Meso-Scale Hydrologic Modeling for Climate Impact Assessments: A Conceptual and A Regression Approach

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CP-94-10
May 1994

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Foreword

As part of the climate and hydrology work at IIASA, a water balance model for assessing climate impacts on the river basin scale was developed. The application of model raised many research questions, such that the Water Project embarked on a task to analyze alternative methodologies and approaches to modeling climate change impacts at a river basins scale. The task included comparing a variety of alternative modeling approaches and applying these models on river basins in different hydro-climatic zones. To achieve this task, IIASA drew on it network of collaborators to provide models and data. The Institute of Environmental Engineering of the Warsaw University of Technology agreed to develop two models which have been used in the study. This paper presents the theory behind the two approaches and an applications of the model to one of the case study river basins, the Vistula in Poland

László Somlyódy
Leader
Water Resources Project

Preface

The paper present two different approaches to hydrologic modeling for Climate Impact Assessments: A conceptual water balance model and a non-parametric regression model. They both are designed for modeling large-scale river basins (Meso-Scale) at a monthly time step and to accept GCM-based climate scenarios defined as changes in monthly precipitation and temperature. The data requirements for the models are historical, multi-annual series of mean monthly temperature, precipitation, and runoff. These data are used to calibrate the models. GCM data or user-defined sensitivity of climatic variable must be provided for the assessment analyses. The paper describes the theoretical bases of both approaches and presents the results of a comparison of the application of the models to the Vistula River Basin in Poland.

DEVELOPMENT OF A MESO-SCALE HYDROLOGICAL MODEL FOR CLIMATE IMPACT ASSESSMENT

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DEVELOPMENT OF A MESO-SCALE HYDROLOGICAL MODEL FOR CLIMATE IMPACT ASSESSMENT

1. INTRODUCTION

Due to the impact of climate perturbations, serious changes in hydrological processes may occur, influencing regional water supply and causing serious social and economic problems. Most of the existing runoff models are aimed at short-term flood forecasting and cannot serve as a tool for assessing the sensitivity of runoff to climate change. The purpose of the Study is to develop an operational, PC-based runoff model where the input values are standard climatological data historical and obtained from Global Circulation Models.

In order to assess the sensitivity of runoff to GCM-based climate scenarios, there is a need to develop a catchment scale hydrological model able to simulate the monthly runoff differences for the $d{\times}CO_2$ and historical climates, Such a model should fulfil the following criteria:

- The input characteristics should correspond to the standard GCMs outputs, which in most cases are the monthly values of air temperature and precipitation. If other climatic parameters are used, then necessary assumption concerning their behavior in the "warmer" climate should be made.
- The model should produce monthly runoff characteristics for a river basin.
- The model should be implemented on the IBM compatible PC microcomputers.
- The calibration of the model should be done for the Vistula river basin in Poland on the basis of standard hydrological and meteorological data.

Although the model will be tested on the data for the Vistula river basin, it should allow runoff simulation for various climatic conditions and for standard data available in different regions of the World.

There are many types of hydrological catchment models reported in the literature. Thus, first we wanted to adopt one of them for our purpose. The analysis of several models led us to conclusion that every model was built for special purpose sometimes also for the specific catchment. Under such circumstances it is very difficulty, almost imposible, to apply these models for other purposes. In this situation we have decided to build two models specialy designed to compute runoff due to climate changes. One of them is the conceptual model of monthly runoff based on water balance equation (Chap. 2). The second one is the nonparametric regression model (Chap. 3).

2. CONCEPTUAL SIMULATION MODEL BCM OF THE MONTHLY RUNOFF

2.1. Purpose and basic assumptions of the model

The model BCM (Basin Conceptual Model) is to serve for simulation of the monthly runoff changes caused by the increase of CO_2 in the earth's atmosphere. Climatic changes are simulated by means of the so-called Global Circulation Models (GCM) from which, at the assumption of a certain increase of CO_2 concentration in the atmosphere, averaged (for longer periods) monthly temperature and precipitation increases are obtained at the nodes of a grid, set every 0,5 degree of longitude and latitude.[1)] That data is basically the only information which may be utilized in the simulation model of the monthly runoff. Such a restricted input data is the factor which extremely influences the choice of simulation model type. Other factor, none the less important, is the requirement of its parameters limitation. In the specification process of the model the following assumptions have been made, taking into consideration the above mentioned restrictions:

a) Input to the simulation model will be made of historical, multi-annual series of mean monthly temperatures and monthly total precipitation disturbed by increments resulting from the scenarios determined by means of Global Circulation Models.

