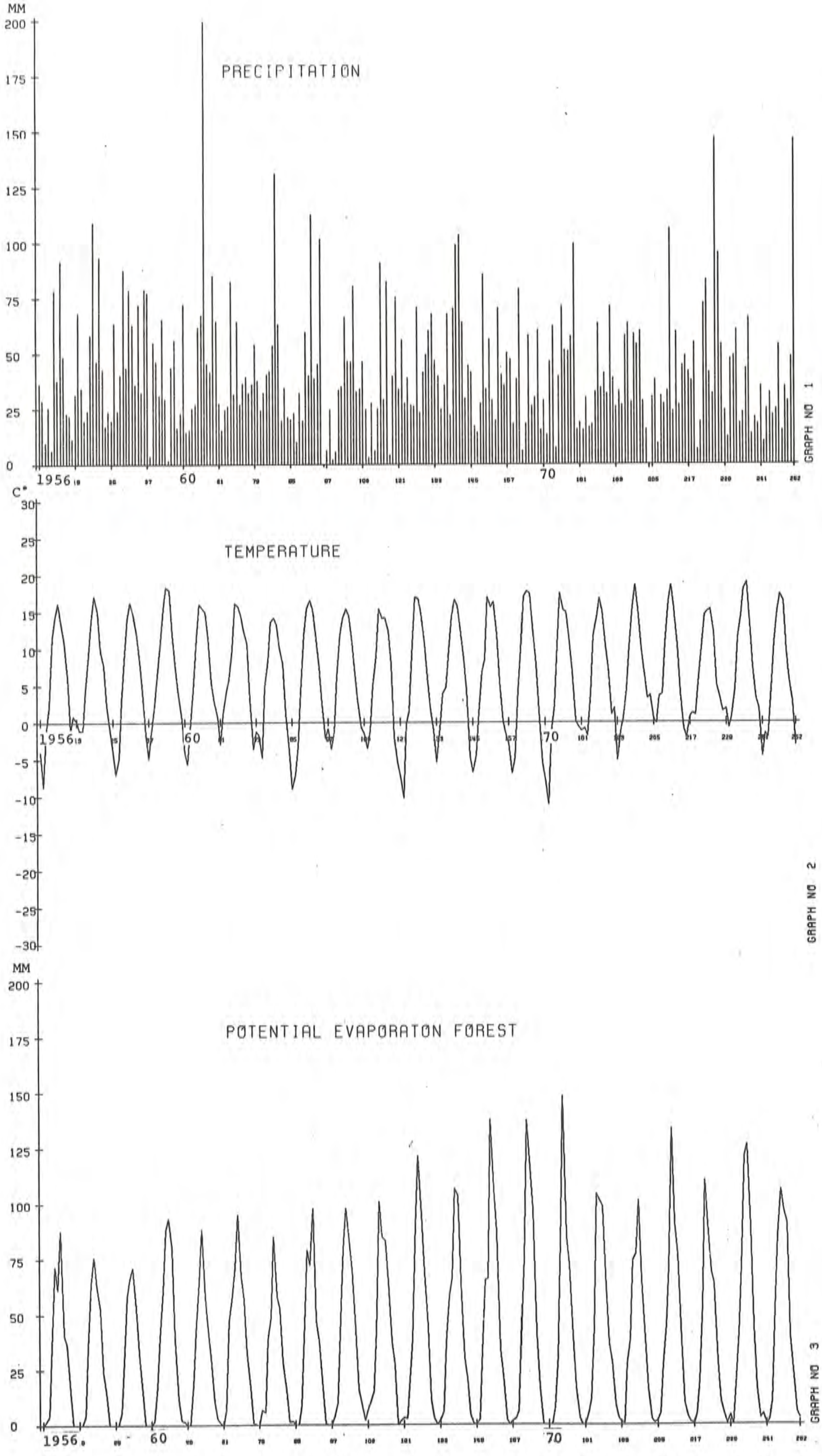


Fig 5.14 Dissection of a hydrograph.

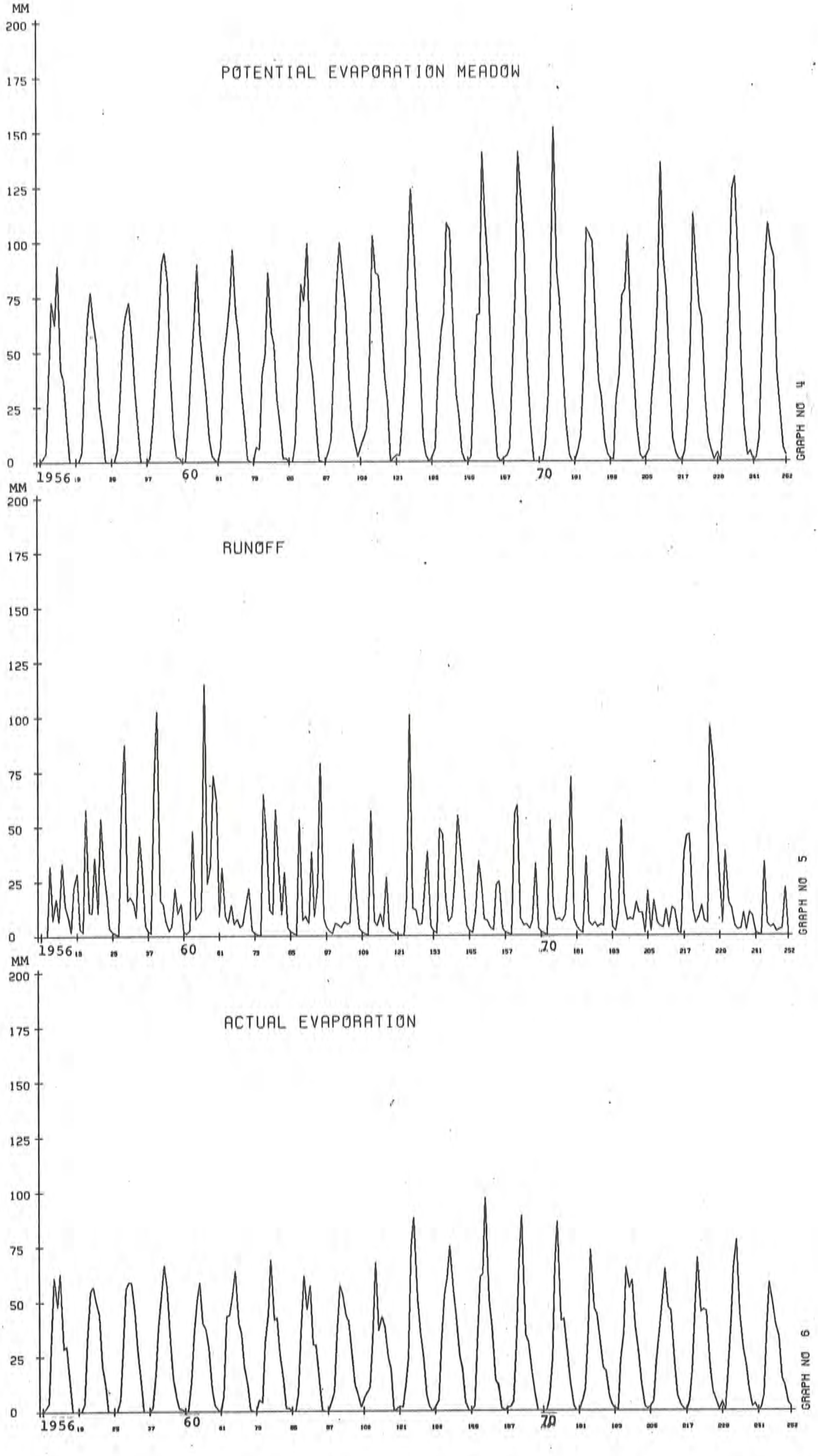
For every month 77% of infiltered water fed surface runoff without delay. The time scale of the runoff process is of negligible order dealing with monthly values (Gottschalk, 1977). As an average, 23% of infiltrated water percolates to groundwater.

