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Hydrological Maps Development of a System for Calculation and Presentation

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Increasing attention is paid to problems concerning water resources planning. It is essential that the hydrological information required is available to the planner in a form that facilitates combination with other types of information.

This paper describes the development of a system for calculation and presentation of regional and comprehensive hydrological information. Main components of the system are the interpolation routines, a water balance model adapted to the space and time scale and a data base for supporting information. Examples of presentations are given.

Introduction

Increasing attention is paid to problems concerning water resources planning. Within the planning a wide variety of aspects have to be taken into account. The search for an optimal solution contains combination of strongly differing information types. Due to this, the producers of the input information have to be prepared to provide presentations of their respective variables in a rich variety of forms. The system underlying the production consequently has to be very flexible.

This paper describes the work done at the Swedish Meteorological and Hydrological Institute on the development of a system capable of fulfilling the above mentioned demands. More precisely the project has been connected with methods for calculation and presentation of hydrological and oceanographical information. The information being of regional or comprehensive type. In figures the spatial scale corresponds with a map scale varying in between 1:250,000 and 1:2.500,000.

The purpose with respect to time scale is to give characteristics of monthly values for any desired period.

The paper will only discuss the hydrological part of this pilot study but the production scheme is mainly in common for the oceanographical information as well.

The methods used have to a large extent been developed by Gottschalk and Krasovskaia (1980) with a research project where applications were tested on the Hjälmaren watershed.

Test Area, Variables

In this project the southernmost province of Sweden was chosen as test area (Fig. 1).

Data were collected from the period 1951 to 1980. Calculations were performed using monthly values as input. Computational elements in the spatial sense were defined by squares of 5×5 km^2. Each element corresponds to one chart of the economical map of Sweden. This is also the element proposed by the National Physical Planning in Sweden.

Input and output variables of the system are summarized in Table 1.

As mentioned above monthly values of each variable have been used in the computations. This is with one exception. To get monthly values of rain and snow, daily values of precipitation and temperature were used.

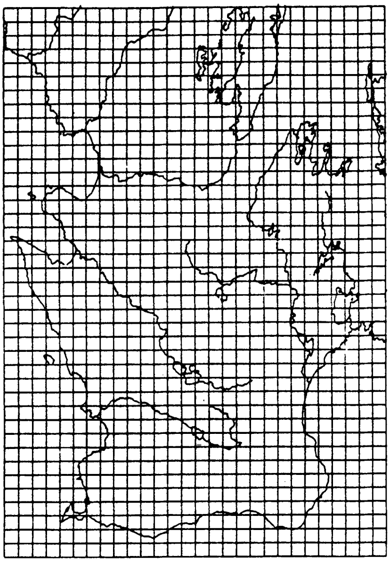

Fig. 1. Test area and computational elements.

Table 1 – Input and output variables

Input	Output
Precipitation	Rain
Temperature	Snow
Cloudiness	Evapotranspiration
Vapour pressure	Runoff
Wind	River flow
River Flow	

