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NORWEGIAN WATER RESOURCES AND ELECTRICITY BOARD
HYDROLOGICAL DIVISION

FLOOD FORECASTING MODEL FOR THE LOWER GLOMMA CATCHMENT

Jan H. Andersen

ABSTRACT

In this study a deterministic model for simulation and forecasts of flood discharges in the lower Glomma catchment is discussed. The model contains two basic routines: the HBV-3 model for calculation of inflow from subcatchments and tributaries, and a routine to route the floods downward the main channel of Glomma. The total area is about 7700 km^2 and is divided into 14 subcatchments along the main channel. The travel time from the upper to the lower reaches is about 3 days. It is therefore possible to make a 3-day forecast of flood discharges for the lower part of the area.

INTRODUCTION

Flood forecasts for the lower part of Glomma have previously been based on statistical relationships between runoff at different locations in the main channel and its tributaries (Tollan and Hegge, 1968).

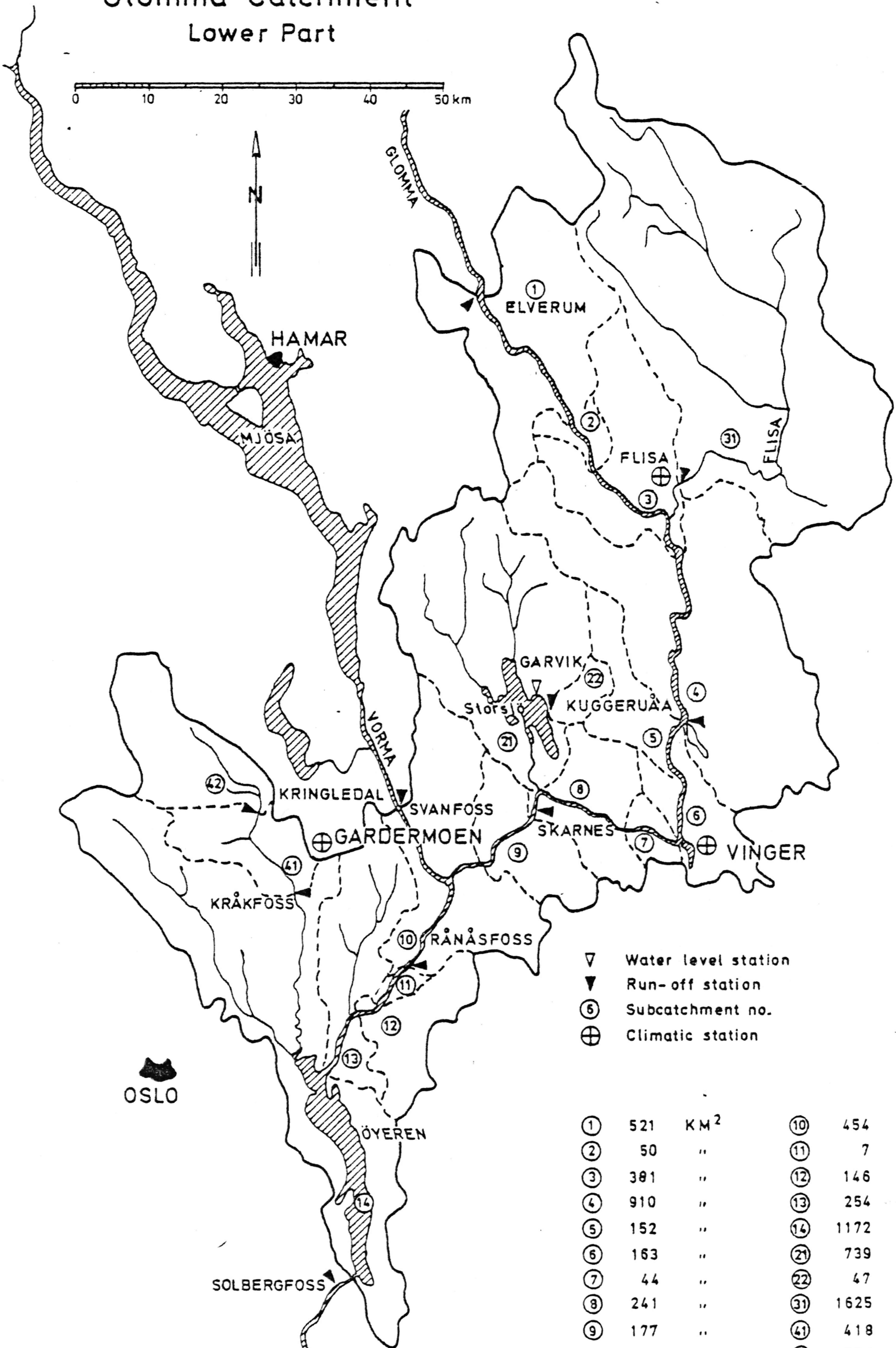
However, changes in the runoff conditions and operation routines of upstream reservoirs have made it necessary to apply a different approach. The basic work on a routing model was carried out by Lars Gottschalk (Gottschalk, 1975. Unpublished). The present model is based on his work and has been extended to include the HBV-3 model for calculation of inflow from tributaries and subcatchments.

DESCRIPTION OF THE CATCHMENT

The modelled area cover about 7700 km^2 of the lower Glomma catchment. The travel time from the upper end at Elverum down to lake Øyeren is about three days. The inflow from lake Mjøsa at Svanfoss is controlled and rather easy to estimate for a periode of three days. Provided the flow from subcatchments along the main channel is calculated, three days forecasts of inflow to lake Øyeren can be worked out.

At lake Storsjø the flow may run into or out from the lake depending on

Glomma Catchment
Lower Part



▽ Water level station
▼ Run- off station
⑥ Subcatchment no.
⊕ Climatic station

1	521	KM^2	10	454	KM^2
2	50	"	11	7	"
3	381	"	12	146	"
4	910	"	13	254	"
5	152	"	14	1172	"
6	163	"	21	739	"
7	44	"	22	47	"
8	241	"	31	1625	"
9	177	"	41	418	"
			42	261	"

TOTAL AREA 7760 KM^2

the difference in water levels at the lake and the main channel of Glomma. The flood damping effect of the lake is thus increased by inflow from Glomma. Unfortunately there are no measurements of the discharges in the channel connecting Glomma to the lake. In 1970 and 1978, however, there are some observations on the direction of the flow.

Comparison of calculated and observed runoff can be made at different locations along the main channel and within subcatchments. The observed records along the main channel are mainly based on data from hydro power stations. The quality of these data are, however, rather poor.

DESCRIPTION OF THE MODEL

Along the main channel the area has been divided in 14 subcatchments. Inflow from these catchments are calculated by applying the HBV-3 model. Data on precipitation and temperature are selected from three climatic stations: Gardermoen, Flisa and Vinger. The runoff from catchment no. 21 is routed through lake Storsjø and flow to or from the main channel of Glomma is calculated.

Flow from subcatchments no.31,22,41 and 42 are included to compare with observed runoff data.

Data defining a mean cross section for eash segment of the channel, are compiled from maps in the scale 1:5000. A model cross-section consists of one rectangular bottom section and two trapezoidal sections determined by the horizontal distances to the nearest 5 meter and 10 meter contour-lines respectivly (Fig.1).

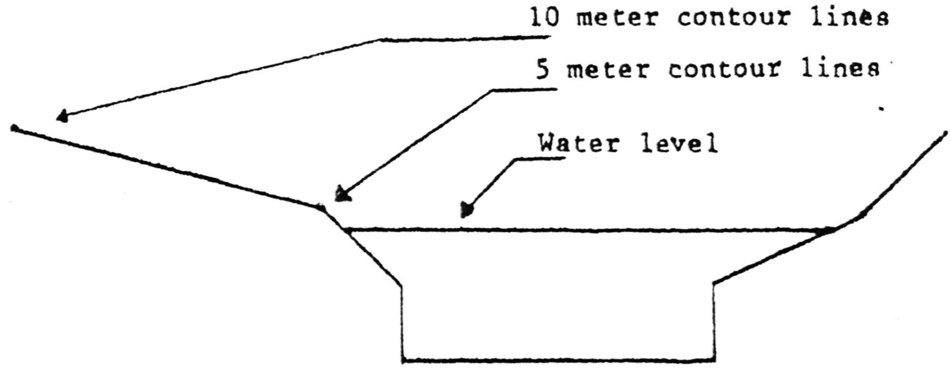


Fig. 1. Model cross section

Outflow from one segment J of the channel is calculated from the following equation:

$$q_J = q_{J-1} + q_{IN} + \frac{dV}{dt}$$

where

q_J : outflow from section no.J

q_{J-1}: outflow from section no. J-1

q_{IN} : inflow from subcatchment no.J

$\frac{dV}{dt}$: changes in storage in section no.J.

Chezy's formula defines the relationship between outflow and water level where the rating curve is not established.

$$Q = A \cdot C \cdot \sqrt{R}\ \sqrt{i}$$

A: mean crossection area

R: hydraulic radius

i: slope of the surface along the section. The slope is kept constant.

The relationship between constant, C, and the parameter of roughness, n, is according to Bykov (1977)

$$C = 1/n\ R^Y$$

$$Y = 0.13 + 0.75\sqrt{R}\ (\sqrt{n} - 0.1) - 2.5\ n$$

The calculation of inflow from subcatchments have been based on daily values. The routing, however, has been performed on hourly values with interpolated data on inflow.

The model can be applied from the foregoing autumn to accumulate the snow reservoir or it can be based on snow measurements made before the start of the melt season.

No procedure for automatic updating has been included.

The HBV-3 model has been calibrated for two subcatchments (no.31, Flisa and no.22, Kuggerudåa). Based on the results from these two calibrations a parameter estimate has been made for the other subcatchments.

DISCUSSION OF THE RESULTS

The simulation of the 1967-flood is presented in Fig.2. The HBV-3 model has been applied to precipitation and temperature from September 1966 to accumulate values for the snow reservoir. This flood has not been used in the calibration of the model and may thus be considered as a test on independent data.

Upstream lake Storsjø, at station Nor, the observed flood hydrograph have fluctuations which are not present in observed hydrographs downstream lake Storsjø. In the simulated hydrographs, however, the fluctuations are still present. This may indicate that the flood damping effect of lake Storsjø is underestimated in the model. The simulated inflow to the lake is therefore probably too low.

In Fig.3 the simulated runoff from subcatchment no.41, Kråkfoss, are compared with observed runoff data. On the recession limb of the hydrograph the simulated values are too low. This indicate that the accumulation of snow throughout the winter has been underestimated.

Three days flood forecasts of runoff at Rånåsfoss and inflow to lake Øyeren are based on snow measurements by the end of February (Fig.5). To include changes of the snow reservoir prior to the main flood the simulations starts by March 1. No attempt has been made to update the model to make the result fit to the observed data. Three days forecasts are worked out by a manual adjustment of the simulated values, based on weather forecasts.

In the beginning of the flood the runoff is dominated by inflow from the subcatchments in the lower part of the area. In the case of the 1978-flood the snow reservoir is probably too low and the forecasts have been based on too low estimates of the temperatures.

Near the peak the runoff is disturbed by inflow to lake Storsjø and operation of the gates at Rånåsfoss hydro power stations to increase the head.

Between May 19 and May 30 both simulated and observed flow direction was into lake Storsjø. The computed values, however, were below 20 m^3/s and too low to have any significant flood damping effect.

CONCLUSIONS

The model should be considered as a first approach towards an operational prognostic model for the lower Glomma catchment. The model can be improved by a better calibration of the HBV-3 model for all the gauged subcatchments. If necessary, data from other climatic station can be included.

Flow measurements in the river connecting lake Storsjø to Glomma are required to obtain more information of the flow at different slopes and water levels.

In the routing model the slope of the surface is kept constant througout the flood. Other methods which includes variable slopes should be considered, provided the costs involved in the operation of the model will not be too high.

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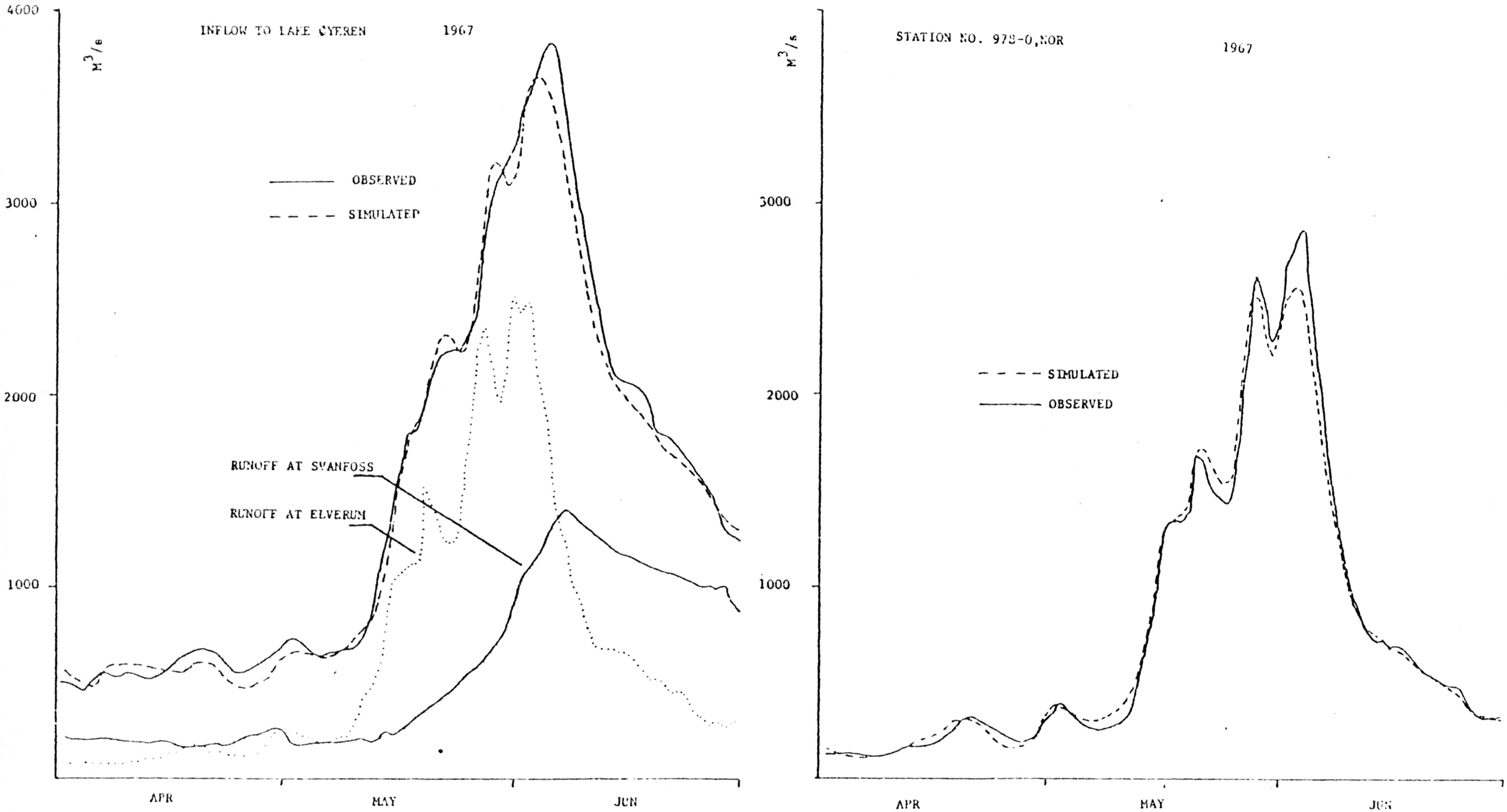


Fig. 2 Hydrographs at station no 978-0, Nor and inflow to lake Øyeren. Flood season 1967.

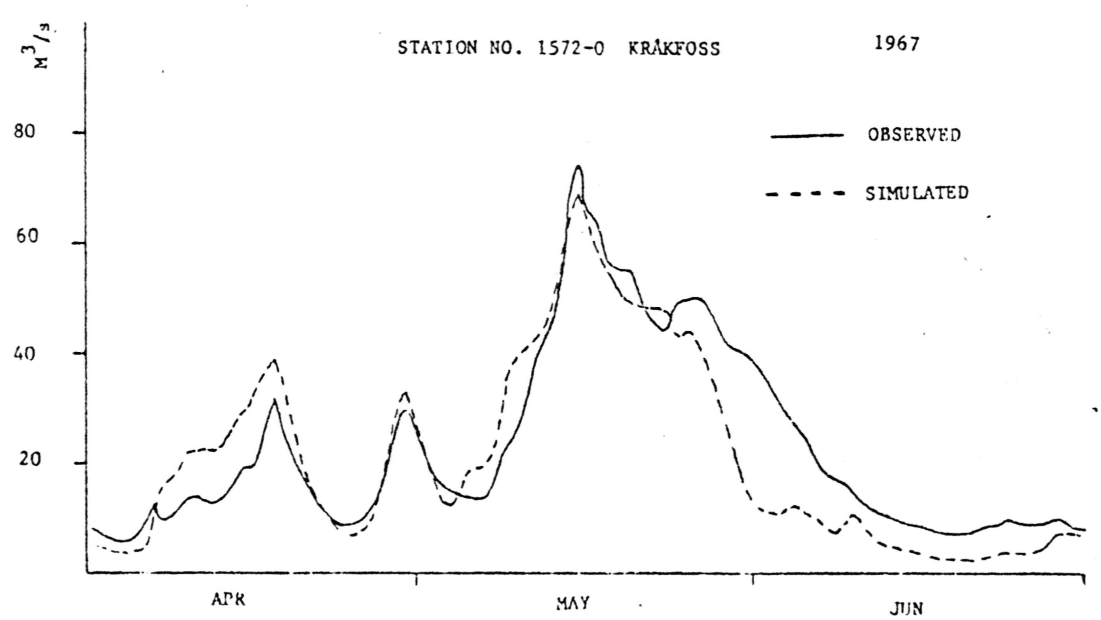


Fig. 3 Hydrographs at station no 1572-0 Kråkfoss. Flood season 1967.