Water balance step 4
Groundwater level does not instantly react on infiltrated and percolated water. The response of groundwater level on climatic input has been studied by Gottschalk and Nordberg (1977). Lag coefficients from this study were used here to consider the reservoir effect in the unsaturated and groundwater zones. The chosen response function is very simple and is the exponential decay function.

No definite choice between the two models has been made. It seems, however, that model B gives most realistic values of actual evaporation and runoff. Further comparison is needed. In fig 5.15 an example is shown of water balance calculations with model B for the time period 1956-1976 for square 6490, 570.



<u>Fig 5.15</u> Water balance calculated with model B. (continued next page).



continued Fig 5.15 Water balance calculated with model B.

6. Information retrieval for water balance maps and other purposes

At the present stage of the project much attention was devoted to the problem of automatical production of comprehensive water balance maps. It should be stressed that this is only one, and, perhaps, not the most important, purpose for information retrievals in the described information system. Other purposes have been commented on above in the foreword and in the introduction.

The flow chart of the calculation steps on the computer is shown in fig 6.1 and 6.2. Retrievals are made as spatial data matrices for a certain time period or as water balance time series for a certain square (fig 5.15). The spatial data matrices are transformed to dot screens. The basic element in the screen consists of five dots ⁙ . Elements are combined to give 16 different dot screens of increasing shade intensity (fig 6.3).

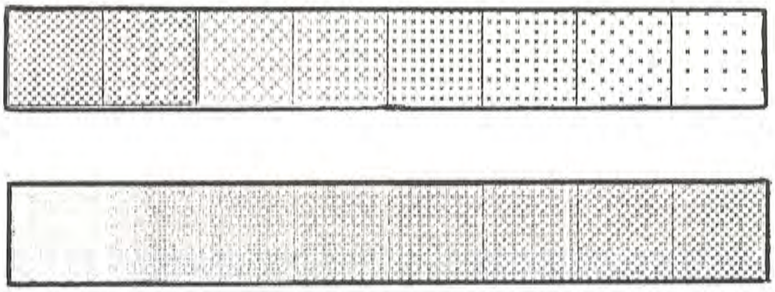


Fig 6.3 Shade intensities of the dot screens.

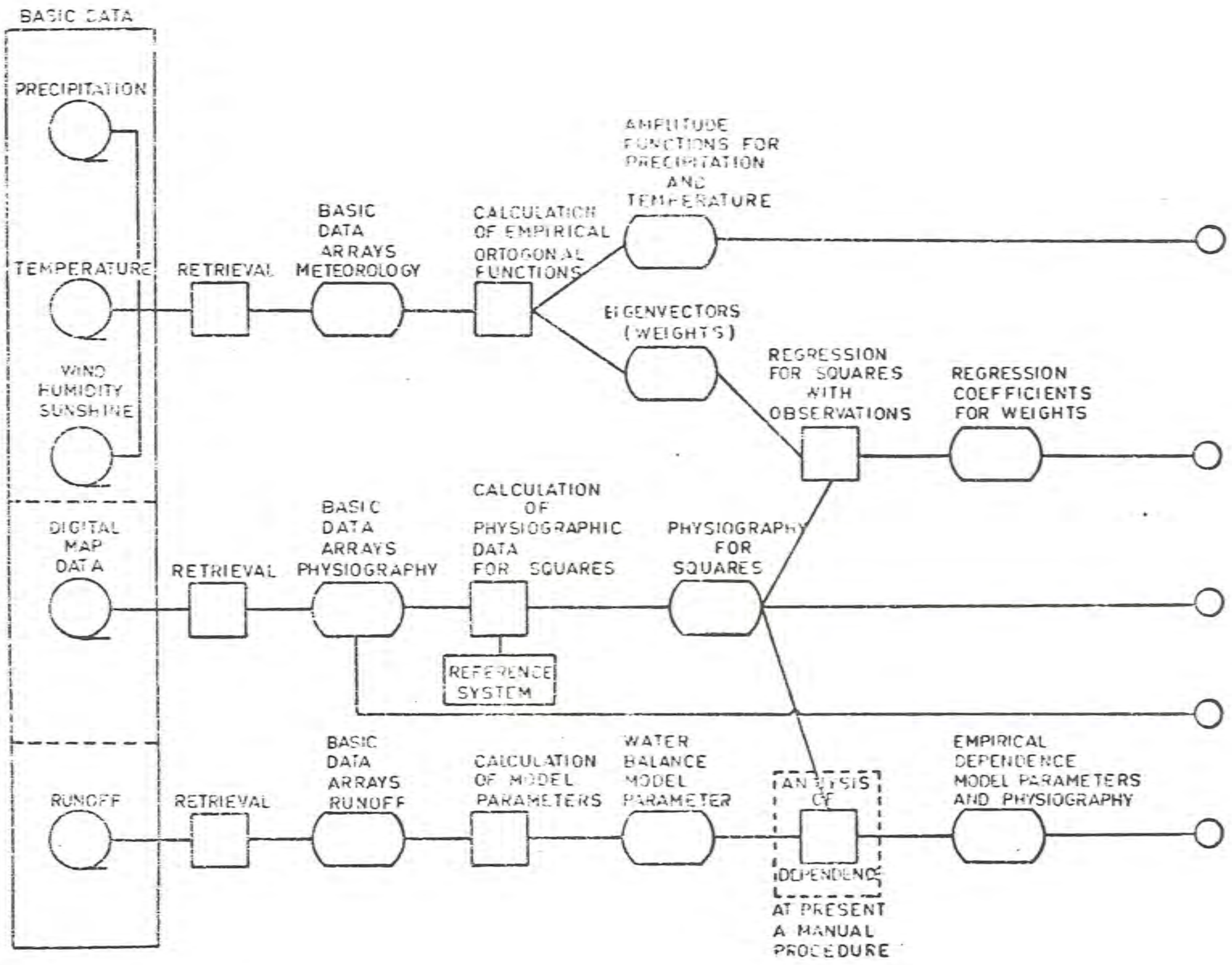


Fig 6.1 Information retrieval for water balance maps.