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1) Suitable increments of temperature and precipitation were obtained from IIASA in 1991.

b) The model should satisfy the law of conservation, what in practice resolves itself into the construction of a model which satisfies the equation of continuity being the simplified form of the water balance equation for each successive month.
c) Each process of water exchange in a river basin will be simulated using simple conceptual models, including possibly the least number of parameters.
d) Identification of model's parameters will be performed on the basis of historical data. Optimum values of parameters will be estimated as a result of the minimization of the sum square differences between the calculated and the observed values of monthly runoff.

2.2. Description of the model's structure

In accordance with the assumptions presented in chapter 2.1. the conceptual model of the monthly runoff consists of the following elements:

EQUATION OF CONTINUITY

The water balance equation in a river basin during each successive i-th monthly period has been assumed as follows:

$$S_{i-1} + A_{i-1} + P_i = E_i + R_i + S_i + A_i \qquad (2.1)$$

where:

P - total monthly precipitation,
E - monthly evapotranspiration,
R - monthly runoff,
S - active storage in the river basin at the end of i-th month,
A - snow accumulation at the end of i-th month.

MODEL OF SNOW ACCUMULATION AND MELTING PROCESS

The model of snow accumulation and melting process is two-parameteric. Both parameters $T1$ and $T2$ are of temperature dimension. The value of $T2$ parameter takes into account the separation of precipitation into liquid - rainfall ($T_i \geq T2$) and solid - snowfall ($T_i < T2$), where T_i is the mean temperature in i-th month. The value of $T1$ parameter determines the lower limit temperature of the snow cover melting process. If $T_i \leq T1$, then only the process of snow accumulation takes place.

In the model of the snow cover melting process it has been assumed that the process proceeds according to the following:

$$M_i = \alpha_i \, (A_{i-1} + P_i) \tag{2.2}$$

where:

$$\alpha_i = \begin{cases} 0 & \text{for} \quad T_i \le T1 \\ 1 & \text{for} \quad T_i \ge T2 \\ (T_i - T1)/(T2 - T1) & \text{for} \quad T1 < T_i < T2 \end{cases} \tag{2.3}$$

M_i - water from snow melting process,

T_i - mean temperature for i-th month,

P_i - total precipitation for i-th month,

A_{i-1} - accumulation of snow from the previous month.

The process of snow accumulation in i-th month is described as:

$$A_i = (1 - \alpha_i) \, (A_{i-1} + P_i) \tag{2.4}$$

Taking into account that data used for the model pertain to hydrologic year, it may be presumed that the initial accumulation of snow $A_0 = 0$.

The distinction of the winter season in a given year is made if the following condition has been satisfied:

$$(A_{i-1} > 0) \vee (T_i < T2). \tag{2.5}$$

If in i-th month the above condition is not satisfied, it is assumed that this month belongs to the summer season. This condition operates as a switch of the model structure, because the model takes into consideration the divergencies of processes occurring during winter and summer seasons.

MODEL OF EVAPOTRANSPIRATION PROCESS

Due to a considerably restricted input data the evapotranspiration process is modelled in a very simplified way. One should then be prepared for the substantial simulation error, since the neglected input data, which is essential for the evaporation process course, assumes the disturbance character.

The current evapotranspiration is determined in each i-th time step according to the formula:

$$E_i = E_{pi}\left(1 - \exp(-k_e\, S_{i-1})\right) \tag{2.6}$$

where:

E_{pi} - index of potential evapotranspiration,

S_{i-1} - active river basin storage at the end of the previous month,

k_e - parameter of the evapotranspiration model.

The monthly potential evapotranspiration index is estimated on the basis of any external model (e.g. Thornthwaite or Penman method)

During winter season the values of the current evapotranspiration, calculated from the formula (2.6) are very small and one should expect that they are considerably smaller than the anticipated error of evapotranspiration model. Owing to this, in the runoff model an assumption has been made that during winter season the evapotranspiration process can be neglected ($E_i = 0$).

MODEL OF RUNOFF PROCESS

During winter season, when condition (2.5) is satisfied, the runoff is calculated for each month from the relation:

$$R_i = k_g\, S_{i-1} + k_w\, M_i \tag{2.7}$$

where:

R_i - monthly runoff during winter season,

S_{i-1} - active storage at the end of the previous month,

M_i - water from snow cover melting,

k_g - parameter of runoff from the active river basin storage,

k_w - parameter of surface runoff during winter conditions.