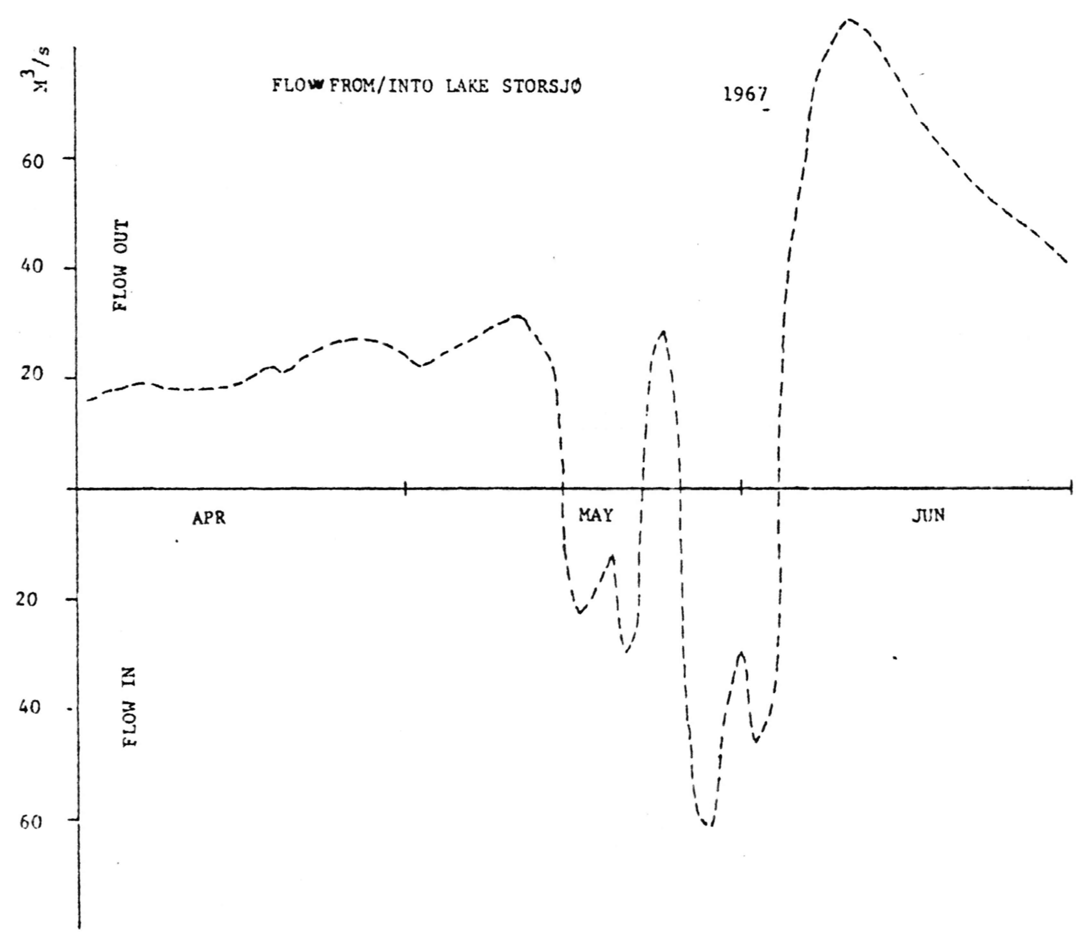


Fig. 4 In/outflow from lake Storsjø. Flood season 1967.

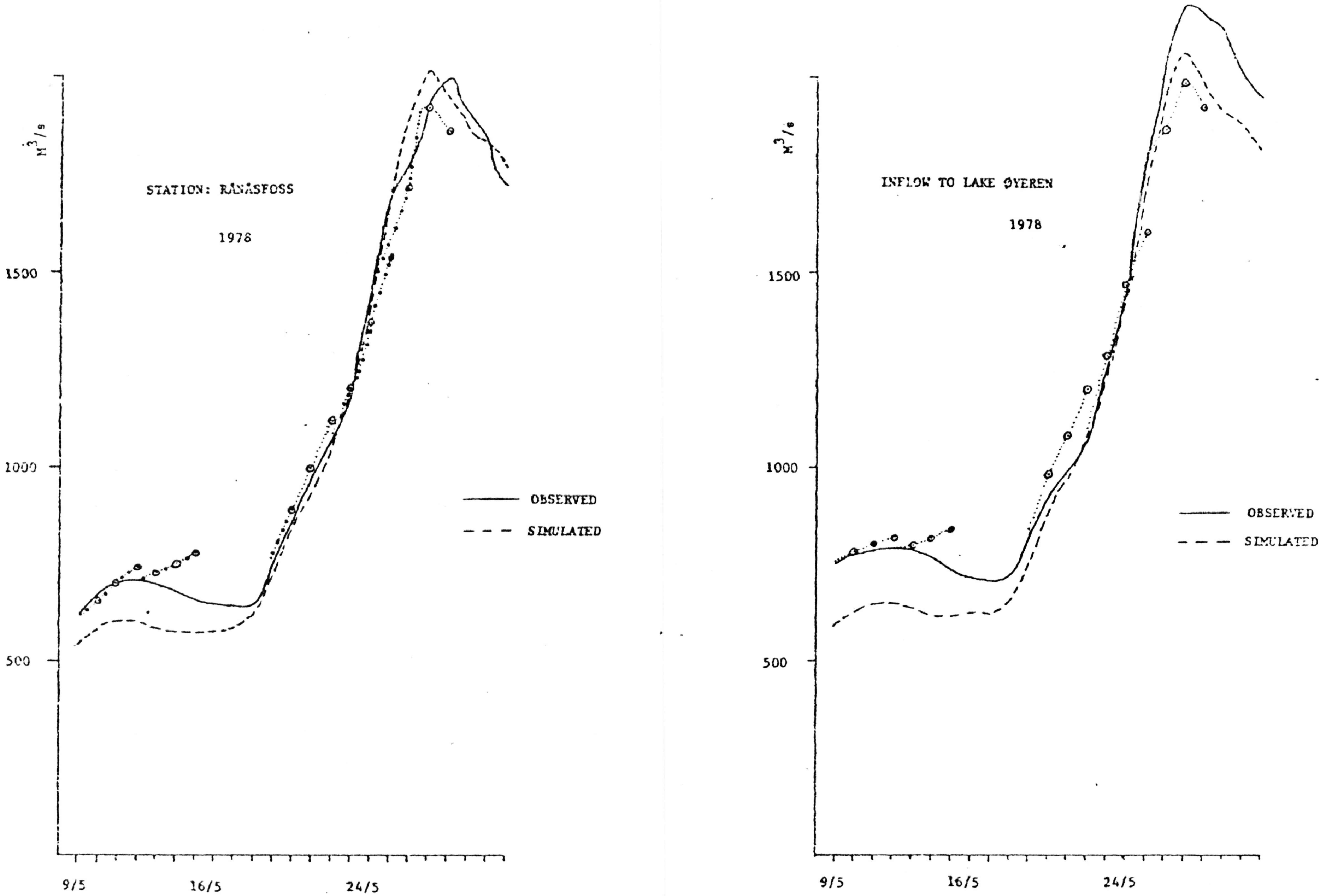


Fig. 5 Three days forecasts at Rånåsfoss and inflow to lake Øyeren. Flood season 1978.

HYDROLOGICAL MODELS FOR THE STUDY OF CHEMICAL PROCESSES IN SOIL COLUMNS AND SMALL WATERSHEDS.

Knut Brustad

ABSTRACT

The present study is a contribution to research within the Norwegian project "Acid precipitation - Effects on Forests and Fish" (the SNSF-project). The purpose is to establish hydrological models that can be used in the study of chemical processes in the ground, primarily the effects of sulphur pollution from precipitation. This requires a hydrologic model that can simulate not only water quantities but also the residence time distribution for the runoff. In this work the retention time theory developed for industrial reactor systems has been applied. By means of tracer response studies a model has been developed and applied for a laboratory system so far.
Results show that even in a homogeneous natural raw humus at least 50% of the pore volume is very passive with flow velocities of only about 10% of the main flow. The resulting residence time distribution shows that the flow to a large degree can be considered as a "plug flow". The response peak will, however, come at least twice as fast as the mean residence time. The distributions are skewed with a long tail. Measurements indicate that the applied tritium tracer is absorbed in this type of soil in the first phase of the experiments and a correction has been applied. At present preliminary studies of small plots of natural soil (5-10 m^2) has been performed and experiments in very small natural catchment areas (30-300 m^2) are under preparation.

INTRODUCTION

During the last decades the problem of increased longrange transport of sulphur pollution has been a matter of grave consern in many countries. Already at an early stage it was suspected that an observed increase in the acidity of many natural waters could be an effect of the acid precipitation (ref: Brække (1976) or

Malmer (1973) who both have a wide literature coverage).

In Europe the problem of increased acidity followed by the death of fish populations has been especially serious in the southern parts of Norway and Sweden. Thus by 1972 the Norwegian authorities started a research project: "Acid precipitation - Effects on Forest and Fish" (the SNSF-project), to get a better understanding of these problems.

From the results obtained in this project and from the works of many other researchers in different countries, we now have answers to many of the basic questions: The transport of sulphur pollution from the industrial centers in Europe to Scandinavia has been mapped. The extent of acidized areas and the effects on aquatic ecosystems have been documented.

There are, however, still many questions to which we do not yet have satisfactory answers and our knowledge about the governing mechanisms for the quality of water passing through a catchment area is still limited. Theese mechanisms include a large number of chemical processes.

To study such processes we find that it is vital to have a good description of the flow of water as a basis. From a hydrological point of view we do, however, find that to establish such a description we are faced with problems which are different from those we find in quantitative hydrology. Among the new important questions that must be answered are the following:

- To what degree is there a close contact between precipitation and the ground before the water leaves a catchment area as runoff ?

- Are there periods when large portions of the precipitation will pass rapidly, with very little contact ?

- To what degree can the runoff be described as a "plug flow" with "old" water leaving first ?

- Inside the soil particles water is found in small capillaries in close contact with the soil. How is the exchange of water between smaller pores and the more rapid flow in large pores ?

The present work is a contribution to efforts within the SNSF-project to get a more precise knowledge about the runoff mechanisms on this level by means of appropriate models.

REQUIREMENTS FOR A HYDROLOGIC DESCRIPTION

Given a small element of fluid with reacting components and with homogeneous conditions, a set of equations describing the chemical processes can in principle be established. Solving such equations will give expressions with variable degrees of complexity, but the expressions will always be time-dependent. Thus to describe the consentration of elements in one such little "particle" passing through a flow system, we must know how long it will take to pass. We call this time period the residence time.

If we want to find the average consentration in the outflow, we must accordingly know how long each part of the flow has stayed in the system. This information will be contained in the distribution function for the residence time (called RTD or RTD-function).

If the rates of the chemical reactions are very fast or very slow compared to the average residence time in a system, the exact form of the RTD will not be significant. For chemical processes with characteristic time constants comparable to the residence time of the flow system, the conversion will be determined by the flow pattern. In choosing a flow model we will have to consider that the model should simulate not only water quantities but also the RTD for the water flow. This information is in principle contained in a dispersion type model. Theese models are, however, not considered to be good for the systems in question.

We want to simulate water transport in small soil columns and natural fields with shallow deposits. We may expect to find many cases where the convective transport both in vertical and horisontal directions are on a scale comparable with the size of the system itself. Considerable parts of the flow may thus pass rapidly through the system with very short residence times.

We also know that large portions of the soil water is contained in small pores with very slow flow. This part of the flow will have very long residence times. For such systems it will be practically impossible to find the necessary information about the velocity fields and dispersion "constants".

Today, quantitative hydrologic models based on a "magazin" consept have been developed to become a fairly reliable tool in modern hydrology. This consept is, however, only built upon a "black box" type model which does not give any information about the internal flow in the system. To become useful for our purposes such a model must be fitted with an "internal structure" in the magazin boxes to ensure that the residence time is simulated in a realistic way.

The construction of such an internal model is built on the residence time theory, originally developed by Dankwerts and Zwietering for application to stationary, industrial reactor systems (see e.g. Himmelblau & Bischoff, 1968). Applications of the theory so far have several limitations, it is, however, built up from very general consepts which can be readily used for natural systems. The necessary experimental evidence for the models can be obtained from tracer studies.

ELEMENTS OF RESIDENCE TIME THEORY

The foundations of residence time theory are rigorously given elsewhere (e.g. Himmelblau & Bischoff, 1968) and only a few essential features are presented here. The basic consept in the theory is the definition of the residence time distribution, E(t), which is defined so that E(t).dt is the fraction of fluid at any instant leaving the system, having spent a time between t and t + dt inside the system.

For a stationary flow the mean residence time, $\bar{t}$ in the outlet is given by the first moment of the RTD:

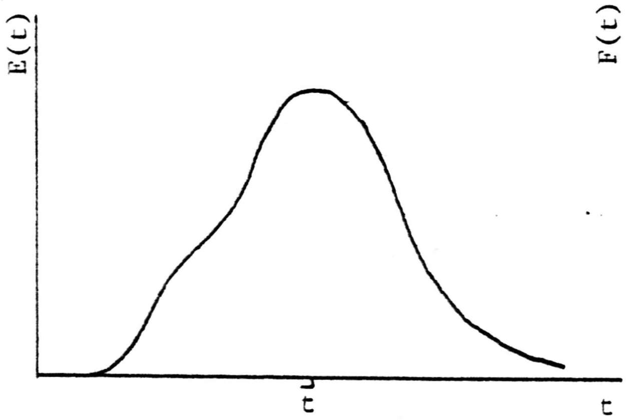
$$\bar{t} = V/Q = \int_0^\infty t \cdot E(t)\,dt$$

where V is the system volume and Q the flow.

We can also define the corresponding cumulative distribution function, F(t):

$$F(t) = \int_{o}^{t} E(t')dt'$$

In figure 1. is shown a typical example of curves for the E- and F-functions of a real system.



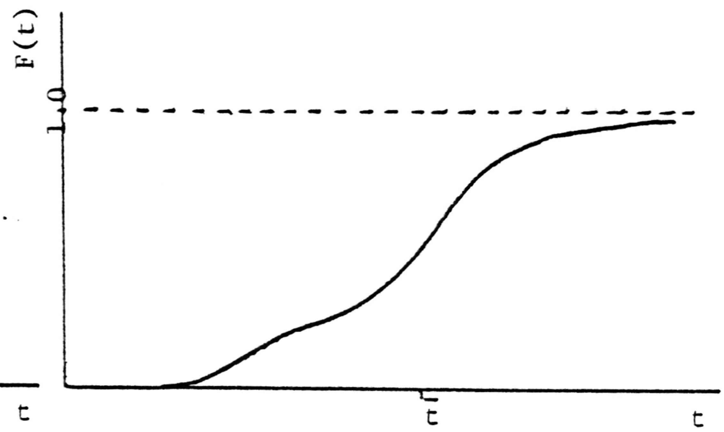


Figure 1.
Typical curves for the retention time distibution E(t) and its cumulative distribution F(t) for a real system.

For many purposes it will be an advantage to transform the distribution functions to a dimensionless scale. This is accomplished by the following transformations:

$$\theta = t/\bar{t}$$
$$E^*(\theta) = \bar{t} \cdot E(t).$$

The cumulative distribution is redefined so that:

$$F^*(\theta) = \int_{o}^{\theta} E^*(\theta')d\theta'$$

In contrast to industrial reactor systems where the fluid flow usually can be controlled, it is unfortunately very seldom possible to obtain stationary conditions in most natural flow systems. In this case it may be an advantage to use the cumulative volume of effluent, q, as abscissae instead of the ordinary time scale. We will then have:

$$q = \int_0^t Q(t')dt'$$

where Q(t) is the timedependent flow through the system. The corresponding dimensionless variable is in this article called η, defined by:

$$\eta = q/\bar{q}$$

where $\bar{q}$ is the mean (effective) retention volume of the actual system. Both the RTD-function, E(t) and the cumulative distribution F(t) can be measured in a flow system by means of experimental tracer curves. For a tracer input with the form of a short pulse, the response, measured as the consentration of tracer in the outlet, will be directly proportional to the E(t) curve. Correspondingly the cumulative function can be found by the system respons to a tracer input in the form of a step function.

MODELS

Models based on the RTD curves alone are inherently lumped models. A certain RTD may be simulated by means of any set of time-dependent differential equations which will fit the curve.

To visualize the models and to relate them to physical flow systems, models are, however, formulated as differential equations for a set of interconnected flow regions, each having an idealized flow pattern. Basically such flow regions are modelled as either perfectly mixed or as regions with "plug flow", i.a. no mixing at all.

By combining two or more of the idealized flow regions, more complicated models may be constructed. This can be done in an arbitrary way or the modeller may use his knowledge about the physical nature of the actual systems to define a certain model structure. In doing so one obtains a model which can be seen not only as a lumped model. To a certain degree physical characteristics may be built into the model, including the spatial distribution of the flow pattern. It must not, however, be forgotten that such an interpretation can only be valid on a qualitative basis.

In describing real flow systems we will primarily be handling 3 types of flow phenomena: mixing (dispersion), bypassing and dead (passive) zones. The effect of the two latter is found in the RTD-curve if a considerable part of the flow has a retention time which is either an order of size less than or, respectively, greater than the average retention time.

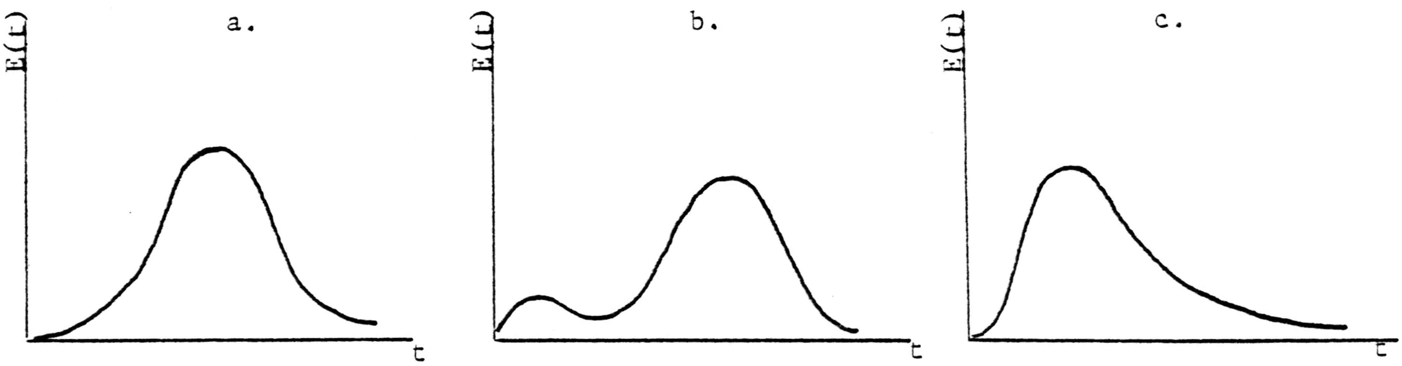


Figure 2 (a,b,c)
Typical RTD-curves exhibiting: a) pure mixing process, b) flow with bypassing, c) dead zones in system.

To describe a stationary flow in natural soil 2 different models have been constructed. The first of theese is intended to describe a vertical gravity flow. It takes into account that a considerable part of the porevolume in many soils consists of small pores with very slow water movements. There may, however, be an exchange of fluid between theese rather passive pores and the main flow of water in greater pores.

In the general case the model also takes into account that parts of the water may pass rapidly in a few channels. This model is referred to as a 3-way-model. It is thought to be useful for vertical flow in natural homogeneous soils.

The general 3-way model is controlled by 4 parameters:

- j = the number of steps (mixing-tanks) in the model (small number means good mixing)
- f = the ratio of passive volume to the totale volume
  $f = v_p/(v_a + v_p)$
- k = the ratio of cross-flow between active and passive zones.
  $Q_{cross} = k \cdot Q_{active}$
- b = the ratio of bypassing flow to total flow.
  $Q_{bypass} = b \cdot Q_{total} = Q_{total} - Q_{active}$

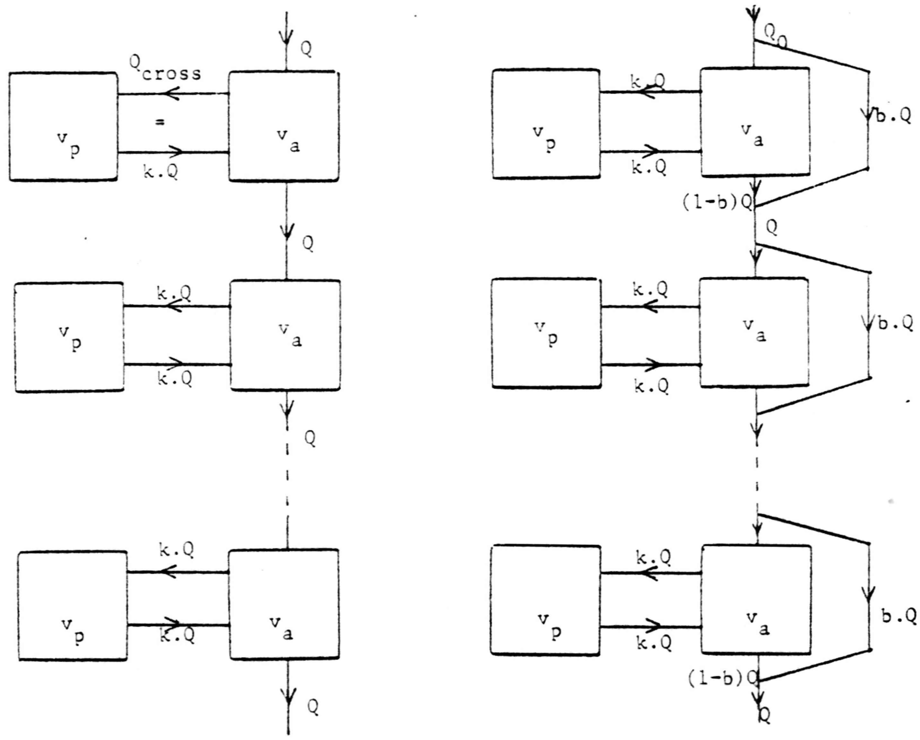


Figure 3
Model structure for the general 3-way model (right) and a simplified version (left) with no bypassing flow.