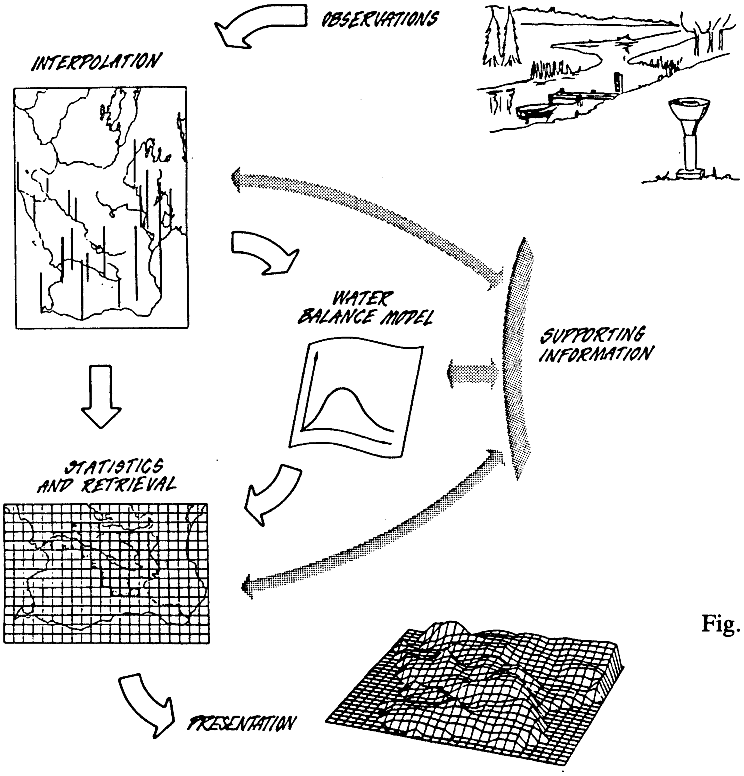

Fig. 2. Main features of the system.

System

The main parts of the system and their interconnections are given in Fig. 2. The routines for interpolation provide estimates for each required computational element and time step. Three types of procedures have been used: Weight coefficients applied on values from surrounding stations, multiple regression analysis and the use of empirical orthogonal functions (EOF).

The first two methods were used for filling in gaps and extrapolation of series in time. The EOF method was used to give estimates for all variables, except river flow for each computational element and month. This part easily gets heavy with respect to computer resources needed. The EOF method appeared to be most effective in this sense. Its interpolational ability was compared with the method of using neighbouring stations and errors of estimates were found to be of the same magnitude.

The use of empirical orthogonal functions as an interpolation tool in hydrology has been presented by Jutman (1984). Shortly the method can be described as a transformation of input series into a new set of series. The new series have the valuable property that a major part of the information of the original series is contained in a small number of the new ones. Also we get a separation into a time

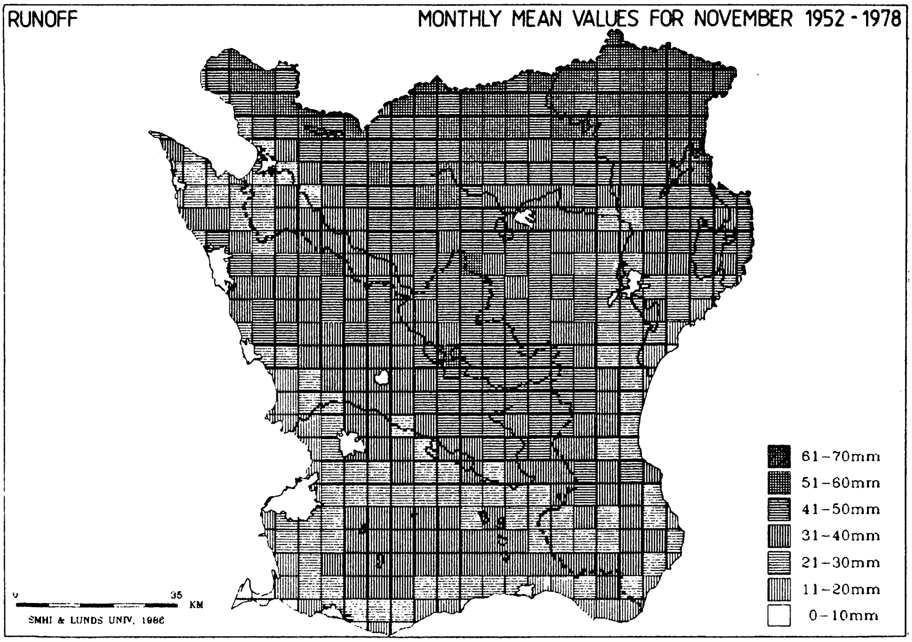

Fig. 3. Runoff – Monthly mean values for November.