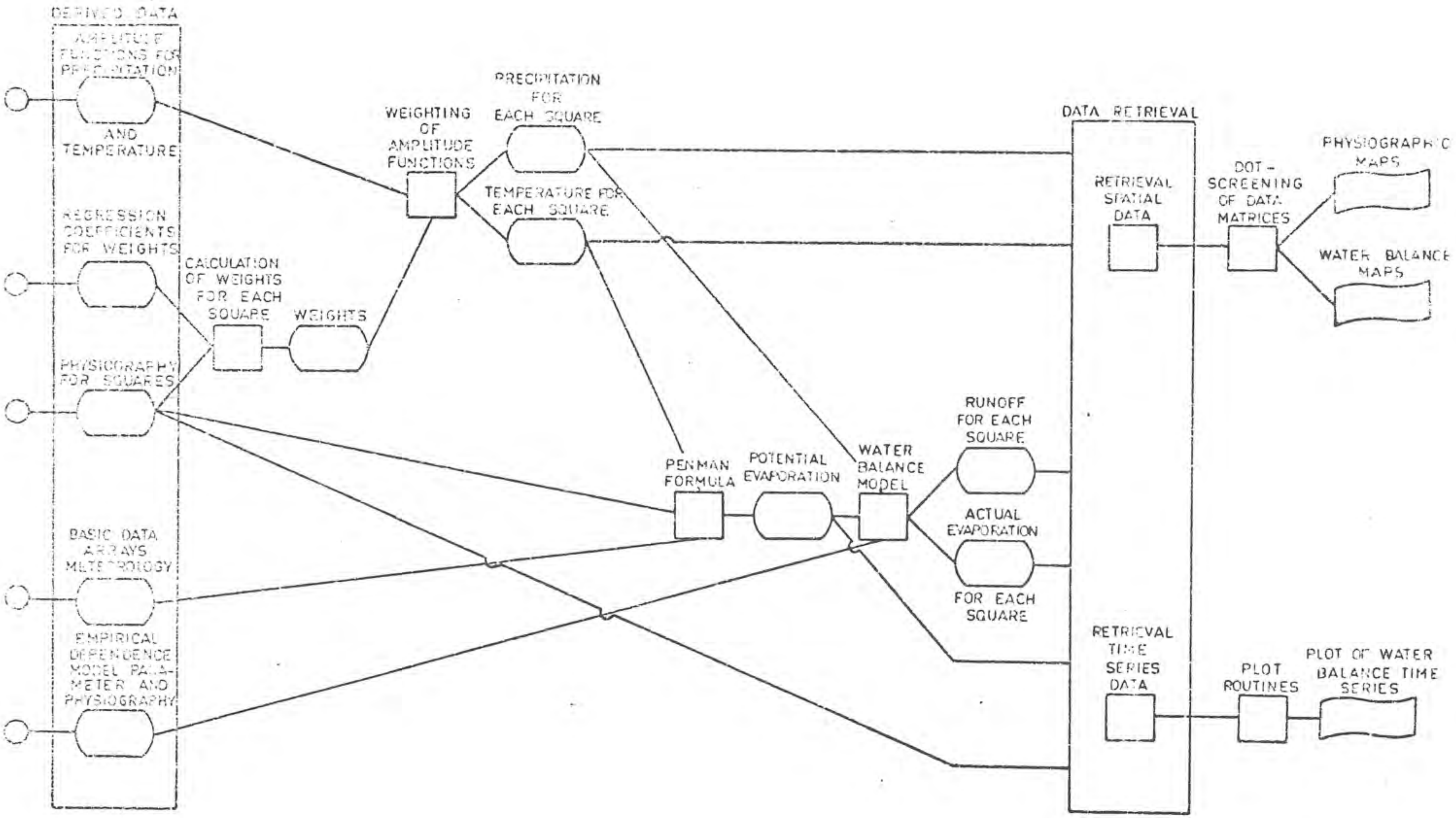


Fig 6.2 Information retrieval for water balance maps (continued).

The following examples of maps are given in the appendix:

6 maps of physiographic elements

- mean elevation
- local relief
- maximal slope
- percentage of lakes
- percentage of swamps
- percentage of forest

5 maps of annual mean values of water balance elements for period 1956-1975

- precipitation
- temperature
- potential evaporation
- runoff
- actual evaporation

5 maps of monthly values of water balance elements for April 1976

- precipitation
- temperature
- potential evaporation
- runoff
- actual evaporation

12 maps of monthly mean values of runoff for period 1956 - 1976

- runoff January - December

7. Conclusions

At the present stage of development of hydrology in Sweden the main problem is the processing and display of the observational data. In this report analyses were concentrated on the data available now: temperature and precipiation observation series and digital topographic map data.

Methods for integration analysis of the present observation data in space were shown and tested. These proved to be both effective and reliable.

The data were subjected to combined analysis. Hydrological phenomenon is the product of climatological and physiographical ones. So these should be analyzed together to get knowledge about hydrological elements.

Problem of data accuracy were studied, as well as problems of grid densities for digital topographic maps. The results showed that 500 m grid step was acceptable from the data accuracy point of view if 10x10 km squares were taken as a computational element. For the true representation of landscape elements on a digital map 500 m step proved to be the largest acceptable for Swedish conditions.

The results of the study: calculated hydrological elements are compatible to other data banks for environmental data. The computational element chosen: 10x10 km can be easily compared to the one used in other banks: 5x5 km by a simple summarizing.

An automatical computer-based system was developed for calculation of hydrological elements on the basis of temperature and precipitation time-series and digital topographic map data. A flow chart scheme presented in the report follows the whole procedure of such calculations, and in particular - water balance calculations.

The system constructed permits retrievals in the data stored, which gives possibilities for automatical hydrological calculations. This procedure is illustrated for the example of water balance calculation.

The procedure of automatical production of maps of hydrological phenomena, based on the 10x10 km computational element has been developed. The principal of cartogram is used and the whole procedure is carried out on the computer. Possibilities of graph-diagram representations are also envisaged. Examples of ready map production are given.

The present study showed how with a synthetical approach one can use the available information to automatically produce the desired hydrological information and present it in a suitable form.

Acknowledgements

This paper is the final report on the project "Spatial correlation of hydrology and physiography", financially supported by the Swedish Natural Science Research Council (NFR), which assistance is gratefully acknowledged. We express here our special gratitude to Professor Ingemar Holmström for his assistance and encouragement in the use of the empirical orthogonal functions. The authors also wish to thank Mrs Kerstin Fabiansen for technical work with the manuscript. Also appreciated is the assistance with dot-screen programs provided by Mr Arne Törnvall.

REFERENCES

Carlston, C.W. and Langbein, W.B.: Rapid approximation of drainage density: line intersection method. U.S. Geological Survey Water Resources Div., Bull., p. 11, 1960.

Cramér, H.: Mathematical methods of statistics. Princeton University Press, Princeton, 1948.

Gottschalk, L.: Correlation structure and time scale of simple hydrologic systems. Nordic Hydrology, 8, 1977, pp. 129-140.

Gottschalk, L.: Urbaniseringens inverkan på avrinningen. 7:e Nordiska symposiet om vattenforskning. Jyväskylä, 1971. Nordforsk, Helsingfors 1973.

Gottschalk, L. and Krasovskaia, I.: Synthetic approach to regional hydrology. SMHI, Research and Training Department, Report serie.

Gottschalk, L. and Nordberg, L.: Mathematical modelling of groundwater level response in different geological environments. SGU, Ser C, Nr 728, Avhandlingar och uppsatser, Årsbok 71, Nr 3, 1977, Stockholm.

Kendall, M.G. and Stuart, A.: The advanced theory of statistics. Vol. 1, Charles Griffin, London 1958.

Korzoun, V.I. et al: World water balance and water resources of the earth. Gidrometeoizdat, Leningrad 1974.

Krasovskaia, I.: Digital physiographic map data and its analysis for hydrologic purposes. 1st report on NFR project "Spatial variation of hydrology and physiography". SMHI, Hydrological Office, Norrköping, 1978.

Krasovskaia, I.: An attempt to estimate some hydrological parameters through physiographic ones. SMHI, HBV PM No 276, 1979.

Lantmäteriet - FRP - faktabanken. Lantmäteriverket. Meddelande 1979:2.