Theoretical response curves for a model with 6 steps and fixed values of k and b are shown in figure 3. To show the effect of different degree of dead zones, the value of f is varied.

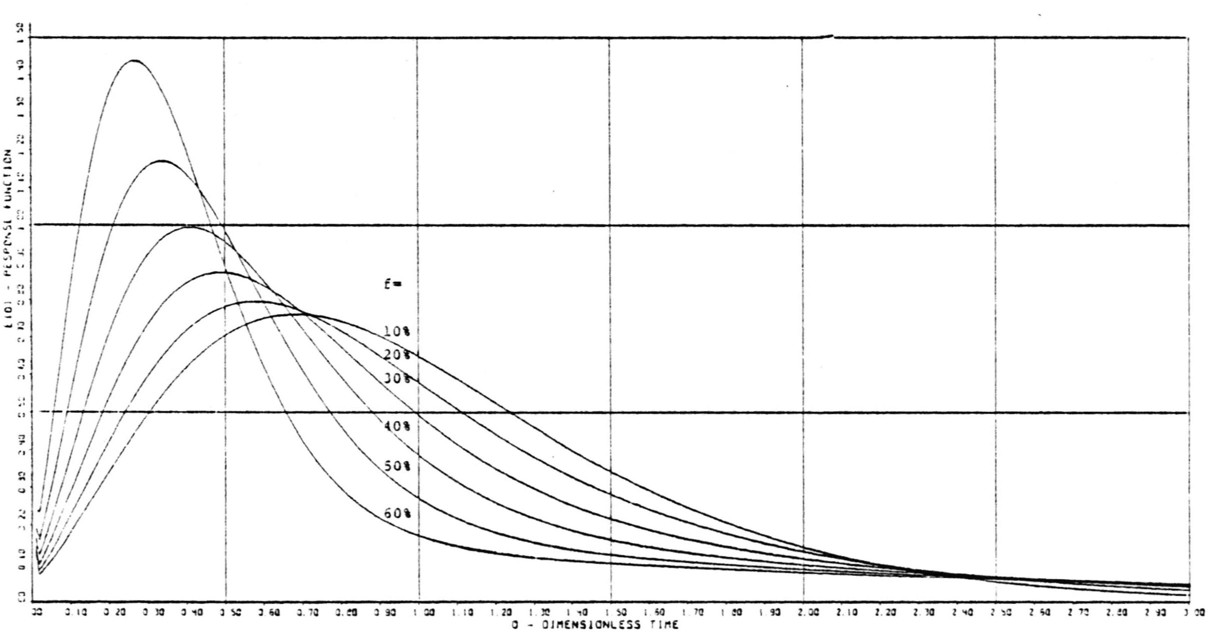


Figure 4
Theoretical RTD curves for 3-way model with number of steps, j = 6, amount of bypassing flow, b = 30% and crossflow between dead and active zones, k = 10%. The amount of dead zones is varied.

The first model is built on the following assumptions:

- the flow will move vertically as a homogeneous "front"
- transport times to the outlet in horizontal direction are negligible
- the distribution of large channels is random.

Under natural conditions, however, we find that as field size increases, the horizontal transport-times will be dominant. We also know that soil channels always tend to end up in larger channels in a natural drainage system. Theese effect would give a rather elongated RTD curve. In the second model, which is not further discussed her, theese effects will be taken into account.

LABORATORY EXPERIMENTS

As a first test for the models a serie of laboratory experiments has been completed. The experiments have been designed and carried out by A. Njøs at Institute for Soil Culture, Agricultural University of Norway, Ås (Seip et al. 1978). The experimental setup is shown in principle in figure 5.

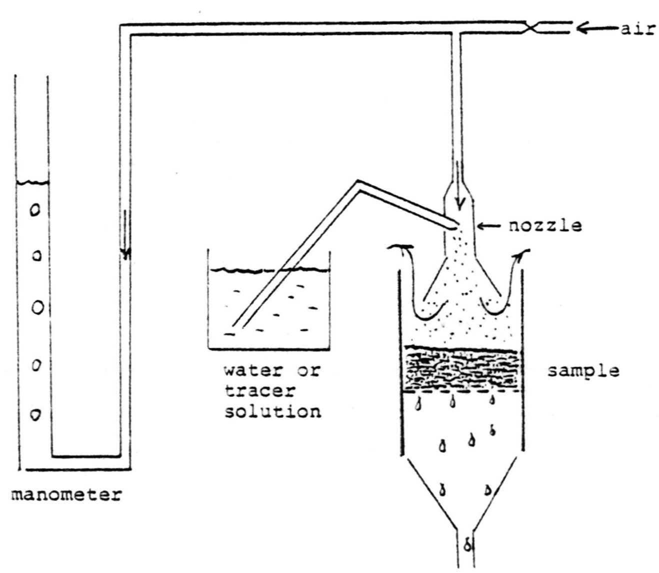


Figure 5.
Principle for laboratory setup.

A stationary flow of fine, evenly distributed water particles over the samples, is created by means of an air flow in a wide tube. A thin tube with a nozzle is inserted into the air flow. This will create a suction, and water or tracer solution is drawn from a container into the air stream in small droplets.

A natural, undisturbed raw humus with a high organic content has been investigated by means of tritium tracer. Both pulse and step inputs have been applied for different samples.

It should be mentioned that the flow rates were relatively high, ranging in size from approx. 0.5 mm/min. to 1.2 mm/min. Interesting is the fact that the results showed tritium tracer to be absorbed during the first phase of the experiments.
This was corrected for by means of a simple first order absorbtion equation.

Without going further in detail, 3 representative RTD curves are shown in figure 6, showing one example of a pulse response, one for a step-response, and an averaged response for 5 samples with step response.

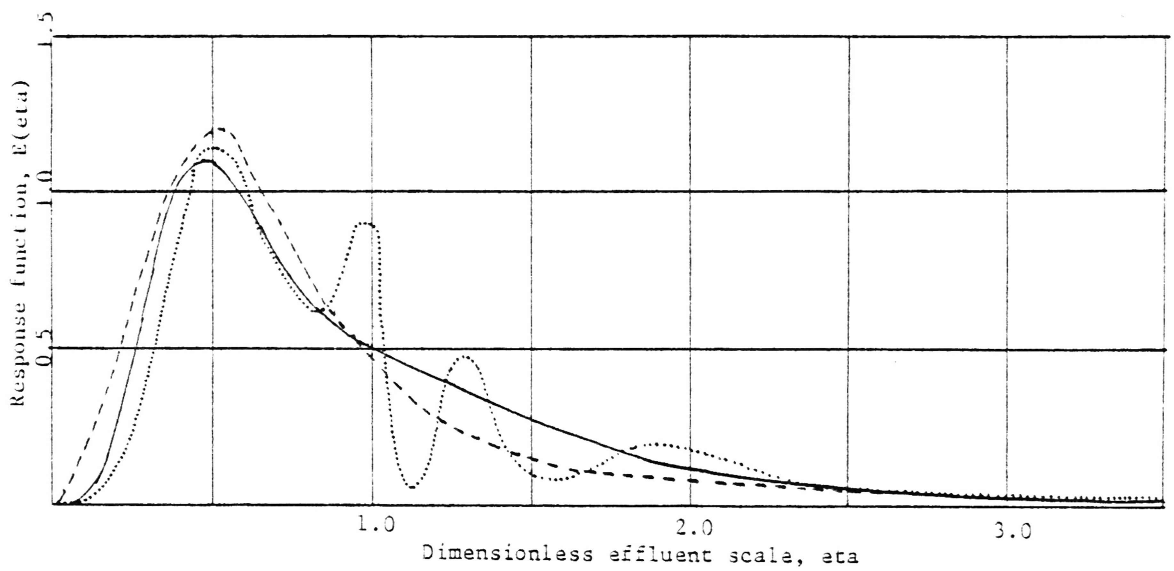


Figure 6.
Typical experimental response curves.
Continous line: pulse response. Broken line: RTD derived from step response. Dotted line: average RTD from 5 samples with step input.

FITTING OF MODEL

The experimental curves were fitted to the 3-way model for homogeneous flow by a manual procedure. Results showed, however, that the bypassing flow was zero or close to zero in most cases. Thus the simpler 2-way model with b = 0 was chosen.

The following range of parameter values was found to cover most of the natural variations between samples:

j = 6 to 9 (number of steps)

f = 45% to 65% (percentage of passive volume)

k = 8% to 15 % (percentage of crossflow).

A good set of values to fit the average RTD curve is given by j = 8, f = 60% and k = 10%. The theoretical RTD for this model is shown in figure 7.

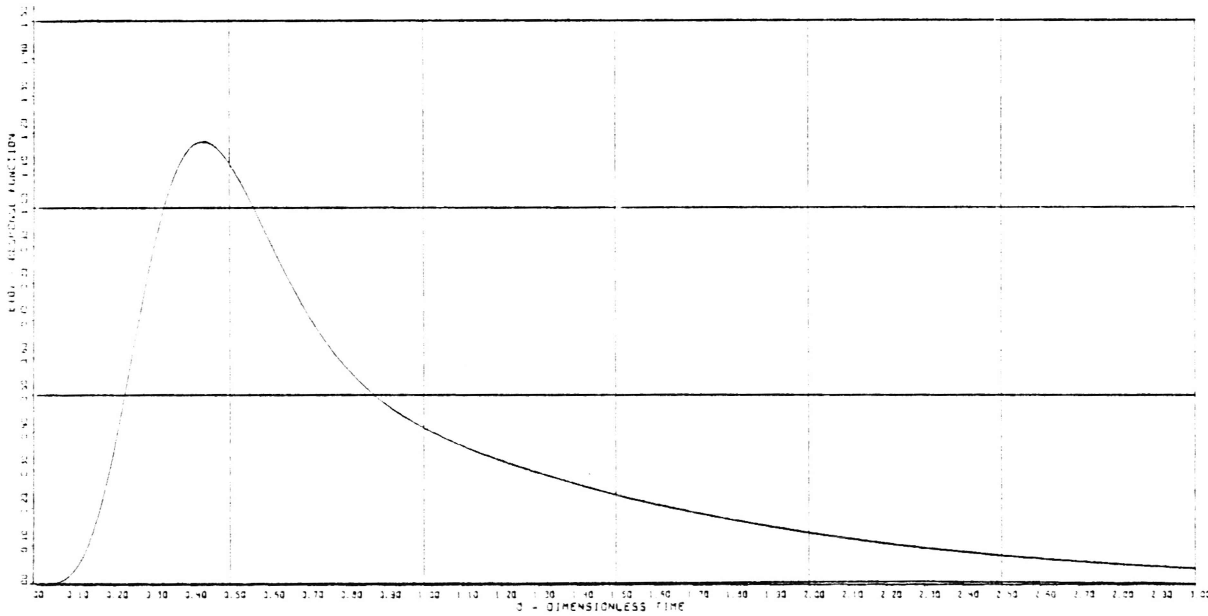


Figure 7.
Theoretical response curve for simplified version of general model (no bypassing, b=0) with j = 6, f = 60% and k = 10%.

DISCUSSION

So far experiments have been carried out for laboratory systems only, and a lot of theoretical and practical work remains. It seems, however, that we can draw some conclusions already at this stage, although it is possible that new experiments may give different results. The conclusions so far will naturally fall in 3 groups, where the first conserns the practical aspects of the experiments. For details here it is referred to the full report which is under preparation (Seip et al., 1978). It should be mentioned that the step technique seems to be vulnerable to noise in measurements especially variations in water flow. Some of this noise is removed by transformation to effluent scale. It seems, however, that under non-stationary flow conditions an accelleration of the flow increases the degree of mixing.

This will cause a jump in the RTD-curve. Problems with tritium absorbtion has already been mentioned.

Secondly, we can make certain conclusions about the flow in this type of raw humus, based upon the experimental curves and model tests. Most important is the fact that the RTD-curved clearly shows a high peak coming at least twice as fast as could be expected from the average retention time. A good explanation to this is that only about 40 to 50% of the total porevolume is active in the main flow. In the rest of the volume the flow velocities are only about one tenth of the main flow. Theese large passive volumes will cause the RTD-curve to have a long tail.

Chemically this could mean that many reactions can approach towards equilibrium in the smaller pores. In the main flow retention times are so small that many reactions would be far from equilibrium. This indicates that the possibility for influence by precipitation is greater than can be expected from the mean travel times. It should be remembered that this conclusion is based upon measurements for very high values of throughflow (about 30 - 60 mm/hour continuously). On the other hand one may expect to find that in many natural soils with a distinct drainage systems, the amount of rapid bypassing may be considerable.

Finally, we may conclude in general that so far the use of tracer response techiques together with flow models based on the retention time theory seems to be promising. Theese techniques seems to be very useful for establishing information about the flow in the unsaturated zone. So far, however, only continuous flow has been investigated. It remains to be seen if theese models can be developed to handle dynamic conditions.

FUTURE WORK

Final report from the laboratory experiments described here is under preparation. Tests in very small plots of natural soils (5 - 10 m^2) have been performed and experiments in small natural catchment areas (30 - 300 m^2) are under preparation and will be started this year.

All the studies of flow mentioned here, will be done concurrently with measurements of the chemical components in the water flow. As a long-term goal we hope to establish models that can contribute to the understanding of someof the basic process that takes place when acid precipitation reaches the ground.

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PRACTICAL USE OF A SIMPLE CONCEPTUAL MODEL

Dan Lundquist

ABSTRACT

A simple conceptual runoff-model of the box-type with linear reservoirs, the SNSF-model, is tested on nine catchments in Norway. The results are analysed to find out to what degree the parameter values are dependant on the geographical/climatological location of the catchments and the physiography within the catchments. This is done with the intention of finding either regionalized parameter-values or standard parameter-sets for different types of catchments. The work presented in the article is part of a Norwegian IHP-project for finding easier parameter-estimation procedures.

PHILOSOPHY

Coceptual models, when used as a method of analysis and as a tool for runoff-prediction, should have the following two properties:

- Rather simple model-structure and algorithms.
- Easy-to-use parameter-estimation routines.

THE SNSF-MODEL

In Norway a simple model, the SNSF-model, has been developed by the author (Lundquist 1976,1977). This model divides the catchment into areas consisting of bare rock, forest, bogs and lakes to simulate the average properties of these four types of areas. The model allows water to be drained from one of the sub-areas to another or directly to the stream. A snow-routine and a routing-procedure are also connected to the model. The model-structure is built up by simple boxes which act like linear reservoirs with buffer-volumes. The structure can be altered depending on the types of areas that are present in the catchment and the drainage-pattern between these. Figure 1 shows the model-structure and table 1 contains a list of the parameters of the model. The only input-variables are precipitation and temperature.

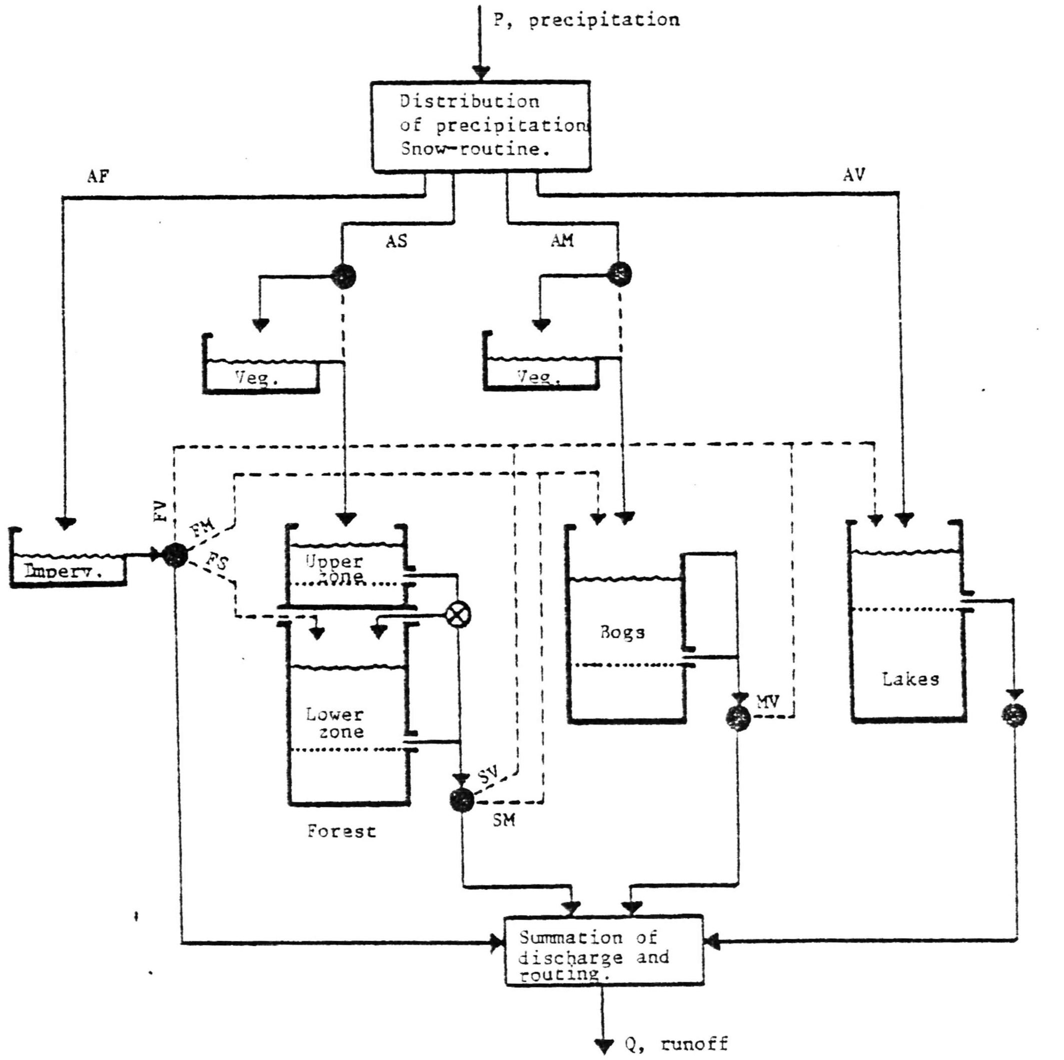


Figure 1. Model-structure.