During summer season, when condition (2.5) is not satisfied, the runoff for each month is determined from the relations:

$$R_i = \begin{cases} k_g S_{i-1} + \dfrac{(P_i - I_i)^2}{P_i + 4I_i} & \text{for} \quad (P_i - I_i) > 0 \\ k_g S_{i-1} & \text{for} \quad (P_i - I_i) \le 0 \end{cases} \tag{2.8}$$

where:

I_i - index of monthly total initial losses:

$$I_i = \begin{cases} 0,2\left(\dfrac{1}{k_s} - S_{i-1}\right) & \text{for} \quad \left(\dfrac{1}{k_s} - S_{i-1}\right) > 0 \\ 0 & \text{for} \quad \left(\dfrac{1}{k_s} - S_{i-1}\right) \le 0 \end{cases} \tag{2.9}$$

R_i - monthly runoff during summer season,

S_{i-1} - active storage at the end of the previous month,

k_g - parameter of runoff from the active river basin storage,

k_s - parameter describing the maximum river basin storage capacity.

The form of the function describing the surface runoff process has been taken from the SCS method used for effective precipitation calculation. Elements of this function have undergone appropriate modification for the monthly runoff.

2.3. Computational algorithm

Simulation of the monthly runoff is carried out by repeated (for each i-th month) solutions of equations which describe successively:

- water accumulation A_i in the snow cover from eq. (2.4), at the assumption that initial value of accumulation $A_0 = 0$,
- monthly evaporation E_i during summer season from eq. (2.6) or $E_i = 0$ during winter season,
- monthly runoff for the winter and summer seasons R_i from formulae (2.7) and (2.8), respectively,
- active river basin storage S_i at the end of the each i-th month:

$$S_i = S_{i-1} + P_i + A_{i-1} - A_i - E_i - R_i \tag{2.10}$$

whereas the initial value of active storage S_0 is not known and should be treated as one of model's parameters. It is, however, strongly correlated with runoff parameter k_ε, that is why its optimization has been disregarded. In the process of model's parameters identification the initial active storage S_0 is determined from the approximate relation:

$$S_0 \approx \frac{R_{o1}}{k_\varepsilon} \tag{2.11}$$

where:

R_{o1} - observed initial monthly runoff,

k_ε - optimum value of the parameter of runoff from the active river basin storage obtained in the process of model identification.

The computational experiments have proved that the runoff model described herein is characterized by a considerable stability which is mainly due to the form of a function defining the evapotranspiration process. In the model, fast damping of initial condition concernig the value of active storage S_0 takes place. Forced deviation of S_0 value, even by several hundred percent from the optimum value, are damped by the model within the few first time intervals (months).

3. KERNEL REGRESSION MODEL RRM OF THE MONTHLY RUNOFF

In this chapter regression model RRM (Runoff Regression Model) of monthly runoff is presented. Essential requirements for the model have been assumed as follows:

- input data should be based on observations of monthly runoff monthly precipitation and monthly mean air temperature,
- a lumped characteristics of climatic elements (precipitation and temperature) and runoff should be used,
- the number of calibrated parameters should be kept as small as possible.

The runoff model is given by

$$R_i = \hat{\text{reg}} \left[T_i, F_i, R_{i-1} \right] \tag{3.1}$$

where:

R_i - monthly runoff [mm],

T_i - mean monthly value of temperature [°C],

F_i - monthly value of water reaching the soil surface as a result of rainfall and snow cover melting [mm],

R_{i-1} - monthly runoff for $(i-1)$ month [mm],

$\hat{\text{reg}}[.]$ - estimator of regression function.

The arguments of the regression function have been decided on the basis of experiments whose goal was to minimize mean square differences between observed and modeled monthly runoff values.

3.1 Model of snowmelt and precipitation input

Assumption is made that $T1$ is the mean monthly air temperature below which the entire monthly precipitation is accumulated on the land surface as a snow cover, and $T2$ is the mean monthly air temperature above which precipitation is not acumulated.

In the month with mean air temperature:

- below $T1$,
  water equivalent of the snow cover A_i is expressed as:

$$A_i = A_{i-1} + P_i \tag{3.2}$$

whereas the water supply F_i from snowmelt and precipitation is

$$F_i = 0 \tag{3.3}$$

- between $T1$ and $T2$,
  the volume of water which is accumulated as a snow cover on the land surface is expressed as:

$$A_i = (1 - \alpha_i) \left(A_{i-1} + P_i\right) \tag{3.4}$$

where α_i is expressed by (2.3)

the remaining volume of the water as a liquid is

$$F_i = \alpha_i \left(A_{i-1} + P_i\right) \tag{3.5}$$

- above $T2$
  the entire precipitation as a liquid can be expressed as

$$F_i = F_{i-1} + P_i \tag{3.6}$$

whereas

$$A_i = 0 \tag{3.7}$$

The values of the $T1$ and $T2$ are estimated by calibration of model (3.1), which goal was to minimize mean square differences between observed and calculated monthly runoff values.