Lindeberg, M.: Beräkning av potentiell avdunstning medelst Penmans formel. Inst för vattenbyggnad. LTH Bulletin. Serie A Nr 20, Lund 1973.

Luchsheva, A.A.: Prakticheskaia girdologia. Gidrometeoizdat, Leningrad 1976.

Mark, D.M.: Geomorphometric parameters: a review and evaluation. Geografiska Annaler, 57 (A), N3-4, 1975.

McCoy, R.: Rapid Measurement of Drainage Density. Geological Society of America, Bulletin v. 82, pp. 757-762, 1971.

Naturgeografisk regionindelning av Norden. Nu, 1977.34, Stockholm.

Pike, P.I. and Wilson, S.E.: Elevation-relief ratio, Hypsometric integral and geomorphic area-altitude analysis. Geological Society of America Bulletin, V. 82, Boulder, Colo, 1971, pp. 1079-1084.

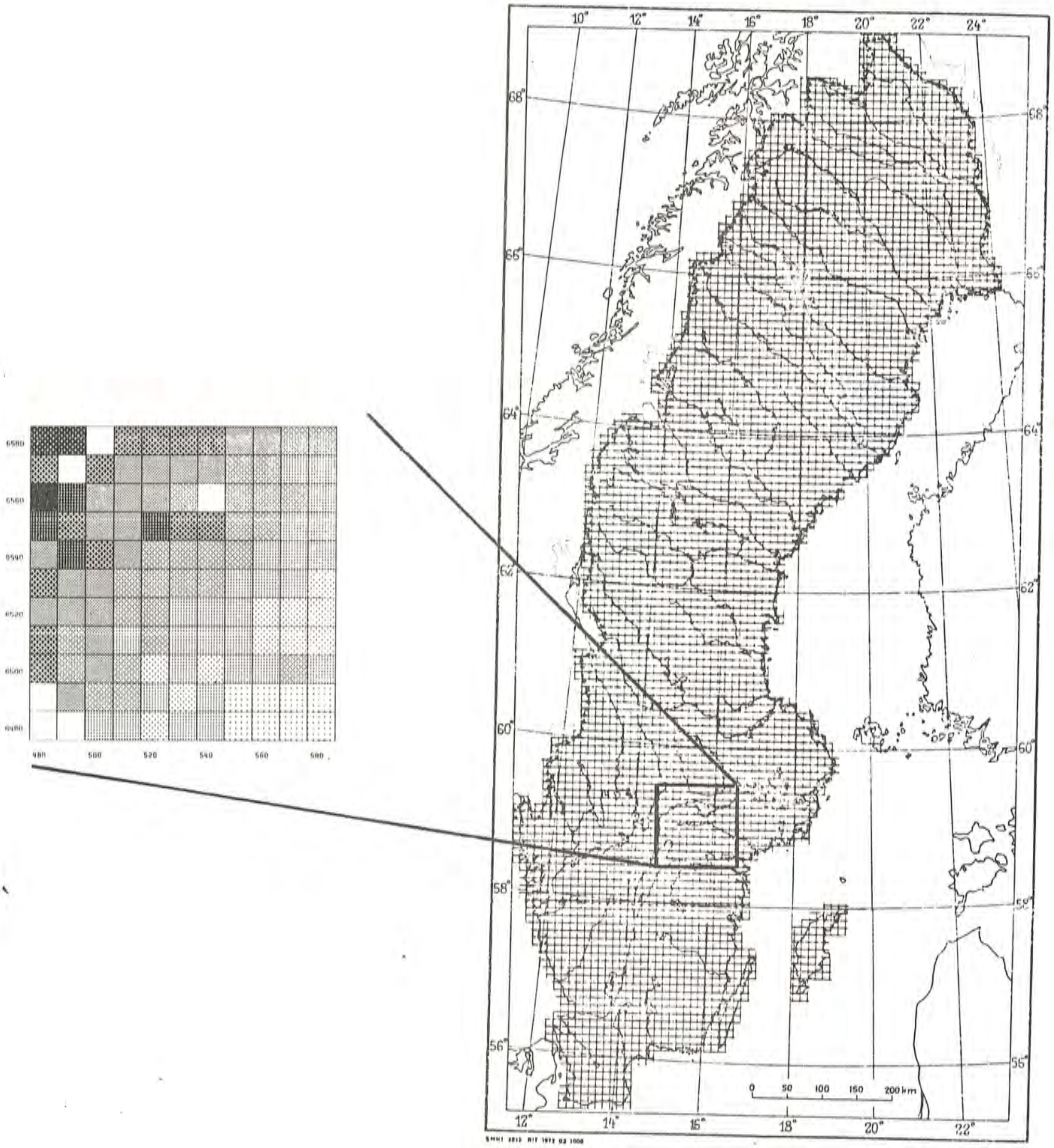
Sellers, W.D.: Physical climatology. The University of Chicago Press. Chicago 1965.

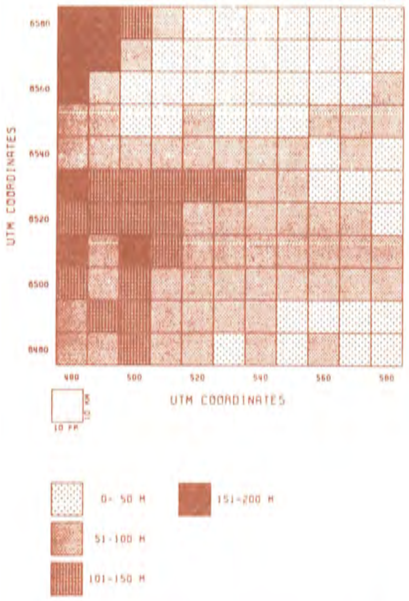
Solomon, S.I. and Quereshi, A.S.: Hydrological Data Banks - Present Status and Future Potential. Engineering Journal. Jan/Feb. 1972.

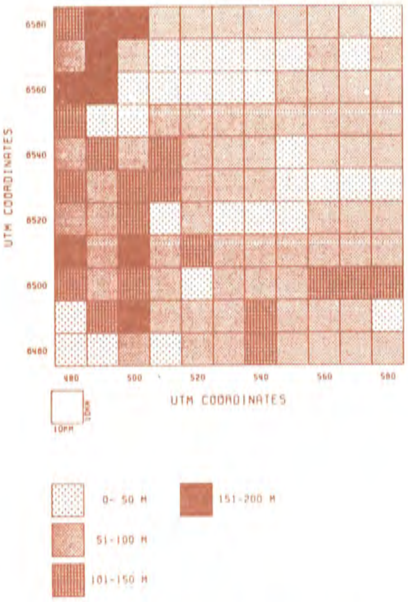
Sveriges Jordarter. SGU, Ser Ba, Nr 17, Stockholm 1958.

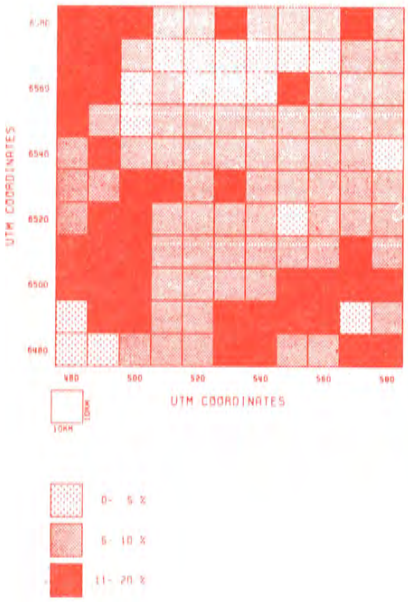
Wallén, C.C.: Global Solar Radiation and Potential Evaporation in Sweden. Meddelanden. Serie B. Nr 24. SMHI, Stockholm 1966.