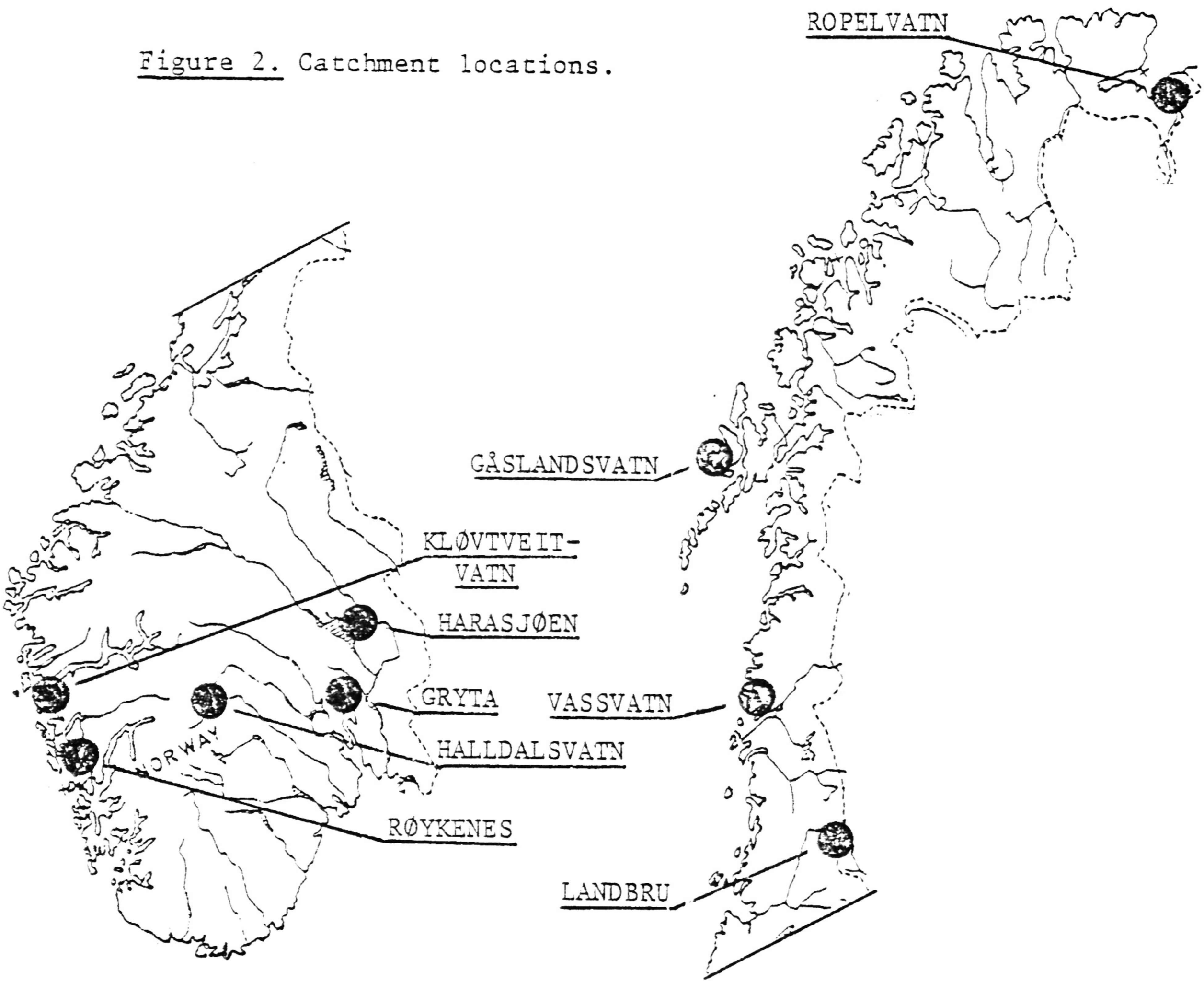
F=Impervious , S=Forest , M=Bogs , V=Lakes.
Ax = Relative area of type x (x=F,S,M,V ; $\sum$ Ax=1.0=100%).
xy = Relative area of type x that is drained to type y.
(Evapotranspiration is possible from all the storages, but is not indicated in the figure.)

Table 1. Model parameters.

IMPERVIOUS	- FMIN	= Retention capacity	QF=F-FMAX
FOREST	- AMIN	= Field capacity - WP	
	KA	= Drainage constant (upper zone)	QA=KA·(A-AMIN)
	KSIG	= Percolation constant (relative)	SIG=KSIG·KA , QA=QA-SIG
	BMAX	= Saturation point - WP	QA=QA+B-BMAX
	BMIN	= Field capacity - WP	
	KB	= Drainage constant (lower zone)	QB=KB·(B-BMIN) , QS=QA+QB
BOGS	- MMAX	= Saturation point - WP	OFL=M-MMAX
	MMIN	= Field capacity - WP	
	KM	= Drainage constant	QM=KM·(M-MMIN) , QM=QM+OFL
LAKES	- VMIN	= Point of zero-discharge	
	KV	= Drainage constant	QV=KV·(V-VMIN)
VEGETATION	- IMAX	= Interception capacity	QI=I-IMAX
Other parameters:			WP=Wilting Point
	KP	= Correction constant for precipitation	P=KP·P
	KE	= Evapotranspiration constant	E=KE·T

The SNSF-model has earlier been tested by the author on five small catchments (0.5-6.0 km^2) in the south of Norway (Lundquist,1978). It has also been used by Krakstad (1978) on the Filefjell representative basin and by Sælthun (1978) in a comparative test of hydrological models for operational use on Norwegian catchments.

Figure 2. Catchment locations.



CATCHMENT STUDY

To investigate the possibilities of easier parameter-estimation procedures, the model has been tested on nine other catchments in Norway. These catchments have different types of physiography and are located in areas with differing climate. The main features of the catchments are listed in table 2 and their locations are shown in figure 2. Runoff, precipitation and temperature is measured at the standard station networks of the Norwegian Water Resources and Electricity Board and the Norwegian Meteorological Institute.

Table 2. Catchment descriptions.

Catchment	Area (km^2)	Heigth a. sea level	Relative areas in model Imper.	Forest	Bogs	Lakes	Discharge (mm/year)
HARASJØEN	58.	280- 550		96%		4%	340
GRYTA	7.	160- 450		100%			530
HALLDALSVATN	58.	850-1190		96%		4%	359
RØYKENES	50.	50- 950		97%		3%	2933
KLØVTVEITVATN	4.4	410- 640		79%		21%	4273
LANDBRU	56.	500-1180		90%		10%	1290
VASSVATN	19.	100-1170	40%	50%		10%	3352
GÅSLANDSVATN	8.4	10- 200		50%	30%	20%	1441
ROPELVATN	47.	50- 280		77%		23%	438

There are two possible solutions to our problem that are of special interst:

- The parameter-values can be geographically and climatologically regionalized.
- The parameter-values are dependant on the physiography within the catchments in a way that makes it possible to create standard parameter-sets for certain types of catchments.

CALIBRATION AND TEST

To avoid calibration problems connected with the accumulation and melting of snow, the model has been calibrated and tested on periods without snow (june-october). For calibration has been used just one summer-period for each catchment. The test is always made on a period that has not been used in the calibration procedure.

A slightly modified version of the original SNSF-model has been used. The modifications are:

- In the lower zone of forest and in bogs evapotranspiration is made dependant of the magazine-contents by using a variable weight-function (=actual storage/maximal storage).
- The posibility of using already established water-level/discharge relationships in lakes is incorporated in the model.

RESULTS

The model calculates runoff in good agreement with the observations for some of the catchments while the agreement is poor for others. Results from these tests are shown in figure 3(a-i).

There are two main explanations to the poor simulations:

- The lack of representative precipitation-data for many of the catchments. When using short calibration-periods (3-4 months) this disadvantage leads to incorrect adjustment of the model and poor simulations in the independent periods.
- The model does not have a box to simulate deeper groundwater and this leads to the unability to simulate correct runoff from catchments with deeper soils.

The good simulations on the other hand seems to be the result of representative precipitation-data and catchments with rapid response to rainfall.

These simulations does not indicate any regional pattern in the parameter-values. This is not even the case when catchments on the wet West Coast is compared to the drier ones further East (see table 3). However, deep groundwater, lakes and bogs have a marked effect on the simulations. This means that a deep groundwater-box should be included in the model for future use. The water-level/discharge relationship in lakes has been tried for six of the catchments but it improved the results only in three of them.

Table 3. Parameter-values for the SNSF-model.

Parameter	HARASJØ	GRYTA	HALLDALS-VATN	RØYKENES	KLØVTVEIT-VATN	LANDBRU	VASSVATN	GÅSLANDS-VATN	ROPELVATN
AF	-	-	-	-	-	-	0.40	-	-
AS	0.96	1.00	0.96	0.97	0.79	0.90	0.50	0.50	0.77
AM	-	-	-	-	-	-	-	0.30	-
AV	0.04		0.04	0.03	0.21	0.10	0.10	0.20	0.23
KFS	-	-	-	-	-	-	0.50	-	-
KFM	-	-	-	-	-	-	-	-	-
KFV	-	-	-	-	-	-	0.50	-	-
KSM	-	-	-	-	-	-	-	0.50	-
KSV	1.00	-	1.00	1.00	1.00	0.80	1.00	0.50	1.00
KMV	-	-	-	-	-	-	-	1.00	-
KP	1.10	1.05	1.10	1.25	1.30	1.25	1.30	2.50	1.50
KE	0.20	0.20	0.25	0.30	0.20	0.20	0.20	0.20	0.25
FMIN	-	-	-	-	-	-	2.5	-	-
AMIN	10.	15.	20.	15.	15.	15.	7.5	10.	15.
KA	0.60	0.50	0.70	0.60	0.70	0.70	0.70	0.70	0.70
KSIG	0.90	0.80	0.90	0.80	0.90	0.82	0.90	0.90	0.90
BMAX	90.	90.	110.	100.	100.	85.	100.	200.	170.
BMIN	40.	40.	40.	40.	40.	40.	40.	40.	40.
KB	0.02	0.10	0.10	0.02	0.10	0.03	0.10	0.10	0.02
MMAX	-	-	-	-	-	-	-	300.	-
MMIN	-	-	-	-	-	-	-	30.	-
KM	-	-	-	-	-	-	-	0.01	-
VMIN	0.	-	0.	0.	0.	0.	-	-	-
KV	0.30	-	0.20	0.70	0.15	0.35	-	-	-
K	-	-	-	-	-	-	6.7092	5.1486	9.7273
ΔH	-	-	-	-	-	-	0.85	0.14	0.40
N	-	-	-	-	-	-	2.0775	1.8761	3.2922

— The water-level/discharge relationship has the form: $Q = K \cdot (H - \Delta H)^N$ —

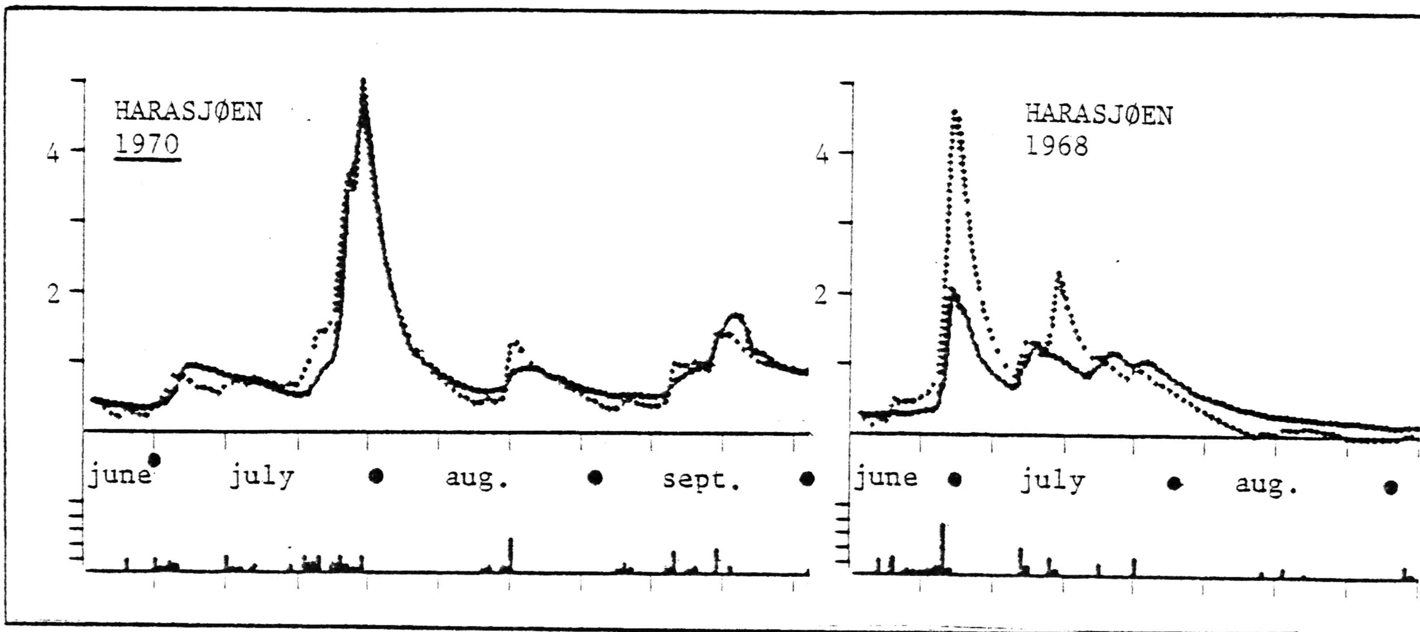


Figure 3(a).

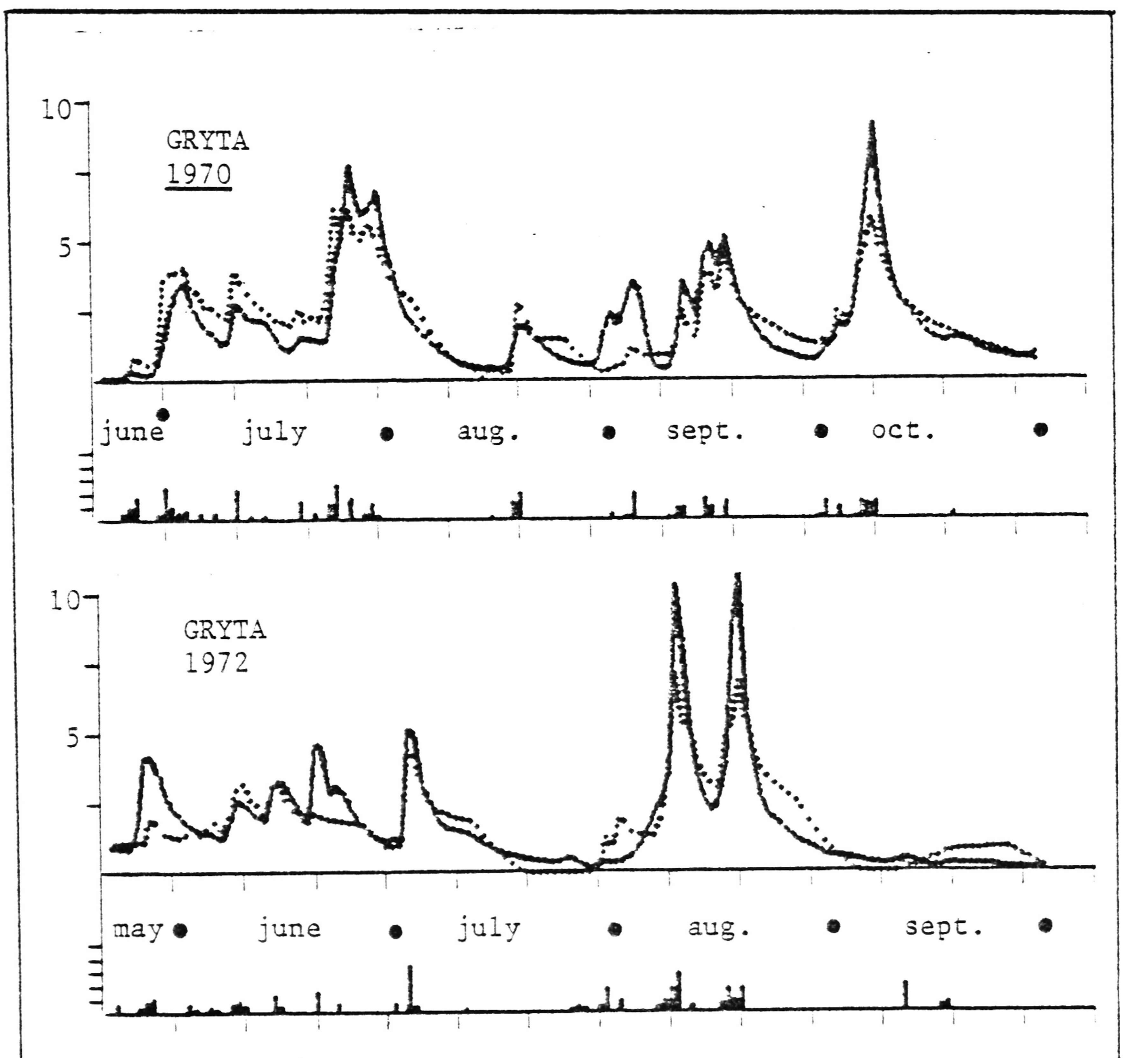


Figure 3(b).

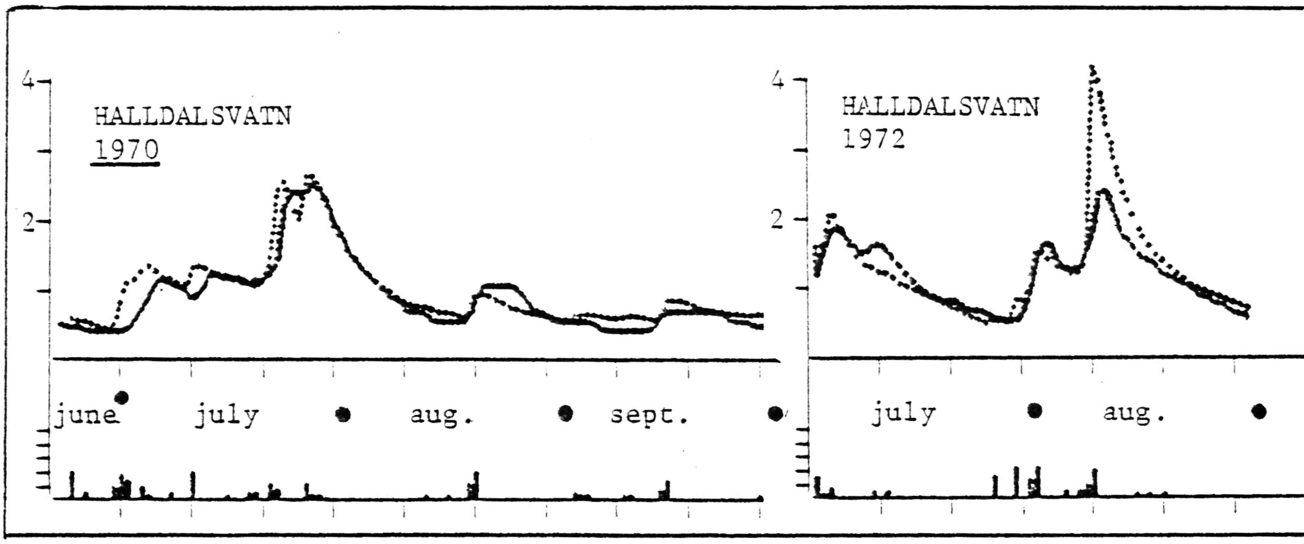


Figure 3(c).