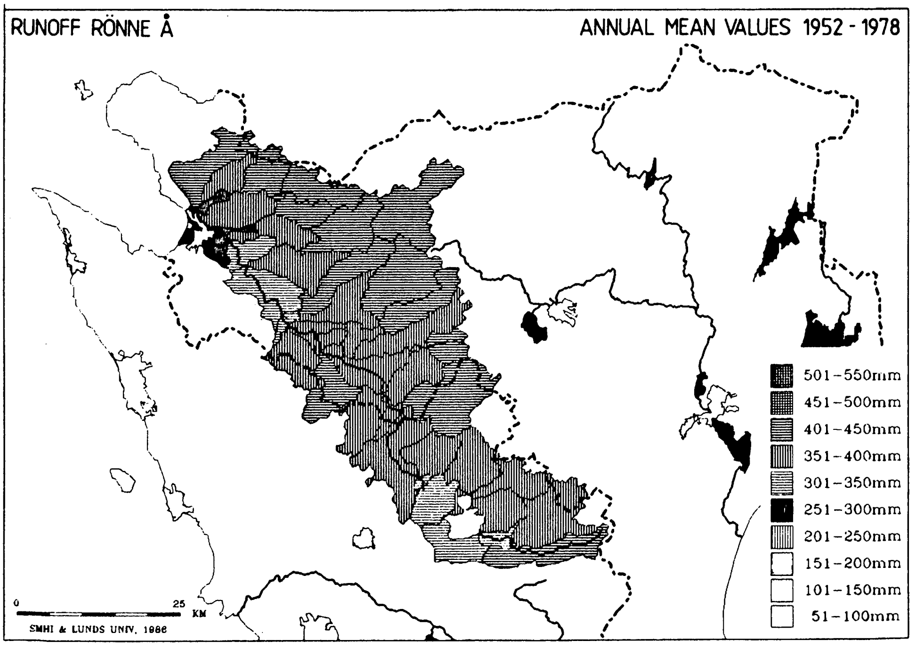

Fig. 4. Runoff – Annual mean values.

dependent part; the new series, and a space dependent part; weight coefficients.

As an example of the property of concentrating information, 60 precipitation series could be described using three of the new series with a variance coverage of 88%.

Output from interpolations serves either as direct input to presentations via statistical procedures or as input to the water balance model. The water balance model being a very important part of the system is described more in detail in the following chapter.

Output from the model or from the interpolation routines is then run through statistical and retrieval routines.

The statistical routines today just contain computation of standard statistics (average, spread etc). A major philosophy for the whole of the system is though that each main part can be improved or exchanged without requiring any changes for the rest of the system.

The retrieval routines work as identifiers of areas and variables to be presented. The retrieval can be performed using both hydrological and administrative criteria. The hydrological retrieval involve the use of coordinates for water divides and river reaches.

The presentation is the important link to the user of the information. Maps and tables are common forms and nowadays also digital maps for the user to combine with other types of information using his or hers own computer. The examples of maps shown in this paper have been produced in cooperation with the Univerity of Lund. The background map is taken from the digital map of Sweden. One of the pictures (Fig. 3) shows a presentation based on the computational elements. The other one (Fig. 4) shows a river in the region for which the division into subbasins is used as a basis for the presentation.

As shown in Fig. 2 more than one part of the system is depending on what is being denoted as supporting information. Several types of hydrological and landscape information is contained under this concept.

Information about topography is used in the interpolation routines. The water balance model need information about land type (forest, lake etc.) as well as soil type. For retrieval purposes the storage contains coordinates of water divides. – These are some examples of contents and usage of the supporting information.

Water Balance Model

A simple box model, schematically described by Fig. 5, has been used for the water balance calculations. One box (1) representent the soil water storage, one box (2) the ground water storage and one (3) the lakes. The model has four regionally varying parameters. One is a precipitation coefficient, while the others determine how fast the modelled runoff responds to infiltration. The use of a simple model with few parameters means that the process of establishing generalized parameters for a region is not too complicated.

The evaporation is calculated by a complementary relationship areal evapotranspiration model (Morton 1983). This model makes it possible to estimate the evapotranspiration from the same climatological data as are required to compute potential evapotranspiration. The idea of the complementary relationship can be explained as follows: At constant net radiation, the potential evaporation increases (according to Penman 1948) when the vapour pressure deficit increases. This results from an increase in air temperature, which is reflected in the saturation vapour pressure, or from a decrease in humidity. Such changes could be expected from the increase in heat flux and the decrease in vapour flux associated with a reduction in the availability of water for evapotranspiration.

The matematical rationalizations of the complementary relationship are formulated by Morton (1983) and will not be given here. The complementary relationship was tested by Morton for 143 basins in many different parts of the world. The yearly evapotranspiration calculated by the model, was compared with evapotranspiration determined from the water balance. The mean deviation was 3.4% and the maximum 9.9%.