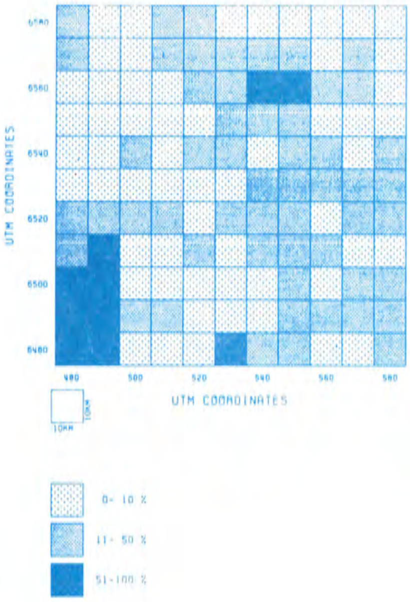
APPENDIX

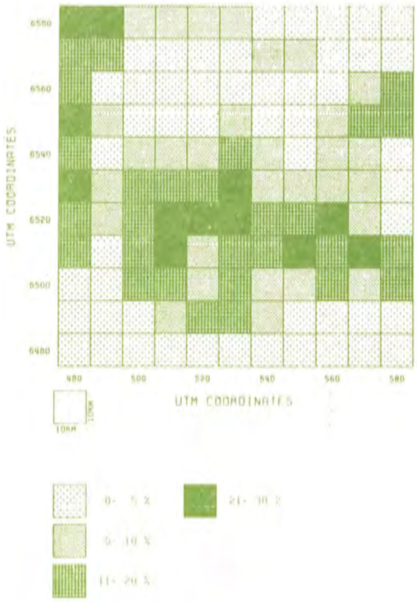

6580
6560
6540
6520
6500
6480
480
500
520
540
560
580
10°
12°
14°
16°
18°
20°
22°
24°
68°
66°
64°
62°
60°
58°
56°
0
50
100
150
200 km
12°
14°
16°
18°
20°
22°

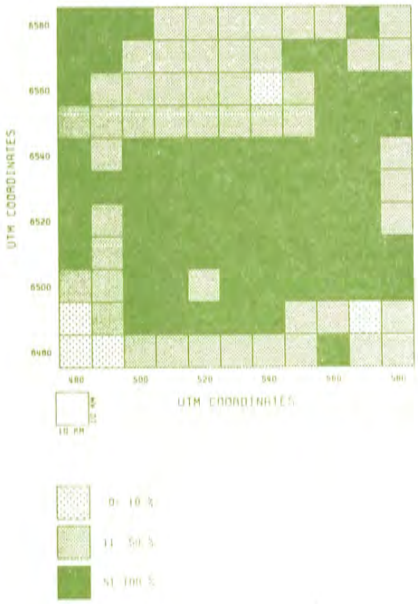

MEAN ELEVATION


LOCAL RELIEF

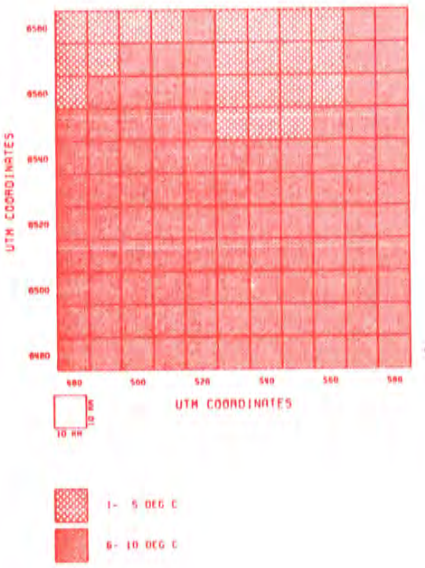

MAXIMAL SLOPE


PERCENTAGE OF LAKES

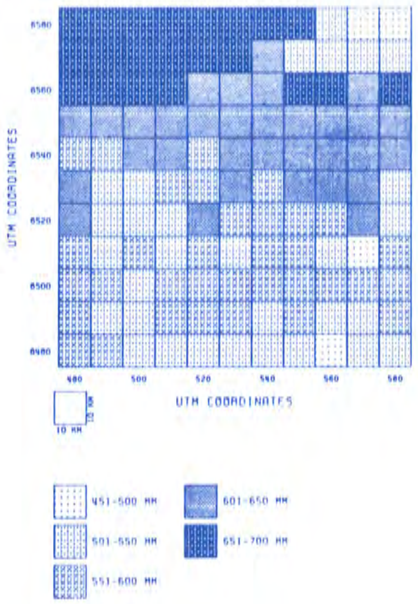

PERCENTAGE OF SWAMPS


PERCENTAGE OF FOREST

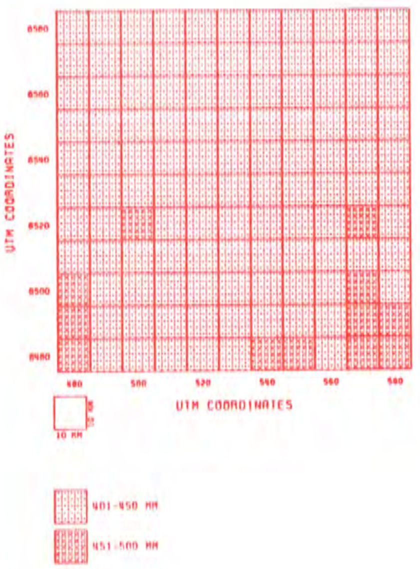
MEAN ANNUAL TEMPERATURE 1956-1976



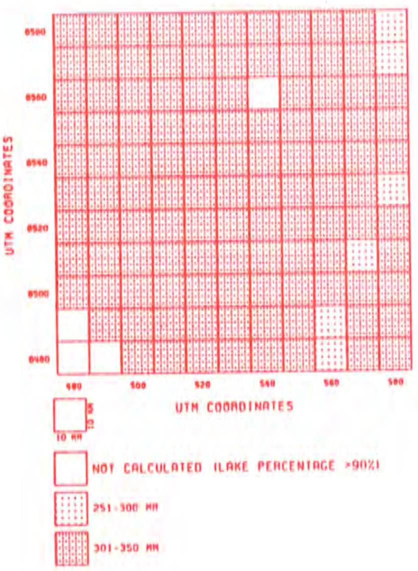
MEAN ANNUAL PRECIPITATION 1956-1976
(CORRECTED TO GROUND LEVEL)



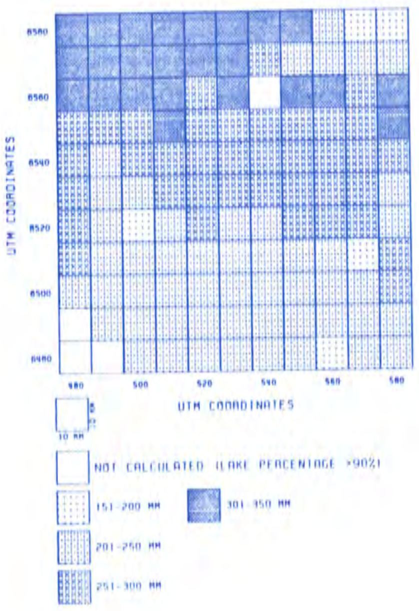
MEAN ANNUAL POTENTIAL EVAPORATION 1956-1976
(MEADOW)