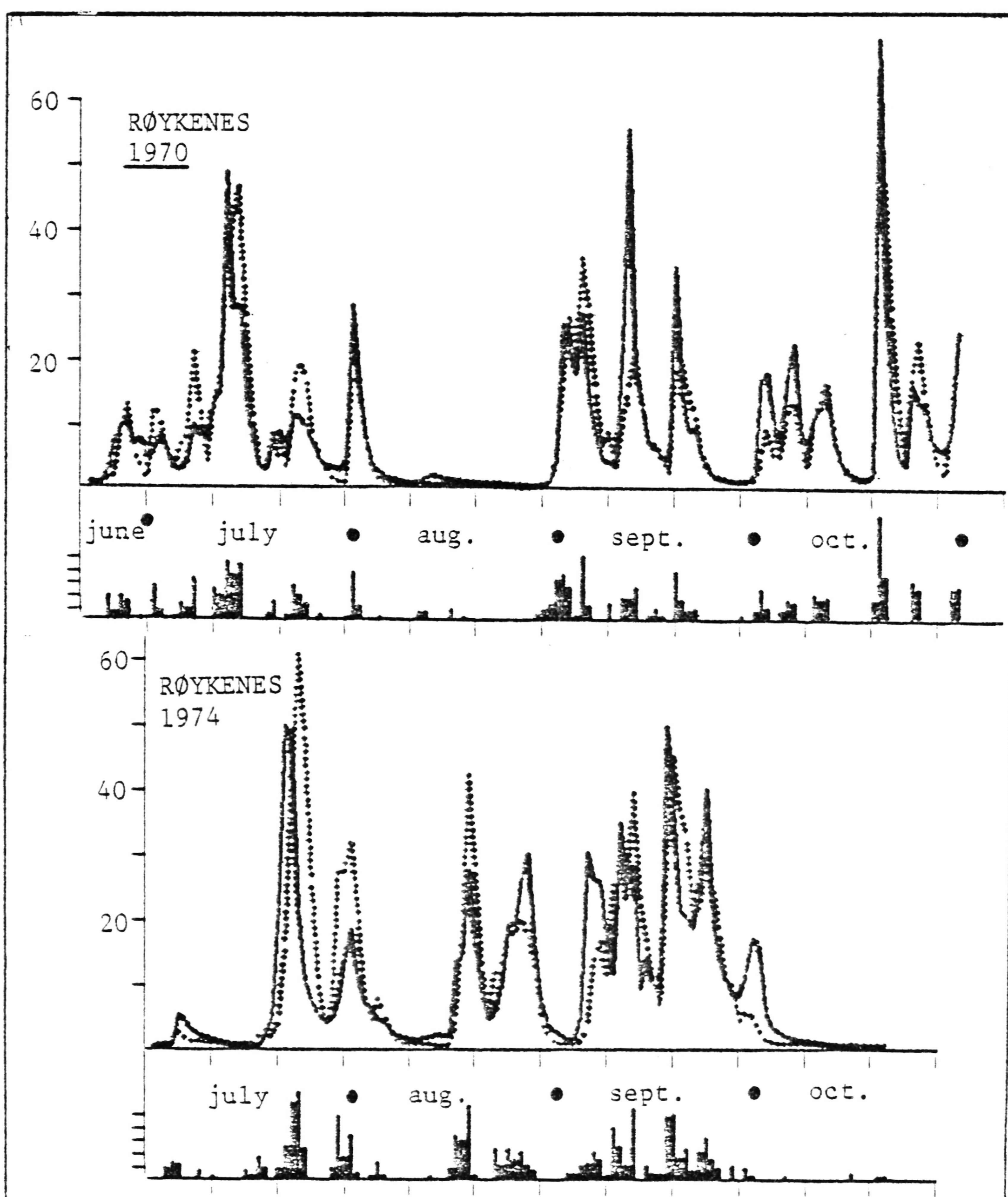


Figure 3(d).

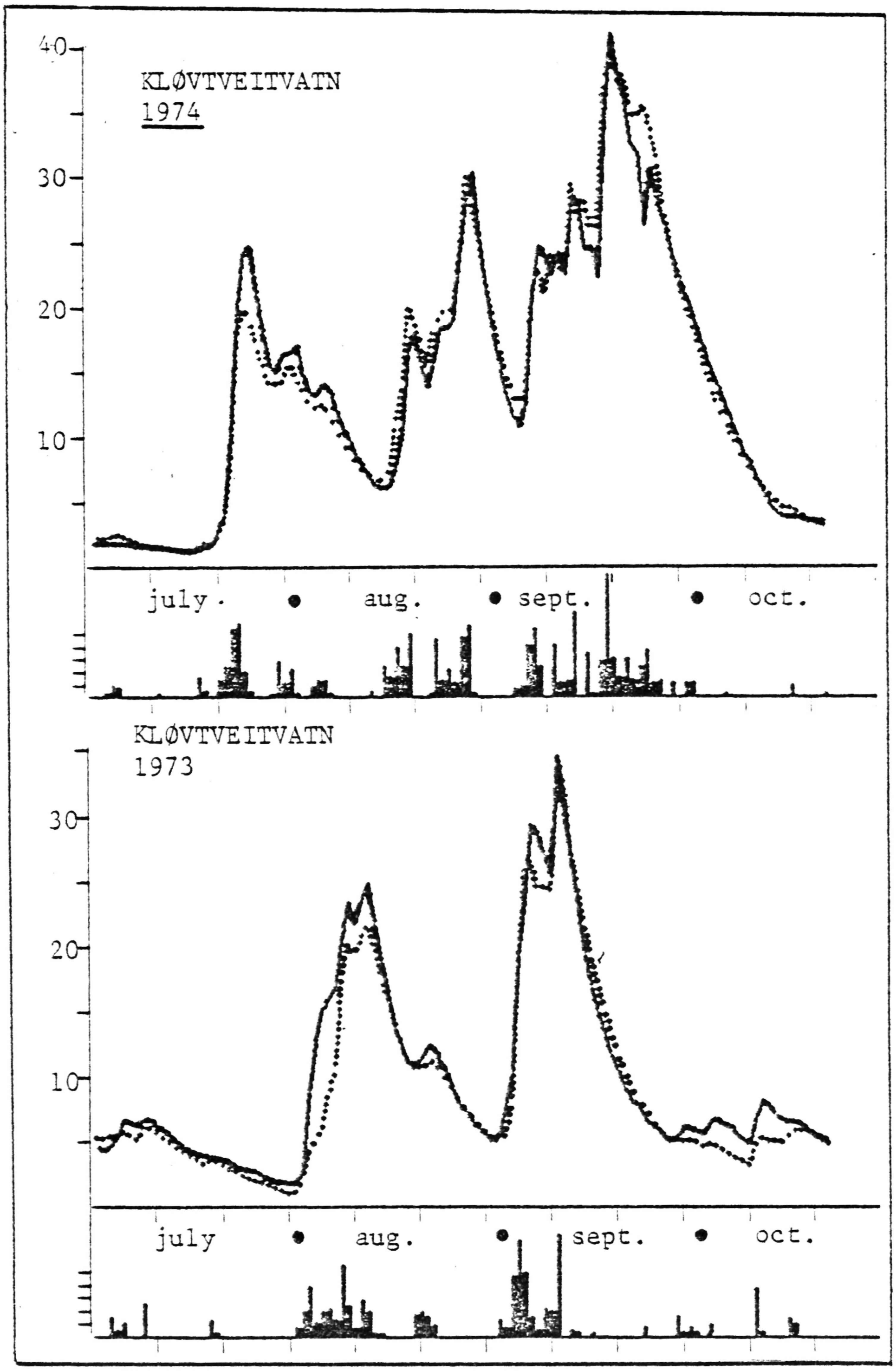
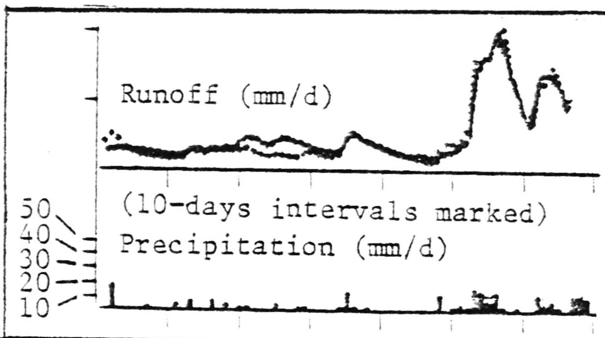


Figure 3(e).



Explanation to figure 3(a-i).

1974 calibration period underlined
1973 test period not underlined

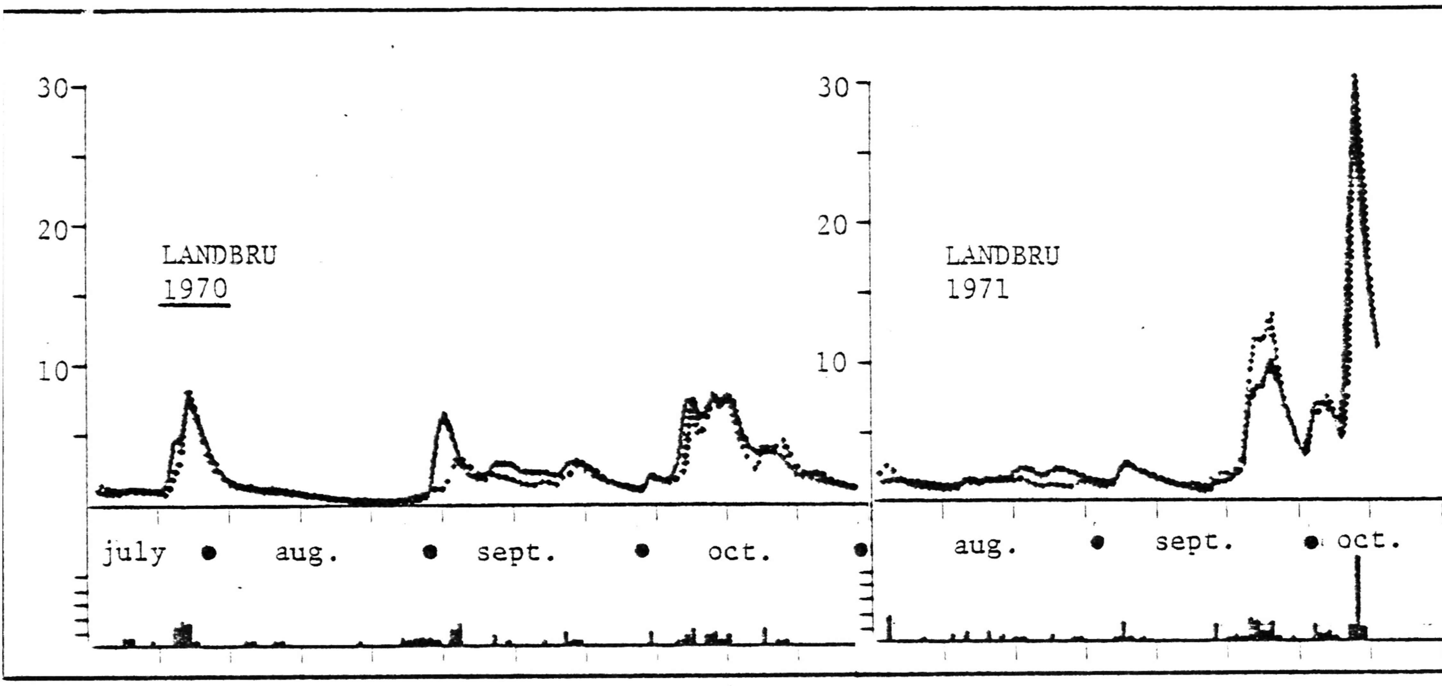


Figure 3(f).

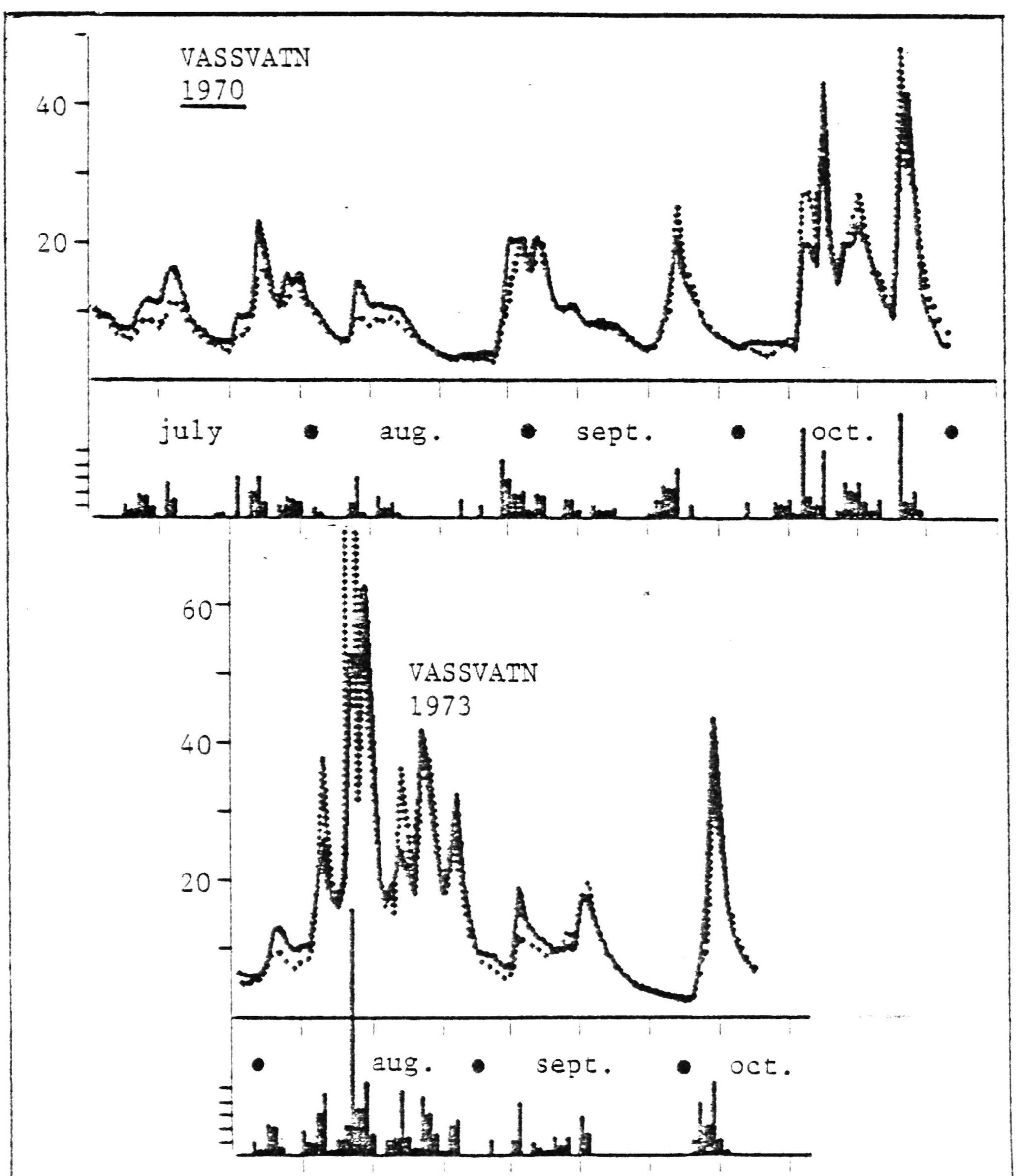


Figure 3(g).

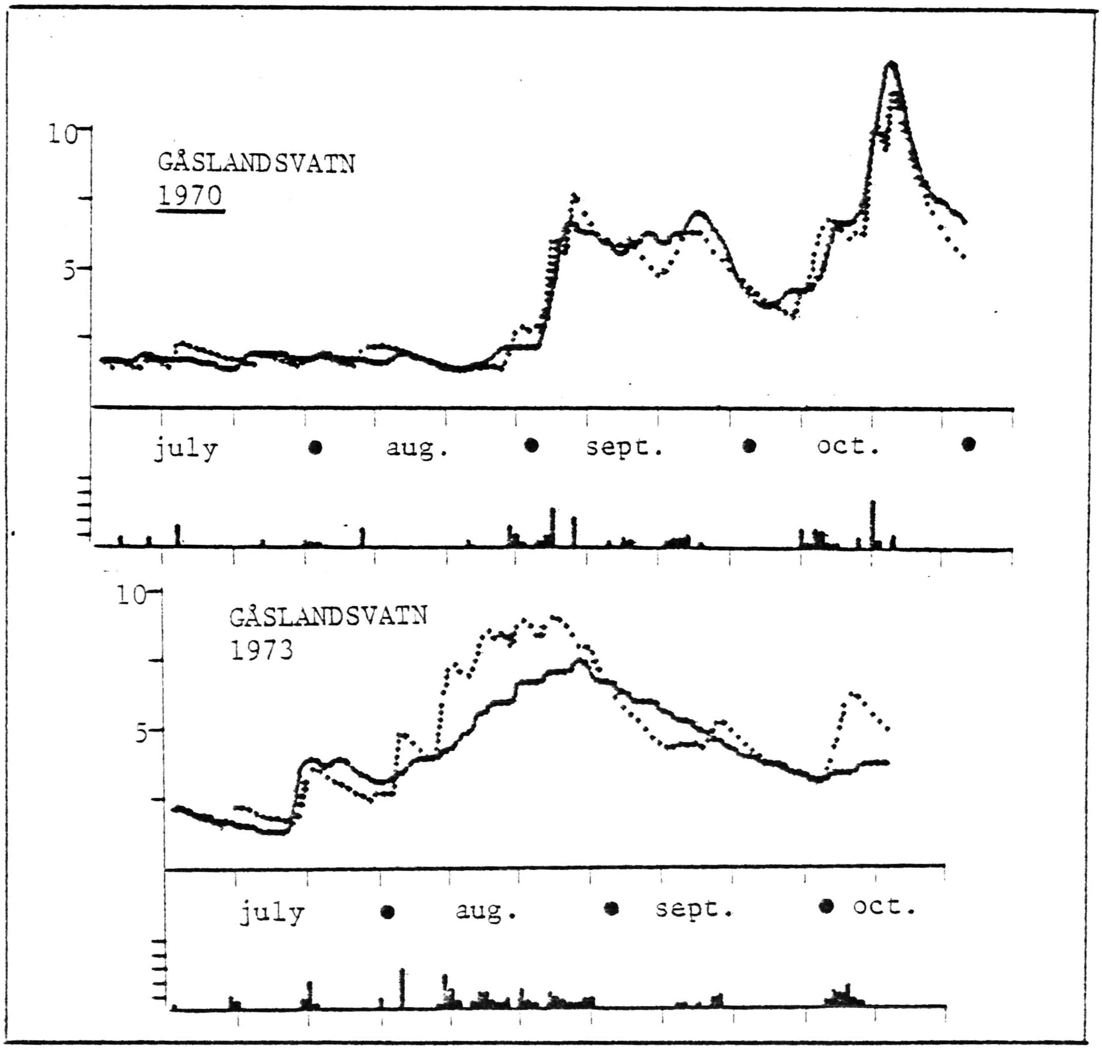


Figure 3(h).