For the calculations of recharge the formula used by Korzun (1977) and Gottschalk and Krasovskaia (1979) is utilized with a slight modification. The recharge is computed as:

$$QTOT \equiv \gamma \frac{W}{2\,WMAX}\,PERC$$

$$\gamma \equiv \sqrt{\gamma_0^2\,(1-(1-EPOT/150)^2\,) + (1-EPOT/150)^2}$$

*Q*TOT – recharge
γ_0 – model parameter
*W*MAX – model parameter = "maximum soil moisture storage"
W – calculated soil water storage
PERC – infiltration = rain + snowmelt
EPOT – potential evapotranspiration calculated according to Penman (1948)

The groundwater storage of the model is assumed to behave as a linear reservoir with the time constant *K*1 (a model parameter)

The model parameters were determined through calibration for 11 basins in Skåne by automatic optimization. The length of most of the streamflow records was short, less than 10 years. The optimization procedure used was a modified version of Rosenbrock's method (Rosenbrock 1960, Clarke 1973).

Of the parameters γ_0, *W*MAX and *K*1 only *K*1 could be found to have any association to soil type.

The purpose of the precipitation coefficient is to correct for the underestimation

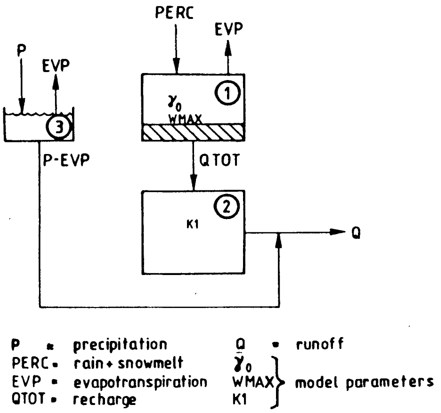

Fig. 5. Model structure.

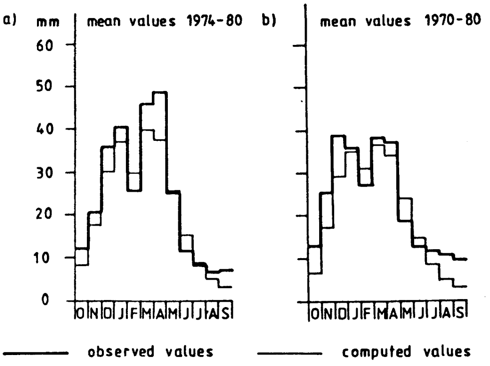

Fig. 6. Observed and computed monthly mean runoff for two basins not used in the calibration process.

of precipitation normally made at observations, but its estimated value may also be influenced by errors in the evaporation calculations. No geographic pattern could be found in the coefficients determined for the calibrated basins. For the computations of the runoff for the whole of Skåne the mean value of the estimated coefficients was used.

With the generalized parameters the runoff was computed for the basins used during the calibration process as well as for two other, considerably greater basins. The results from these two latter basins did not differ from the rest. The standard error of the individual monthly values was estimated to 46% of the mean. This could be compared with the standard errors determined by Alley (1984) when investigating several water balance models based on monthly data. The standard error for all those models was, after calibration, approximately 40% of the mean.

Table 2 contains the standard error of the monthly mean runoff values, estimated from the same time series as the standard error of the individual months.

Fig. 6 shows the computed observed monthly mean runoff for two basins for which no calibrations were made.

Table 2 – Standard error of monthly mean runoff

	Standard error	Mean value		Standard error	Mean value
Oct	4.4 (mm)	15.7 (mm)	Apr	10.1 (mm)	43.0 (mm)
Nov	5.5	27.3	May	7.4	18.1
Dec	7.4	46.3	Jun	4.6	9.9
Jan	8.5	44.1	Jul	4.0	9.9
Feb	8.9	29.6	Aug	4.6	7.8
Mar	12.7	52.7	Sep	5.8	8.9
			Year	43.9	287.4

Conclusions

The system developed is an information system for hydrological information of regional or comprehensive character. It transforms observational data to map information through the use of interpolation routines and a water balance model. Flexibility of the system has been a main concept, especially concerning the possibilities of choosing form of presentation.

The work of the water resources planner involves the connection of information about variables of quite different types. The hydrological input is only one of them. The hydrological information provided therefore has to be adapted to the task particularly in the sense that all specific hydrological interpretations already have been done.

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