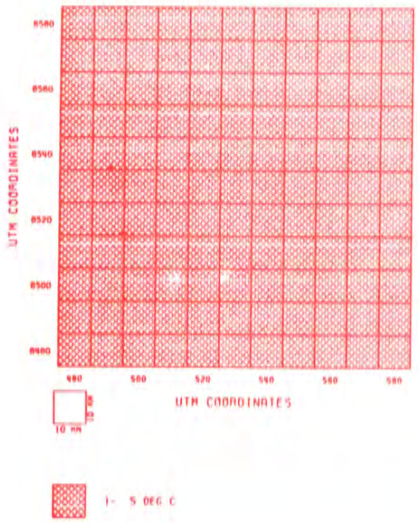
MEAN ANNUAL ACTUAL EVAPORATION 1956-1976
(LAND SURFACE)



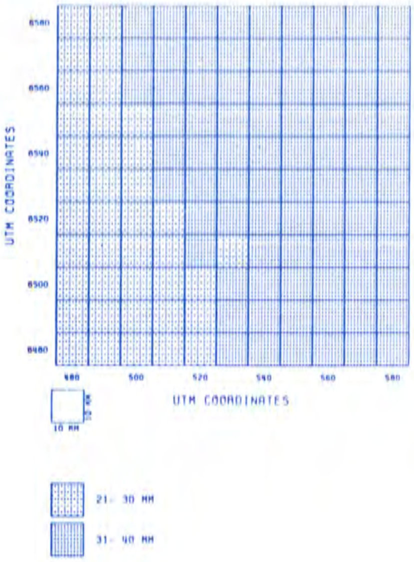
MEAN ANNUAL RUNOFF 1956-1976



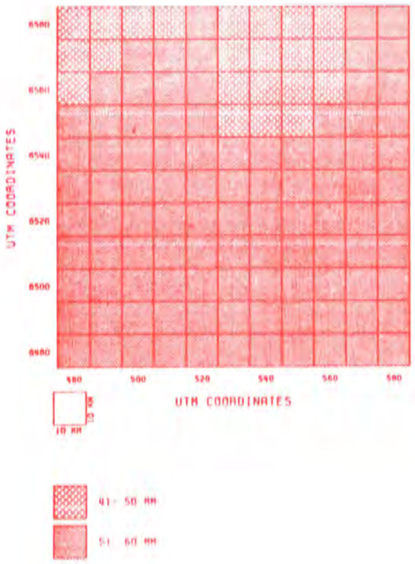
TEMPERATURE FOR MONTH APR. 1976



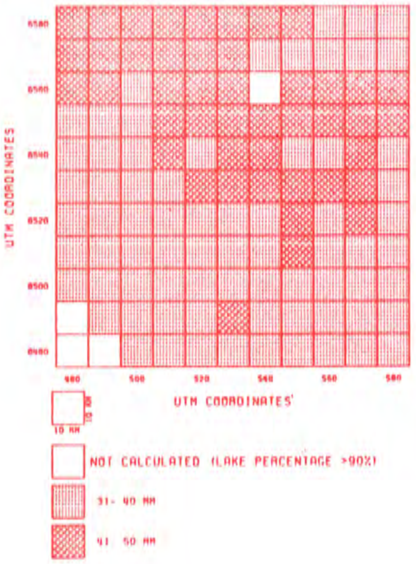
PRECIPITATION FOR MONTH APR. 1976
(CORRECTED TO GROUND LEVEL)



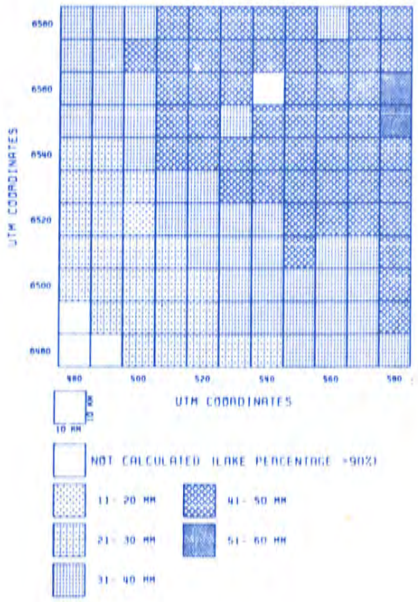
POTENTIAL EVAPORATION FOR MONTH APR. 1976
(MEADOW)



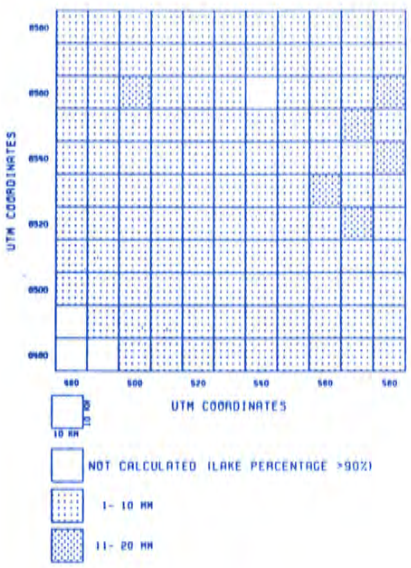
ACTUAL EVAPORATION FOR MONTH APR. 1976
(LAND SURFACE)