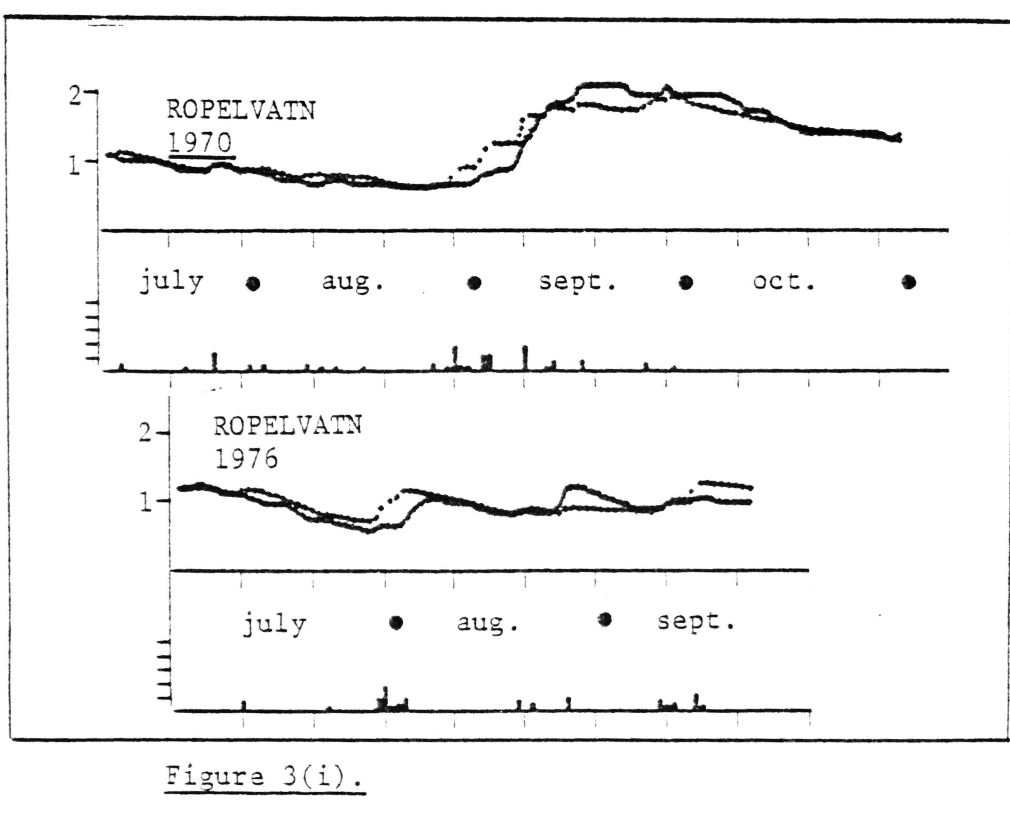


Figure 3(i).

CONCLUSIONS

This parameter-estimation-test does not indicate that geographical/climatological regionalization of parameter-values to conceptual models is possible. On the other hand it shows that standard parameter-sets might be possible to establish. Especially this is the case for a model like the SNSF-model which separates the properties of different types of areas.

Finally, a last conclusion:

- Model-building is fun, calibration is tiresome and verification is hard.

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CONTROL OF THE QUALITY IN HYDROLOGICAL DATA.

Lars Andreas Roald

ABSTRACT

In this paper, the results from various tests on methods for detecting errors in hydrological data are presented. Finally the framework of a new Norwegian system for quality control of data is described.

INTRODUCTION

The increase in the use of hydrological data for various technical or scientific purposes has, in recent years, shown that the historical series contain many un - dected errors as discussed in Riise and Wingård (1976). The major hydrological agencies in the Nordic countries engaged in large scale collection of hydrologi - cal data, have cleary recognised this problem. This has led to the organizing of a working group, FAG-6, whose task is to evaluate various methods for detect- ing these errors. The working group shall develop and recommend a procedure for this quality control in the future.

In this paper, some methods tested in Norway are described. Finally the future quality control system in Norway is discussed.

PRIMARY DATA PROCESSING AND QUALITY CONTROL.

Essential to obtain data of high quality are the controls made in the field. To- day many controls are made before the data are processed. In this paper, how - ever, we will only deal with methods that can be applied during the primary pro- cessing of the data.

Due to the large amount of data being collected, the quality controls are to - day fairly crude. Access to display devices and interactive computer systems will hopefully, in the years to come, facilitate the primary processing and quality control considerably.

METHODS FOR QUALITY CONTROL.

Many errors within hydrological data occur sporadic. These errors may appear a single day or in a few consequtive days. More serious are the various types of systematic errors that may occur in the records. In Roald (1977) a dis - cussion of the various types of errors and their causes can be found.

The methods available for quality control can be classified in the methods designed to be used in the primary processing of new data, and methods for controlling the quality in the historical records. The latter methods will probably be used more infrequent and can, therefore, utilize more refined tools.

DETECTION OF SPORADIC ERRORS.

Most of the Nordic countries have included tests in their primary processing routines which list cases when the water stage or runoff or the day to day change exceeds certain limits. Based on this idea a programme was constructed which evaluates the means and extremes for each day in the year for a freely chosen period. The means and extremes are plotted in a diagram as shown in figure 1.

The programme may also plot data for a given year into the same diagram. It is possible to obtain a list of cases when the data exceed certain seasonal dependent limits. A similar plot may be obtained using the difference or quotient between the value on a day and the day before as shown in figure 2. Plots of this kind will often identify sporadic errors.

The series shown in figures 1 and 2 disclose no errors in the year under consideration, but indicates at least six errors in the reference period. The errors have later been confirmed and were found to range from 10 to 35 cm in the water stages.

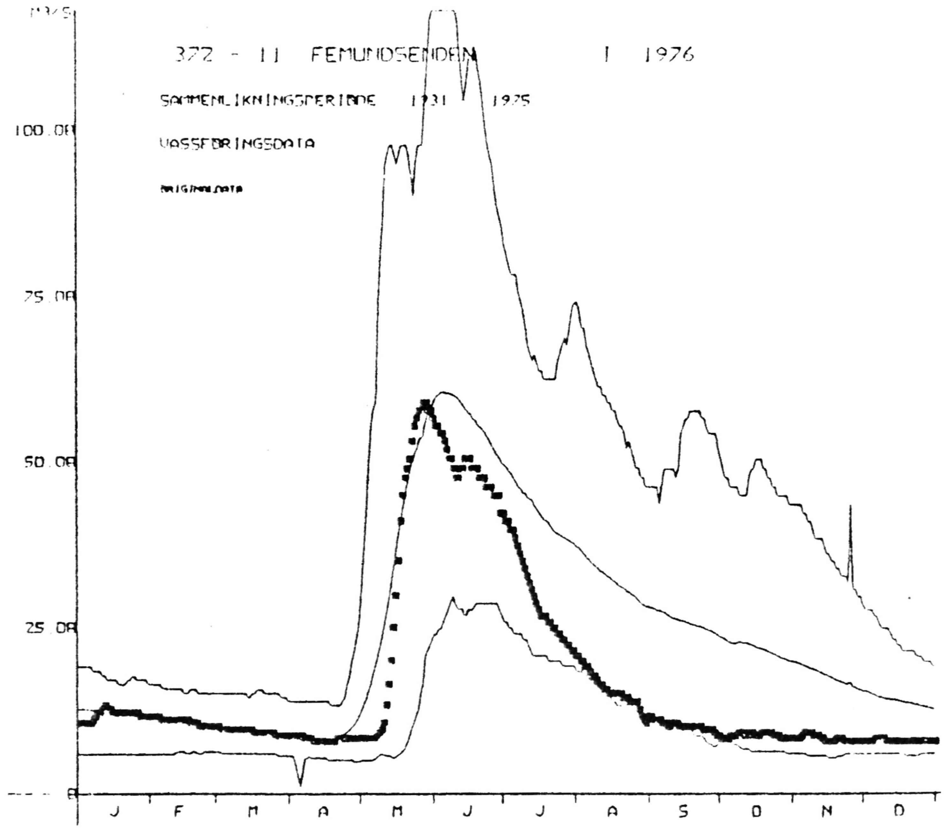

Fig. 1 Means and extremes for each day in the year from the runoff series in lake Femunden in the period 1931-75. Data from 1975 is plotted into the same diagram.

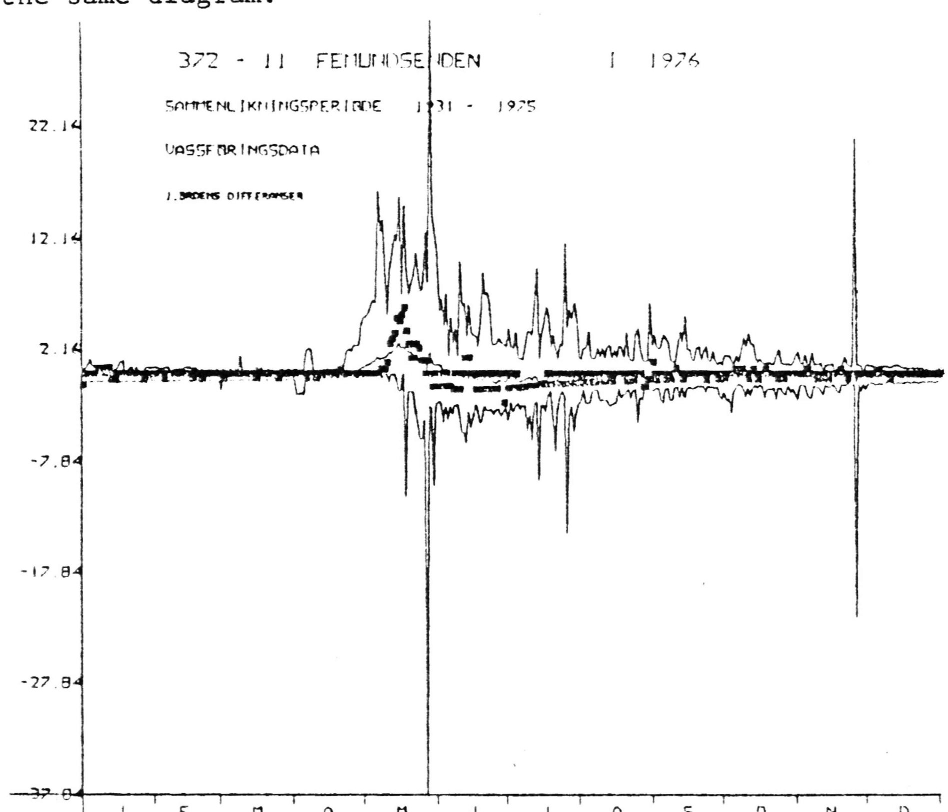

Fig. 2 Means and extremes for the difference in runoff between a day and the previous one for each day in the year for the same series as shown in fig. 1. The large peaks in the extremes indicates errors in this case.

The series referred to above is the runoff from lake Femunden of 200 km^2. The river stations usually show a far greater valiability, in particular at high water stages, as shown in figure 3. For such stations we may obtain some indication that a flood is abnormal, but we have to use data from other stations to verify this. Errors in the low flows are usually easy to identify even for rivers.

Based on experiences from this programme a number of programmes are now under construction. Some of this programmes are designed to identify errors in the primary processing. Other will be designed to detect such errors in the historical records. Test runs have so far identified several errors as large as meters which have escaped past quality control.

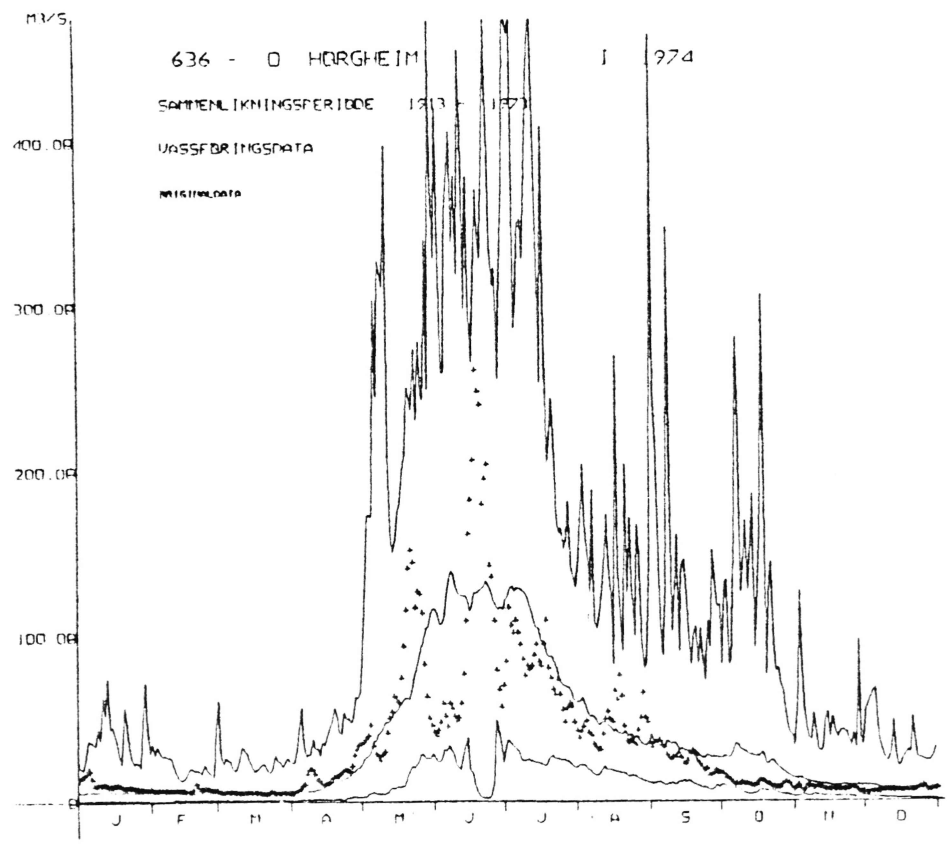

Fig. 3 Means and extremes for each day in the period 1913-73 for a river runoff station. The peaks are here more difficult to judge. Observe the low minium runoffs for July. This is evidently caused by some errors.

DETECTION OF SYSTEMATIC ERRORS.

Systematic errors are usually more difficult to prove than the sporadic ones. Some errors are caused by faulty instruments or by the observing routine at the station. Such errors should preferably be detected during inspections in the field or during the processing of the data.

A large group of errors are caused by inadequacies in the stage-discharge relationship. In Norway many rating curves are established from measurements over a fairly narrow range of water stages. The extreme flows are therefore usually computed from the extrapolated part of the rating curve. To obtain a measure of the uncertaincies in the computed discharges, a programme has been constructed that makes a frequency analysis for the discharges estimated from the extended part of the rating curve as described by Andersen (1977).

A special class of possible errors are those that may be identified as inhomogenities.

A change in homogenity may be caused by natural processes such as changes in the climatical input or by human activities such as deforestation, urbanisation or large scale diversions for hydropower production.

A change in homogenity may also be caused by sytematic errors of various kind. Erosion or accumulation of sediments in the river bed may change the stage-discharge relationship. Similar effects are also caused by vegetation or icedams in the stream. To identify such stations it is necessary to check the data for inhomogenities and decide the reasons for the changes.

Traditionally double-mass analysis has been used to identify the inhomogenities. The results from a double mass analysis are, however, often difficult to inte - prete. Furthermore this method only identify inhomogenities affecting the yearly means. This method is described in Ehlert (1972). A programme has been written by Mr. Lørum at NVE for such analysis. An improved method for testing the suspected inhomogenities is presently being developed by Dr. Gottschalk at the SMHI.

As a supplement to this method time series analysis following methods described in Hansen (1971) and Box and Jenkins (1970) have been attempted for most of the long Norwegian time series.

The time series is analysed for trends and the yearly cycle is decided by esti - mating the monthly means and standard deviations. If the series is weakly stationary, the means and standard deviations may be used to deseasonalize the series. To ascertain whether the yearly cycle is removed or not, the autocorrelation function or ACF is plotted for lags up to 60 months as shown in figure 4.

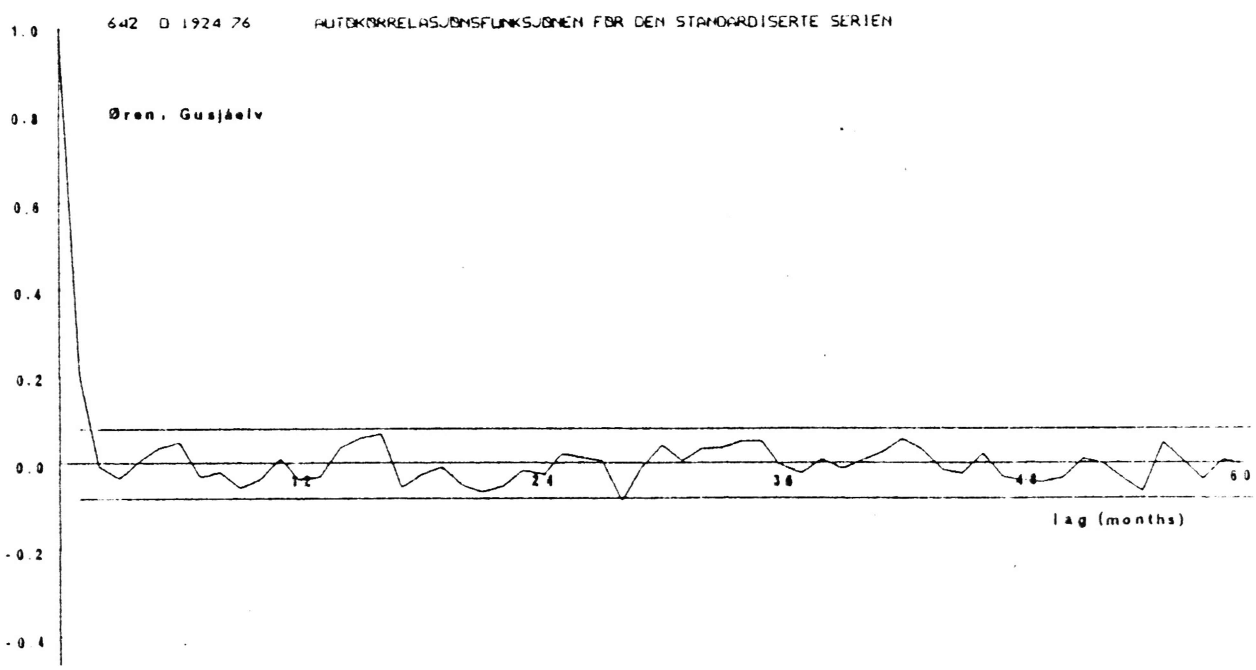

Fig. 4 The ACF-plot for the deseasonalized time series of monthly runoff at Øren gauging station. This series is considered as homogenous.

For about on third of the series the ACF-plots indicated that the series were homogenous. For about on third of the series it was found that the yearly cycle could not be removed. Most of these series are characterized by regu - lations for hydropower production starting within the period. This is the case for the example shown in figure 5. By repeating the analysis for the period prior to the inhomogenity a homogenous series is usually found. Many series contains various minor irregularities in their ACF-plots as shown in figure 6. Some of these are caused by regulations covering more or less the entire period.

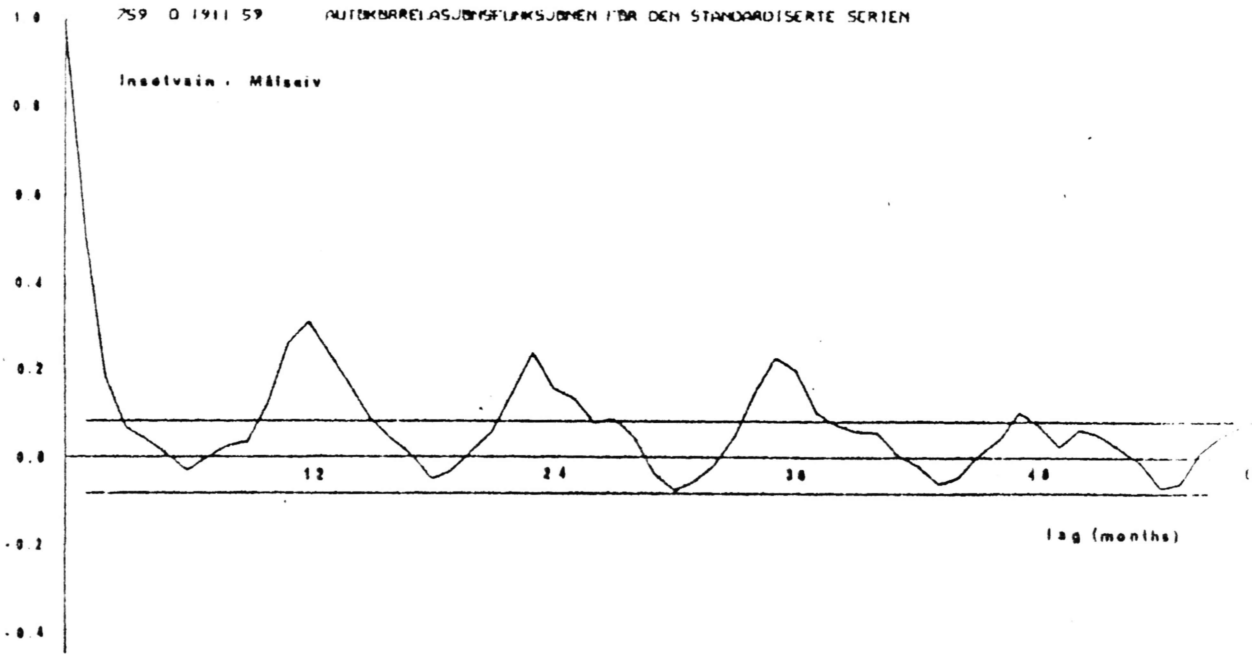

Fig. 5 The ACF-plot for the runoff series at Innsetvatn gauging station. The yearly cycle could not be removed for this series except for the period before 1930 when the water course was regulated.

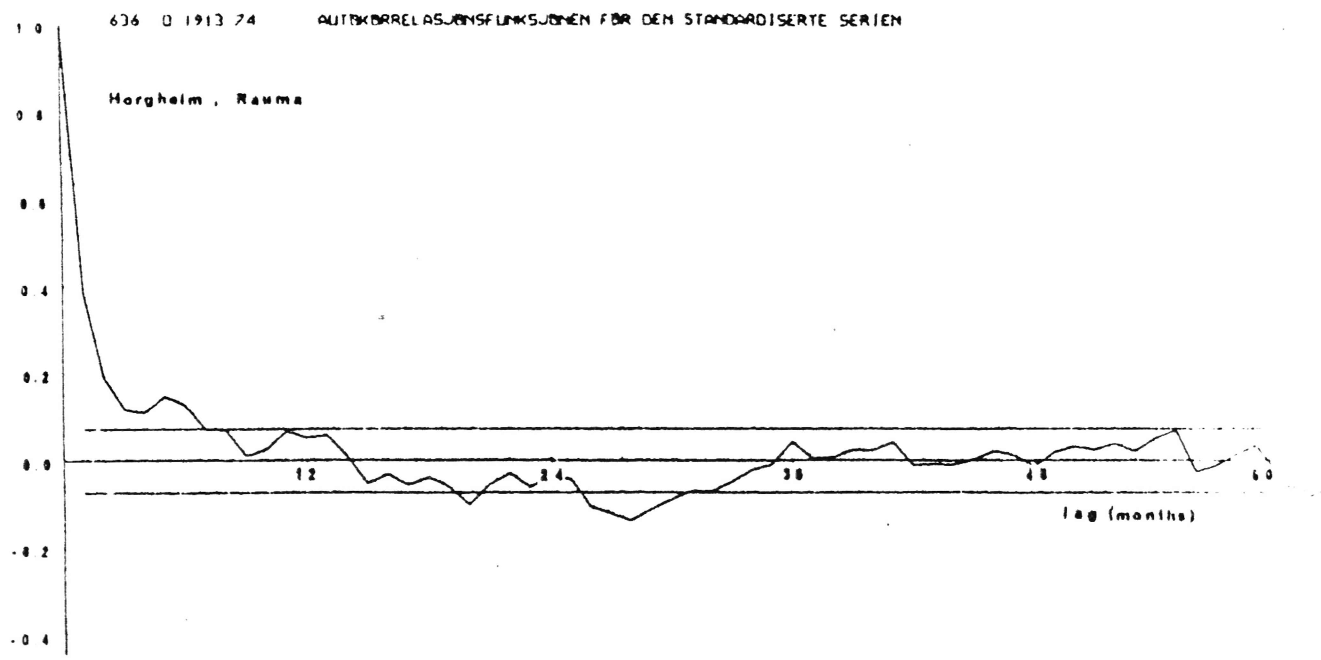

Fig. 6 The ACF-plot for the same series as shown in fig. 3. The ACF contain somewhat more irregularities than expected. In this case it is reasons for suspecting data from one or two years. Furthermore the corrections for icedams seems to be dubious in certain periods. Irregularities as those shown here have elsewhere been shown to be caused by exterior ef - fects.

In figure 7 the ACF-plots is shown for a series indicating a strong inhomogenity. Using double mass analysis this has been confirmed as an undetected change in the stage-discharge relationship as shown in figure 8.

In the region where this station is situated, there are indications of a change in the amount of precipitation making the results of the analysis more difficult to interprete.

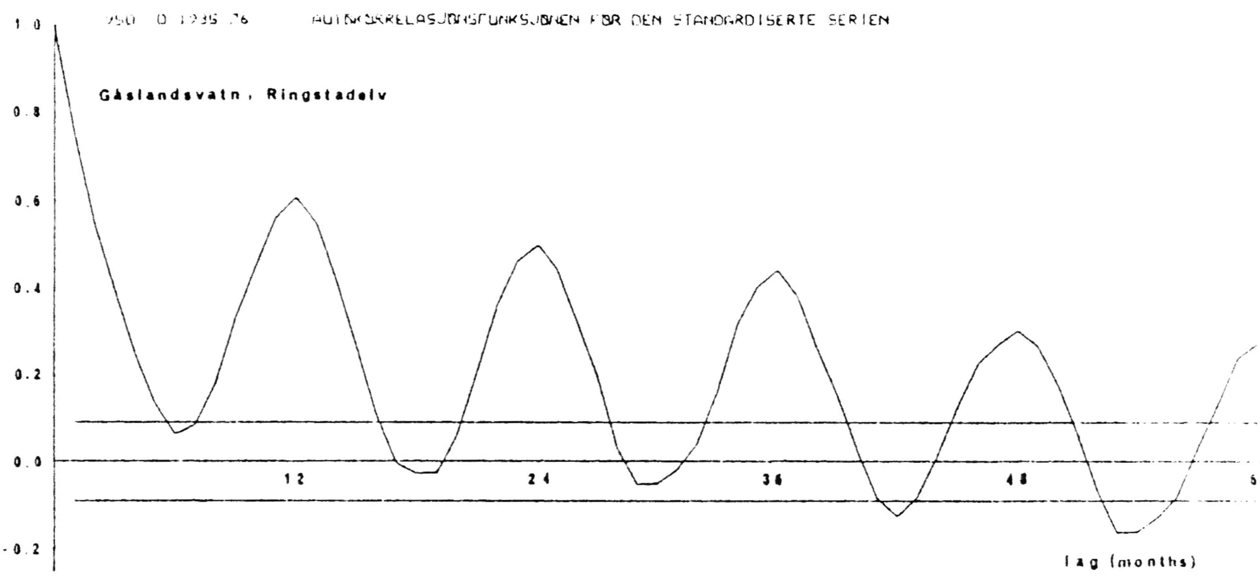

Fig. 7 The inability of the procedure to remove the yearly cycle in this case proved to be caused by a change in the controlling river profile.

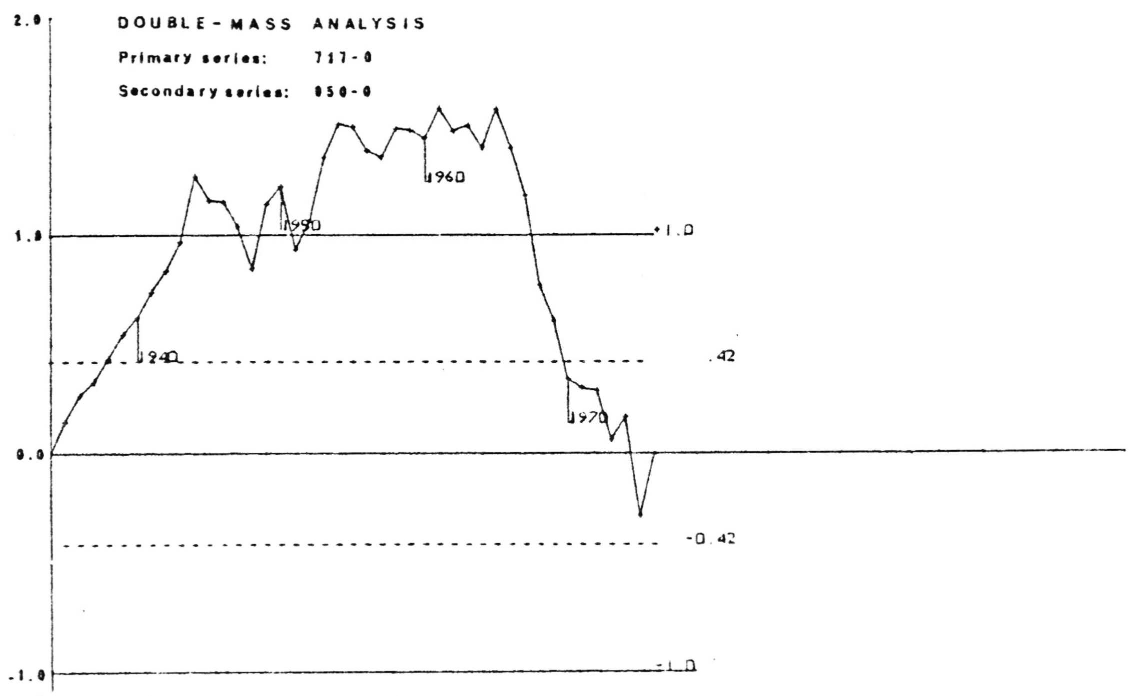

Fig. 8 To check the case shown in fig. 7 a double-mass analysis was run using several adjacent gauging stations as reference. A problem was in this case that some of the stations were effected by an increase in the precipitation during the period.

This method require fairly long series to give useful informations. Furthermore the method should preferably be used for natural catchments, but it may also succeed for regulated periods if water is not diverted out of the catchment and the regulation is not changed within the period.

Care should be taken to exclude cases caused by some exterior effects such as changes in the climatical input. This is obtained by comparing ACF-plot from adjacent stations. In figure 9 such plots are shown for three stations in Trysilelv river. The upper two plots are taken from stations in the main river and indicated a periodicity of about 1½ year. Similar oscillations are also found at two other stations in the main stream. This indicates that he oscillations are caused by some physical process. The lower plot in figure 9 is taken from a series observed in a tributary stream. Even here the same oscillations may be seen. Evidently this effect are caused by some regional process and should not be considered as indications errors.

THE FRAMEWORK OF A NEW SYSTEM FOR DATA QUALITY CONTROL IN NORWAY.

In Norway a new system for primary processing of hydrological data is now under consideration. The quality control routines will be implemented into this system as an integrated part.

In the future data will mostly be collected by various types of self-recording instruments. Part of the data will be directly transmitted to the main office. More data will probably be received from various sources, in particular the hydropower companies and river regulation authorities.

The new system will utilize digital and graphical display devices to a large extent permitting the staff to examine and correct the incoming data in a far more efficient manner than it is possible today.

A procedure will be established for controlling the data before and during the digitizing. One program system will be developed to control the data during the primary processing. This system shall be designed to sort out cases with possible sporadic or systematic errors in the input data. To verify if these errors are real, the staff may select from a number of tests available in a stepwise procedure. The final decission as to whether an error has occurred or not should be taken maually. Errors may then be corrected in the same run.

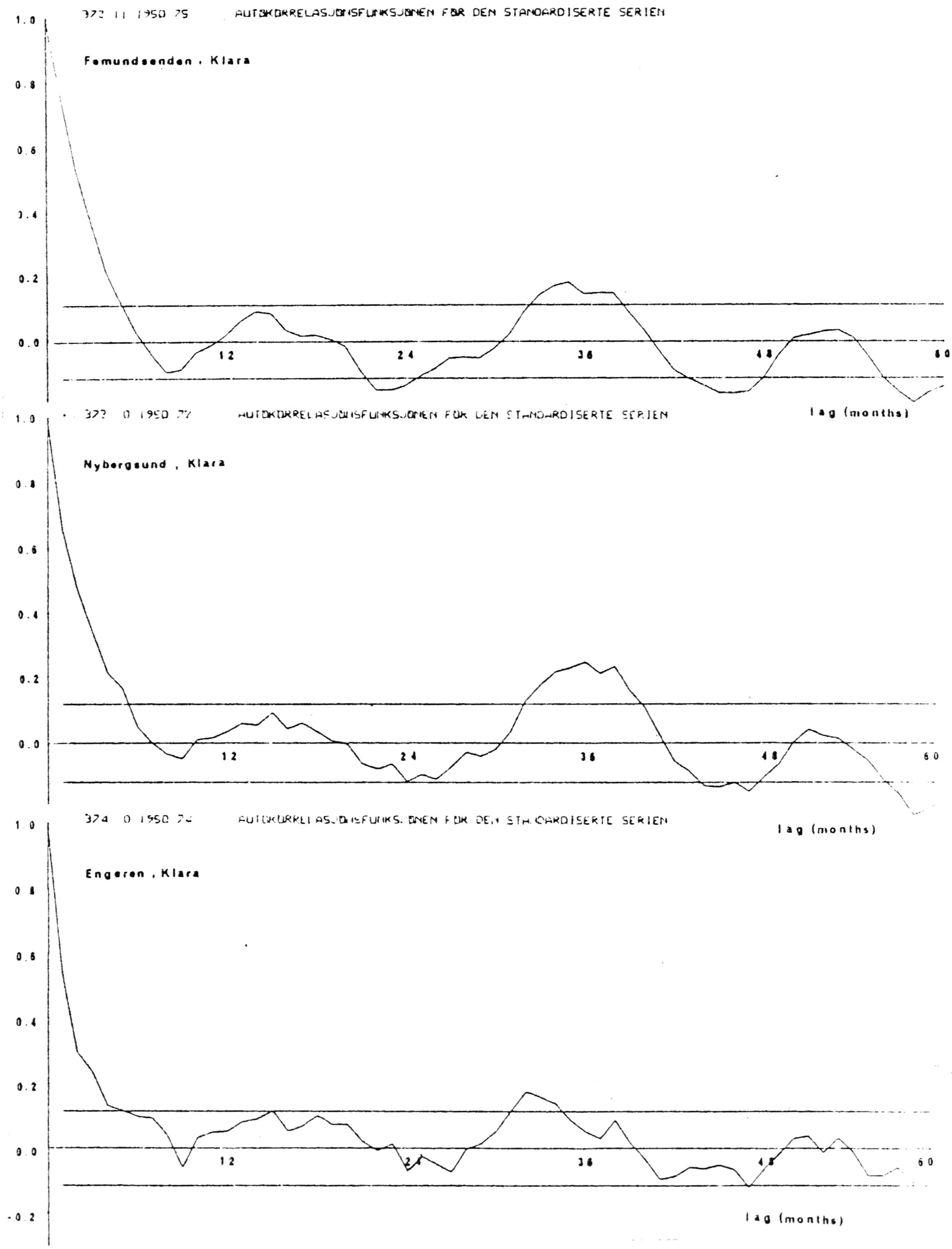

Fig. 9 The three ACF-plots shown here, indicates that a 1½ year periodicity may be found within a certain region. The upper two plots are from two gauging stations in the Trysilelv river. The oscillations are also seen in the ACF-plots from two other stations between the stations shown here. The bottom plot indicates that the oscillations even may be found in a tributary stream.

To obtain a sufficient fast procedure certain test limits should be stored in the station directory on disc. The present station directory are now under reconsideration and will probably be extended to contain much of this infor - mation. This will also be utilized by another program system designed to ana - lyse the uncertaincy in the rating curves.

A third system will be implemented consisting of programmes for homogenity analysis. This system will consist of programmes for time series analysis and for double mass analysis.

This system will also include programmes for indentification of sporadic errors. All these systems will include tests for checking the continuity for river systems with more than on discharge station.

CONCLUSIONS

Using a new programme, several sporadic errors have been detected in the historical series in Norway. The experiences from this program are now used to develop parts of a new system for quality control of the hydrological data.

Time series analysis is found to be a useful tool for obtaining a measure of the homogenity in long time series. Several changes in the stage-discharge relationships have been detected using this method.

The methods so far considered can indicate that an observation or a series may be in error, but they can not prove conclesively that the value is wrong. It is, therefore, necessary to apply a number of tests to sort out all possible errors in a stepwise procedure as described above. The final decission as to whether an error has occurred or not, should always be made by the person responsible for the station.

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COMPARATIVE TESTS OF HYDROLOGICAL MODELS FOR OPERATIONAL USE ON NORWEGIAN CATCHMENTS. AN INTER-INSTITUTIONAL PROJECT

Nils Roar Sælthun

ABSTRACT

During 1977 there has been a joint effort by Norwegian research institutions to evaluate existing hydrological models. The work has been aimed at preparing models for operational use, and to single out fields for further development work. The models tested are the Swedish HBV-3 model, the Norwegian SNSF-model, linear transfer models, and regression models for snowmelt runoff volume predictions. This paper outlines the work done and presents som results and conclusions of the project.

INTRODUCTION

There is a growing interest in use of hydrological models for flow forecasting in Norway. The purpose of forecasting has partly been flood warning (Andersen, 1978), but a major interest has been the prospects of reservoir inflow forecasting for hydropower plant operation.

Work in this field was initated in 1976 by a pilot project joined by several research institutions and financed by river regulation authorities. The HBV-3 model as described by Bergstrøm (1976) was tried out on two catchment, one of which was the local catchment of the intake reservoir of a large hydropower plant. The work is documented in a report by Aam, Fossdal, Wingård, Killingtveit and Fjeld (1977).

This work was continued by the present project joined by

- the Hydrological Divison at the Norwegian Water Resources and Electricity Board.
- the Norwegian Research Institute of Electric Supply.
- the Institute of Hydraulic Construction at the Technical University of Norway.

and with the assistance of

- the Norwegian Computing Center
- the Foundation of Scientific and Industrial Research at the Technical University

The purpose of the project was to:

- test out models and forecasting methods on catchment of interest to hydro - power production
- give recommendations on the priority of further development work
- outline the data requirements and information flow lines for routine iss - uing of hydrological forecasts.

The project was intended to develop know-how and prepare computer software for the planned hydropower hydrological service (Riise, 1978). It has been financed by government funds, river regulation authorities and the participating insti - tutions. The financial coordination was through the Association of River Regu - lation Authorities and the project has been administered by the Advisory Board on the Norwegian Hydrological Service from the autumn 1977.

The project is documented by 30 reports, and results, conclusions and recom - mendations is given in the final report by Wingård, Sælthun, Aam and Killing - tveit (1978).

MODELS

The following models and forecasting methods were tried out:

- HBV-3, developed at SMHI, described by Bergstrøm (1976)
- SNSF, developed initially as a small catchment model by Lundquist (1978)
- linear transfer models, based on the Box-Jenkins methods (Box and Jenkins, 1970) implemented on Norwegian computers and adapted to hydrological fore - casting by a subproject (Damsleth, 1978 a,b)
- prediction of snowmelt runoff volume by selective linear regression on precipitation volumes (Killingtveit, 1978 a)

System charts of the HBV-3 and SNSF models are shown in fig. 1. Both models describe the hydrological system mainly by coupled reservoirs. The main differ - ence is that the SNSF model consists of reservoirs coupled in parallell as well as in series, identifying different land types within the catchment. On the other hand, it lacks the soil moisture accounting routine of the HBV-3 model.