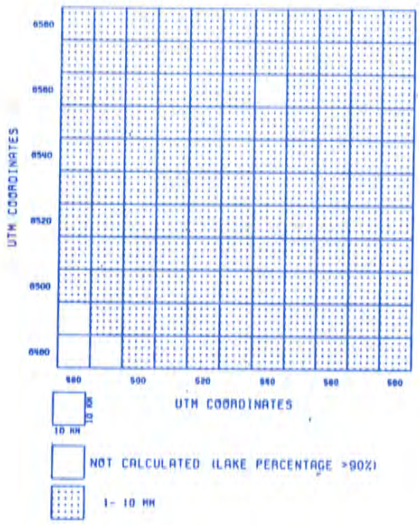
RUNOFF FOR MONTH APR. 1976



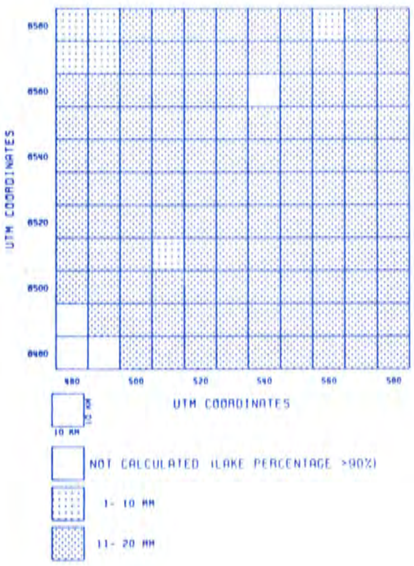
MEAN MONTHLY RUNOFF JAN. -1956-1976



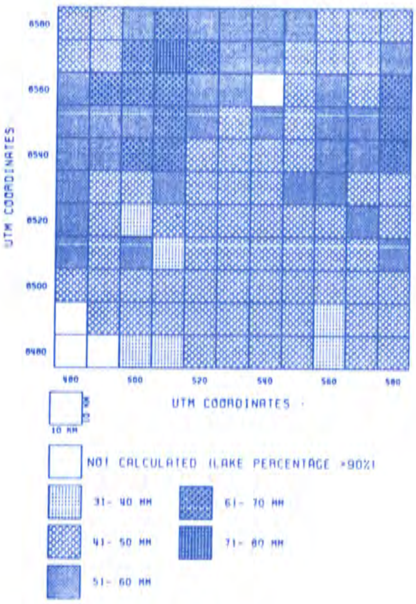
MEAN MONTHLY RUNOFF FEB. -1956-1976



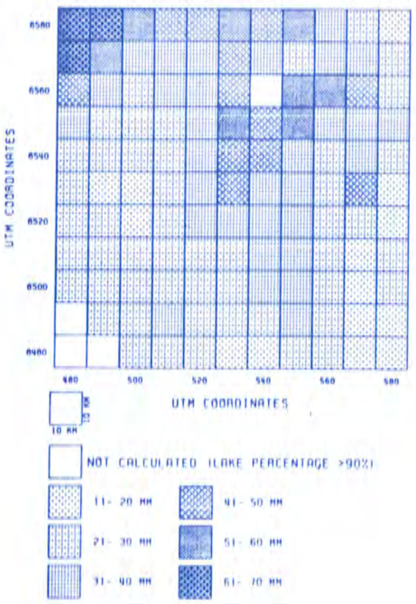
MEAN MONTHLY RUNOFF MAR. -1956-1976



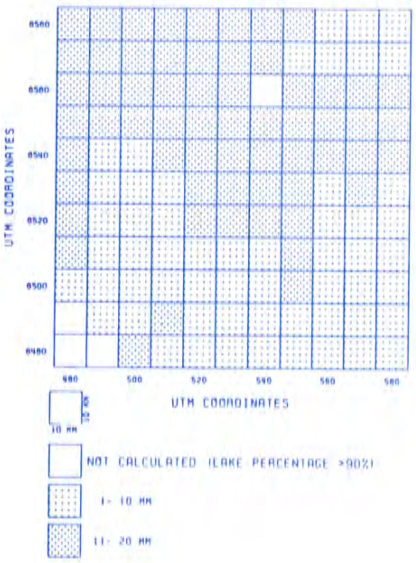
MEAN MONTHLY RUNOFF APR. -1956-1976



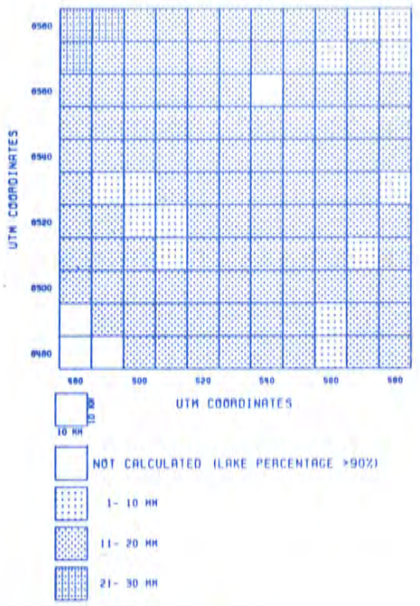
MEAN MONTHLY RUNOFF MAY -1956-1976



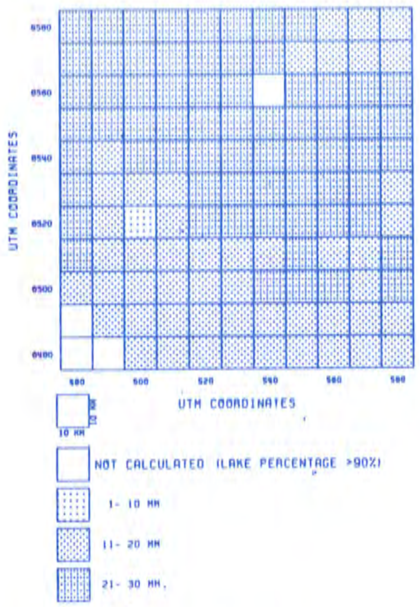
MEAN MONTHLY RUNOFF JUNE -1956-1976



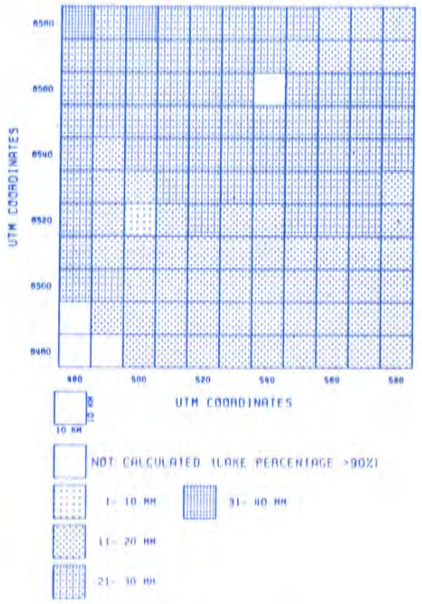
MEAN MONTHLY RUNOFF JULY -1956-1976



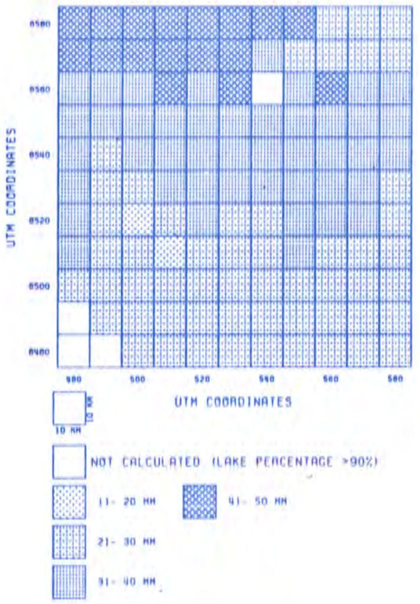
MEAN MONTHLY RUNOFF AUG. -1956-1976



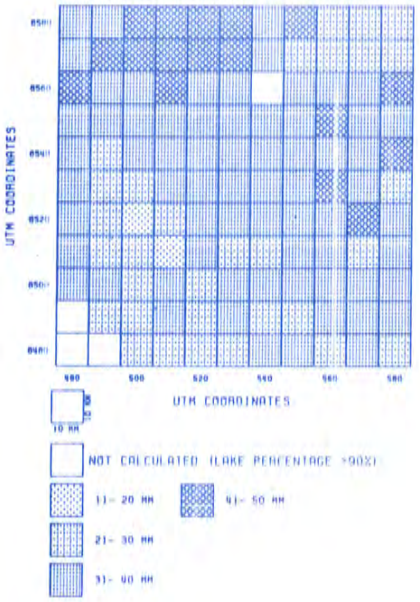
MEAN MONTHLY RUNOFF SEP. -1956-1976



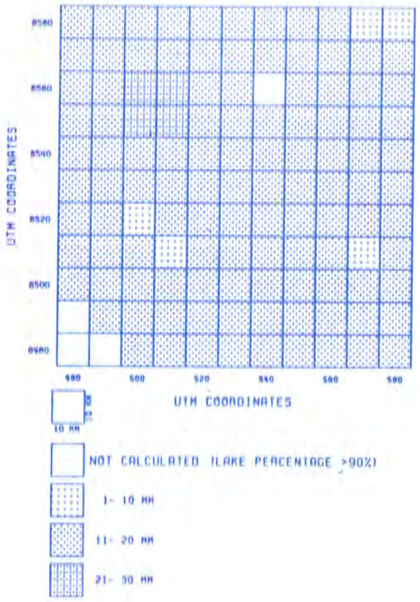
MEAN MONTHLY RUNOFF OCT. -1956-1976



MEAN MONTHLY RUNOFF NOV. -1956-1976



MEAN MONTHLY RUNOFF DEC. -1956-1976



Notiser och preliminära rapporter

Serie HYDROLOGI

Nr 1 Sundberg-Falkenmark, M
Om isbärighet, Stockholm 1963

Nr 2 Forsman, A
Snösmältning och avrinning, Stockholm 1963

Nr 3 Karström, U
Infraröd-teknik i hydrologisk tillämpning: Värmebilder som hjälpmedel i recipientundersökningar, Stockholm 1966