The linear transfer model predicts expected runoff by a linear combination of observed precipitation, temperature and runoff.

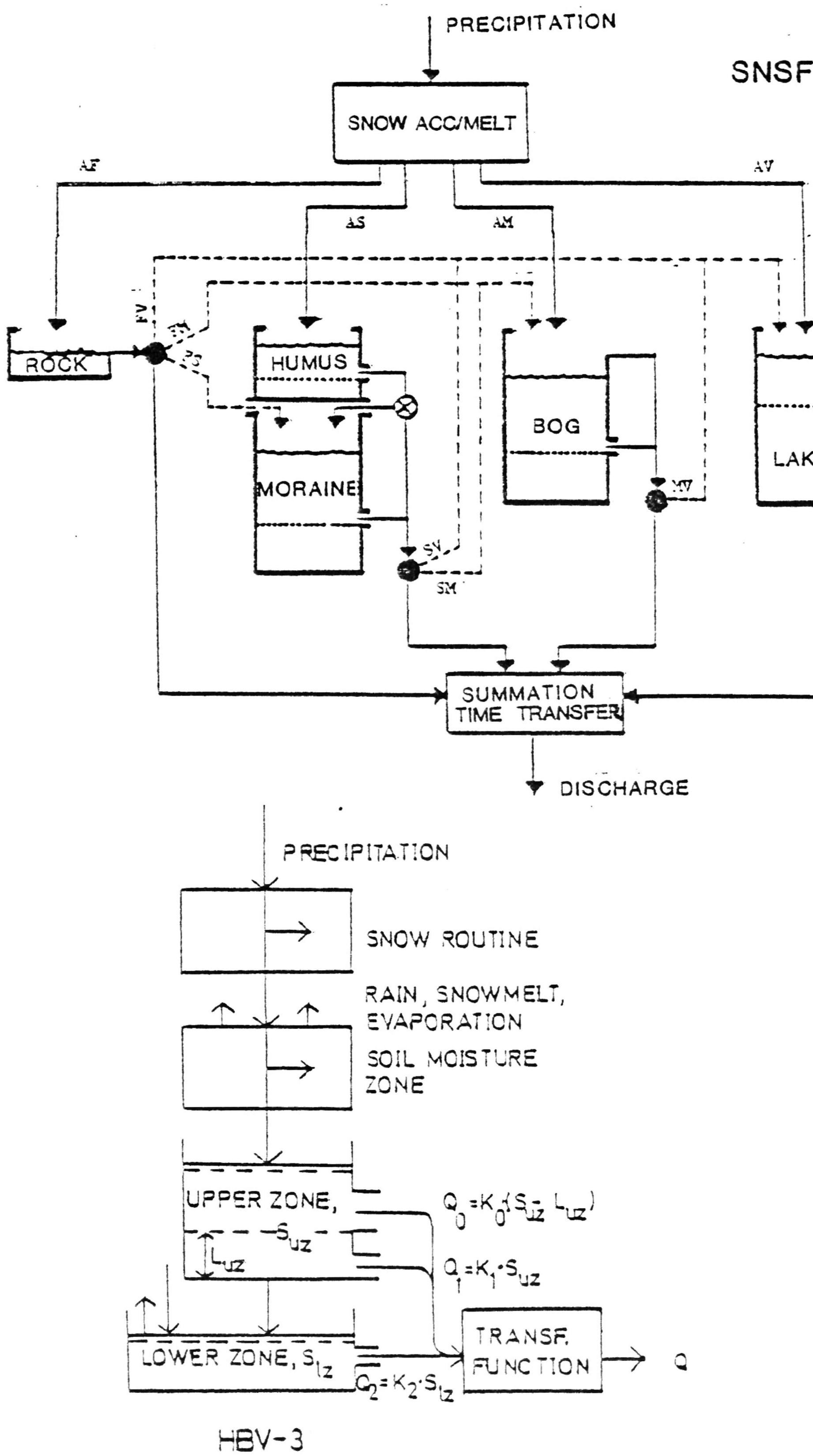

Fig. 1. System charts of the SNSF and HBV-3 models.
Latter illustration from Bergström (1976).

In climatic regions where snow accumulation is of importance in the hydrological regime, linear models as well as the conceptual models must be combined with snow accumulation/melt models if they are to be used in winter or melt seasons. All three models have been used together with the temperature based snow submodel of the HBV-3 model. This submodel was in the later stages of the project modified to account for areal snow distribution in addition to the orginal elevation snow distribution (Killingtveit, 1978 b).

CATCHMENTS

The models have been tested on nine catchments. The geographical distribution is shown in fig. 2, and the model/catchment combination in table 1.

Table 1. Model/catchment combinations.

Models / Catchments	HBV-3	SNSF	Regression	linear transfer models
Aursunden	x	x	x	
Knappom	x	x		x
Ølsjø/Bløytjern		x		x
Bøylefoss	x	x		x
Svartevatn			x	
Næverdal	x	x	x	
Reithølen			x	
Storvatn	x	x		
Rødsjø/Krinsvatn			x	

The catchments covers several typical climatic and physiographic regions in southern Norway. Areas ranges from 167 to 1625 km^2.

Discharge data are partly measured flows at gauging stations, and partly computed reservoirs inflows. Climatic data, precipitation and temperature, have been made available to the project by courtesy of the Norwegian Meteorological Institute, and are measured at standard meteorological stations.

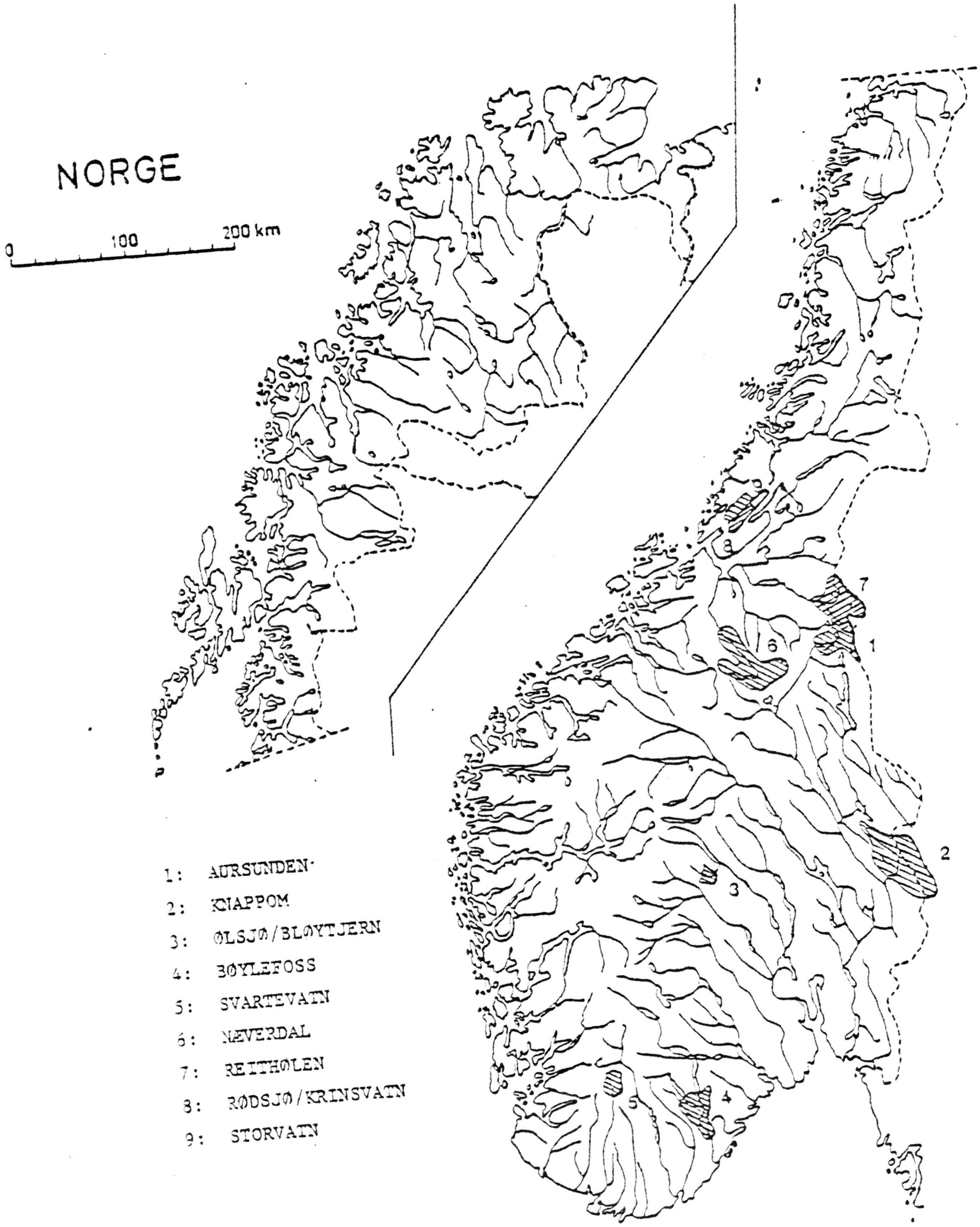

Fig. 2. Geographical distribution of catchments.

Station representativity is varying, from zero to four precipitation stations within the catchment. As a rule, the meteorological stations are situated in the lower parts of the catchments, and accordingly represent the upland parts poorly.

RESULTS

The SNSF and HBV-3 model both worked very well. It was not possible to distinguish clearly between the performance of the two models. The main error sources seemed to be

- non-representative input data
- the use of daily mean temperature as the only indication of precipitation type
- the assumption of constant snow depth within an elevation interval, and constant temperature melt factor in the snowmelt submodel.

In fig. 3 and 4 tests of the models on independent observations for two catchment in different hydrological regimes are shown.

It may be possible to make the linear transfer models work satisfactorily on five or seven day means when they are combined with snowmelt submodels. As snow models presently have to be adjusted to the actual catchment together with an hydrological model on observed flows, this greatly reduces the big advantage of linear models: simple adjustment. Another weakness of the linear models is that they do not seem to account properly for evaporation and varying soil moisture capacity. Temperature tend to fall out of the prediction equations, giving the same model response at midsummer as in the autumn.

The regression models for melt runoff volume forecasts perform well if there are representative precipitation stations with sufficiently long observation period. In that case, this method, which is very easy in use, compares with snow surveys.

CONCLUSIONS

The main conclusions of the project are:

1) Conceptual models like the HBV-3 and the SNSF are performing well enough to be put to operational use for hydrological forecasting in any part of Norway. Their degree of complexity matches very well the state of input data and meteorological forecast accuracy.

2) The largest improvements of the models can be expected by development of the snow submodel.

3) The use of the models is mainly limited by lack of observations of hydro - logical and meteorological data. Improvement of the data base is important to further development of forecasting methods.

4) In operational use, collection of data describing the state of snow cover and soil moisture can be of great value when the forecasting model is up - dated. That is when the state of the model is adjusted to correspond to the catchment by the time the forecast is made. Such data will ease the use of automatic updating methods. Existing soil moisture measuring techniq-ues are probably not good enough to improve model performance, however.

5) At present, it is essential to test out the models in operational use. This will make it possible to give estimates of the forecast errors and to get more knowledge about the value of hydrological forecasts in the day to day operation of power plants. In the project report the routines of model calibration, data collection, model updating and forecasting is sketched. Possible methods of coupling the hydrological forecast with short and long range reservoir management planning is also outlined.

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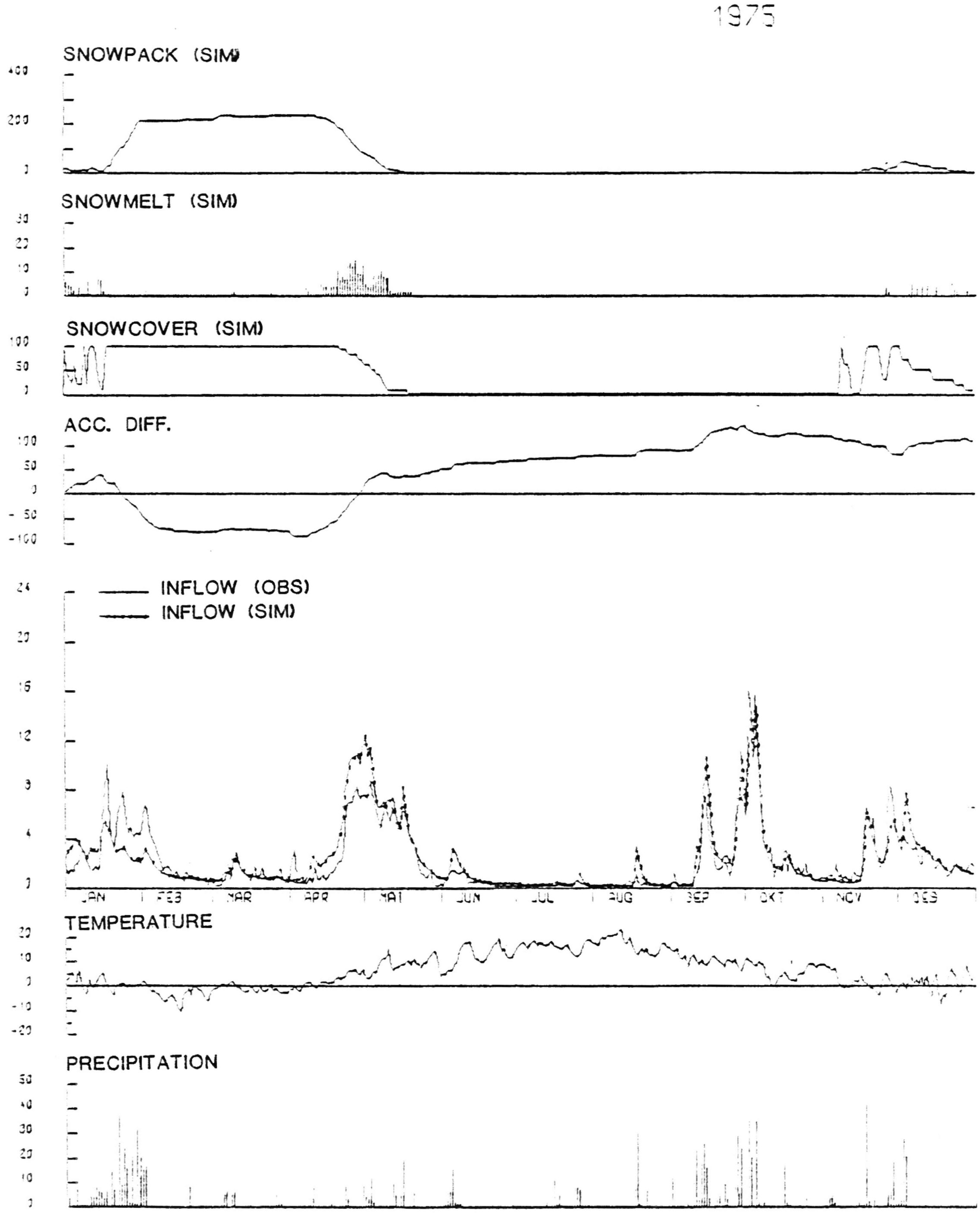

Fig. 4. Simulated reservoir inflow and snow variables, and observed precipitation, temperature and inflow for the local catchment of Bøylefoss hydropower plant.
Simulation model: SNSF.
Ordinate units: mm, mm/d, %, ^{o}C.
Catchment area: 1196 km^2.
Elevation range: 135 - 965 m.a.s.l.

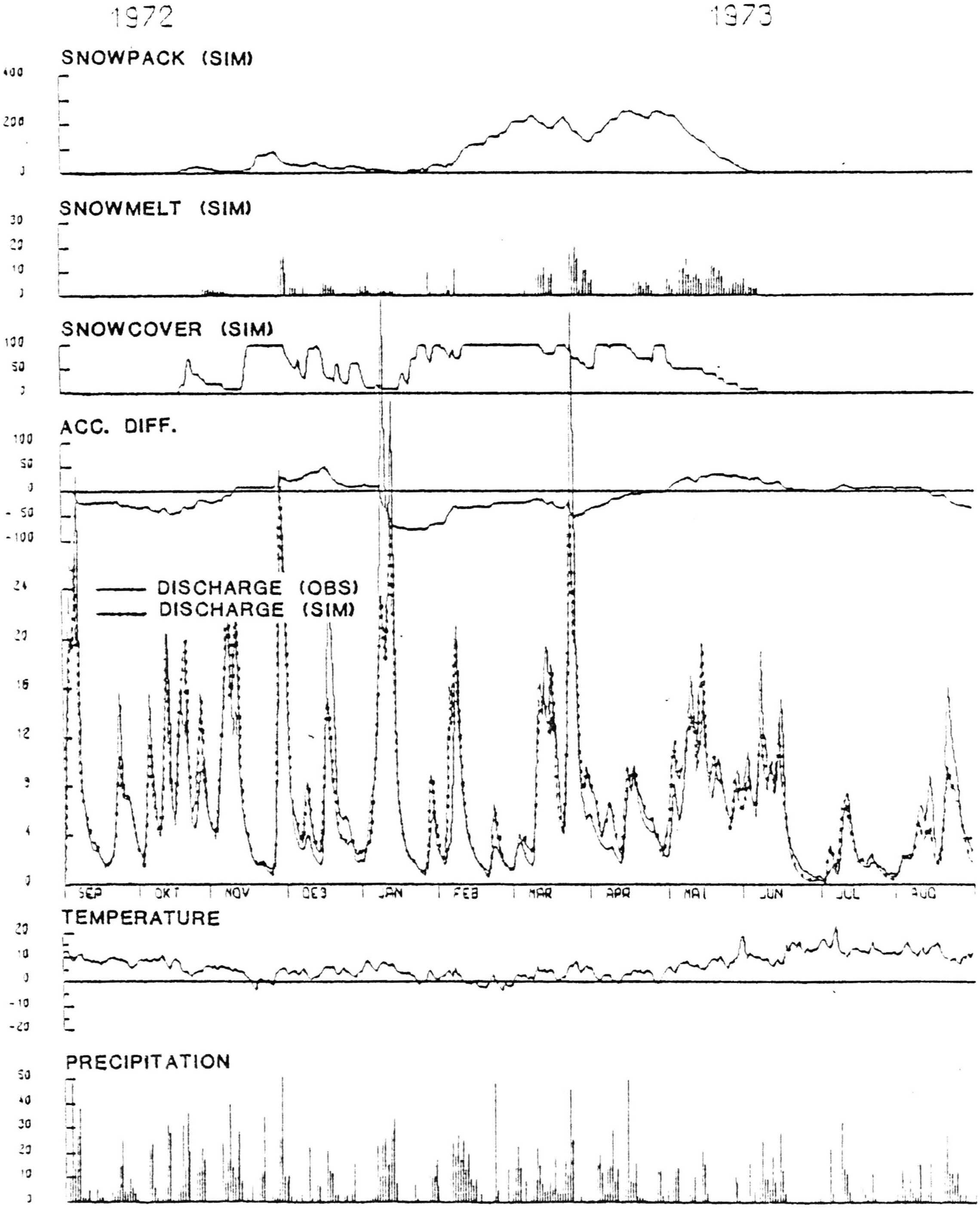

Fig. 3. Simulated discharge and snow variables, and observed precipitation, temperature and discharge for Storvatn catchment.
Simulation model: HBV-3.
Ordinate units: mm, mm/d, %, °C.
Catchment area: 167 km^2.
Elevation range: 80 -620 m.a.s.l.