Nr 4 Moberg, A
Svenska sjöisars isläggnings- och islossningstidpunkter 1911/12-1960/61. Del 1. Redovisning av observationsmaterial, Stockholm 1967

Nr 5 Ehlin, U och Nyberg, L
Hydrografiska undersökningar i Nordmalingsfjärden, Stockholm 1968

Nr 6 Milanov, T
Avkylningsproblem i recipienter vid utsläpp av kylvatten, Stockholm 1969

Nr 7 Ehlin, U och Zachrisson, G
Spridningen i Vänerns nordvästra del av suspenderat material från skredet i Norsälven i april 1969, Stockholm 1969

Nr 8 Ehlert, K
Mälarens hydrologi och inverkan på denna av alternativa vattenavledningar från Mälaren, Stockholm 1970

Nr 9 Ehlin, U och Carlsson, B
Hydrologiska observationer i Vänern 1959-1968 jämte sammanfattande synpunkter, Stockholm 1970

Nr 10 Ehlin, U och Carlsson, B
Hydrologiska observationer i Vänern 17-21 mars 1969, Stockholm 1970

Nr 11 Milanov, T
Termisk spridning av kylvattenutsläpp från Karlshamnsverket, Stockholm 1971

Nr 12 Persson, M
Hydrologiska undersökningar i Lappträskets representativa område. Rapport I, Stockholm 1971

Nr 13 Persson, M
Hydrologiska undersökningar i Lappträskets representativa område. Rapport II. Snömätningar med snörör och snökuddar, Stockholm 1971

Nr 14 Hedin, L
Hydrologiska undersökningar i Velens representativa område. Beskrivning av området, utförda mätningar samt preliminära resultat. Rapport I, Stockholm 1971

Nr 15 Forsman, A och Milanov, T
Hydrologiska undersökningar i Velens representativa område. Markvattenstudier i Velenområdet. Rapport II, Stockholm 1971

Nr 16 Hedin, L
Hydrologiska undersökningar i Kassjöåns representativa område. Nederbördens höjdberoende samt kortfattad beskrivning av området. Rapport I, Stockholm 1971

Nr 17 Bergström, S och Ehlert, K
Stochastic streamflow synthesis at the Velen representative basin, Stockholm 1971

Nr 18 Bergström, S
Snösmältningen i Lappträskets representativa område som funktion av lufttemperaturen, Stockholm 1972

Nr 19 Holmström, H
Test of two automatic water quality monitors under field conditions, Stockholm 1972

Nr 20 Wennerberg, G
Yttemperaturkartering med strålningstermometer från flygplan över Vänern under 1971, Stockholm 1972

Nr 21 Prych, A
A warm water effluent analyzed as a buoyant surface jet, Stockholm 1972

Nr 22 Bergström, S
Utveckling och tillämpning av en digital avrinningsmodell, Stockholm 1972

Nr 23 Melander, O
Beskrivning till jordartskarta över Lappträskets representative område, Stockholm 1972

Nr 24 Persson, M
Hydrologiska undersökningar i Lappträskets representativa område. Rapport III. Avdunstning och vattenomsättning, Stockholm 1972

Nr 25 Häggström, M
Hydrologiska undersökningar i Velens representativa område. Rapport III. Undersökning av torrperioderna under IHD-åren fram t o m 1971, Stockholm 1972

Nr 26 Bergström, S
The application of a simple rainfall-runoff model to a catchment with incomplete data coverage, Stockholm 1972

Nr 27 Wändahl, T och Bergströn, E
Oceanografiska förhållanden i svenska kustvatten, Stockholm 1973

Nr 28 Ehlin, U
Kylvattenutsläpp i sjöar och hav, Stockholm 1973

Nr 29 Andersson, U-M och Waldenström, A
Mark- och grundvattenstudier i Kassjöåns representativa område, Stockholm 1973

Nr 30 Milanov, T
Hydrologiska undersökningar i Kassjöåns representativa område. Markvattenstudier i Kassjöåns område. Rapport II, Stockholm 1973

SMHI Rapporter

HYDROLOGI OCH OCEANOGRAFI

Nr RHO 1 Weil, J G
Verification of heated water jet numerical model, Stockholm 1974

Nr RHO 2 Svensson, J
Calculation of poison concentrations from a hypothetical accident off the Swedish coast, Stockholm 1974

Nr RHO 3 Vasseur, B
Temperaturförhållanden i svenska kustvatten, Stockholm 1975

Nr RHO 4 Svensson, J
Beräkning av effektiv vattentransport genom Sunninge sund, Stockholm 1975

Nr RHO 5 Bergström, S och Jönsson, S
The application of the HBV runoff model to the Filefjell research basin, Norrköping 1976

Nr RHO 6 Wilmot, W
A numerical model of the effects of reactor cooling water on fjord circulation, Norrköping 1976

Nr RHO 7 Bergström, S
Development and application of a conceptual runoff model, Norrköping 1976

Nr RHO 8 Svensson, J
Seminars at SMHI 1976-03-29--04-01 on numerical models of the spreading of cooling water, Norrköping 1976

Nr RHO 9 Simons, J, Funkquist, L och Svensson, J
Application of a numerical model to Lake Vänern, Norrköping 1977

Nr RHO 10 Svensson, J
A statistical study for automatic calibration of a conceptual runoff model, Norrköping 1977

Nr RHO 11 Bork, I
Model studies of dispersion of pollutants in Lake Vänern, Norrköping 1977

Nr RHO 12 Fremling, S
Sjöisars beroende av väder och vind, snö och vatten, Norrköping 1977

Nr RHO 13 Fremling, S
Sjöisars bärighet vid trafik, Norrköping 1977

Nr RHO 14 Bork, I
Preliminary model studies of sinking plumes, Norrköping 1978

Nr RHO 15 Svensson, J och Wilmot, W
A numerical model of the circulation in Öresund. Evaluation of the effect of a tunnel between Helsingborg and Helsingör, Norrköping 1978

Nr RHO 16	Funkquist, L En inledande studie i Vätterns dynamik, Norrköping 1978
Nr RHO 17	Vasseur, B Modifying a jet model for cooling water outlets, Norrköping 1979
Nr RHO 18	Udin, I och Mattisson, I Havsis- och snöinformation ur datorbearbetade satellitdata - en metodstudie, Norrköping 1979
Nr RHO 19	Ambjörn, C och Gidhagen, L Vatten- och materieltransporter mellan Bottniska viken och Östersjön, Norrköping 1979
Nr RHO 20	Gottschalk, L och Jutman, T Statistical analysis of snow survey data, Norrköping 1979
Nr RHO 21	Eriksson, B Sveriges vattenbalans. Årsmedelvärde (1931-60) av nederbörd, avdunstning och avrinning
Nr RHO 22	Gottschalk, L and Krasovskaia, I Synthesis, processing and display of comprehensive hydrologic information