The initial value of the water equivalent of the snow cover is $A_0 = 0$. This is result of assumption that November 1 the snow cover in river catchment does not exist.

3.2 Regression function

A kernel (nonparametric) regression to estimate the unknown relationship between variables in equation (3.1) is proposed. The kernel regression [Feluch 1990; Adamowski, Feluch 1991] imposes no assumptions concerning the particular form of the regression function, what is substantiated in relationship (3.1).

In general the regression estimator assumes that a random variable Y is related to a random vector $\boldsymbol{X}$ of dimension k. The multivariate random sample of size n of $(k+1)$ dimensional random variables is given by

$$\{\boldsymbol{x}_i, y_i\} = \{x_{1i}, x_{2i}, \ldots, x_{ki}, y_i\} \quad i=1,2,\ldots n \tag{3.8}$$

with joint an unknown density $f(\boldsymbol{x},y)$. The marginal density of $\boldsymbol{X}$ is [Rao, 1983]

$$g(\boldsymbol{x}) = \int_{-\infty}^{\infty} f(\boldsymbol{x},y)\,dy \tag{3.9}$$

and the conditional density of Y given $\boldsymbol{X} = \boldsymbol{x}$ is

$$f(y|\,\boldsymbol{x}) = \frac{f(\boldsymbol{x},y)}{g(\boldsymbol{x})} \tag{3.10}$$

The conditional mean or regression of Y on $\boldsymbol{X}$ is

$$\text{reg}(\boldsymbol{x}) = E(Y|\,\boldsymbol{X}=\boldsymbol{x}) \tag{3.11}$$

or

$$\text{reg}(\boldsymbol{x}) = \frac{1}{g(\boldsymbol{x})}\int_{-\infty}^{\infty} y\ f(\boldsymbol{x},y)\,dy \tag{3.12}$$

The nonparametric estimator of the unknown joint density $f(\boldsymbol{x},y)$ can be expressed as [Feluch 1990]

$$\hat{f}(\boldsymbol{x},y) = \frac{1}{n}\sum_{i=1}^{n}\frac{1}{h_y}\,K\left(\frac{y - y_i}{h_y}\right)\prod_{l=1}^{k}\frac{1}{h_{x_l}}\,K\left(\frac{x_l - x_{li}}{h_{x_l}}\right) \tag{3.13}$$

where:

h_y - smoothing factor corresponding to the realization of random variable Y,

h_{x_l} - smoothing factor of l-th variable X_l

$\boldsymbol{x}$ - vector of k-variables $\boldsymbol{x} = \langle x_1, x_2, \dots x_k \rangle$

$K(.)$ - Gauss kernel function expressed as:

$$K(y) = \frac{1}{\sqrt{2\pi}} \exp\left(-\frac{y}{2}\right)^2 \qquad \text{for} \qquad -\infty < y < \infty \qquad (3.14)$$

The nonparametric estimator of the marginal density (3.12) is given by [Feluch 1990]

$$\hat{g}(\boldsymbol{x}) = \frac{1}{n} \sum_{i=1}^{n} \prod_{l=1}^{k} \frac{1}{h_{x_l}} K\left(\frac{x_l - x_{l\,i}}{h_{x_l}}\right) \qquad (3.15)$$

Based on (3.12) and (3.13), the nonparametric estimator of the regression function is expressed as [Feluch 1990; Adamowski, Feluch 1991]

$$\hat{\mathrm{reg}}(\boldsymbol{x}) = \frac{\sum_{i=1}^{n} y_i \prod_{l=1}^{k} \frac{1}{h_{x_l}} K\left(\frac{x_l - x_{l\,i}}{h_{x_l}}\right)}{\sum_{i=1}^{n} \prod_{l=1}^{k} \frac{1}{h_{x_l}} K\left(\frac{x_l - x_{l\,i}}{h_{x_l}}\right)} \qquad (3.16)$$

In this Study estimation smoothing factors are estimated by the method given in the above mentioned papers.

4. DESCRIPTION OF THE VISTULA RIVER BASIN AND ANALYSIS OF THE DATA

The Vistula basin has been chosen to estimate the impact of climatic changes on the river runoff. The Vistula river basin lies in the area located between the 17th and 25th degree of longitude east and 49th and 54,5th degree of latitude north. The area of the whole natural river basin is 199813 km^2, 87% of which is situated within borders of Poland. The Vistula river basin has been divided into four parts of diverse conditions of runoff formation. The differentiated parts of the river basin are monitored by meteorological stations.

The Vistula basin up to the gauging station at Zawichost, covering A = 50685 km^2, includes its upper course with mountainous tributaries. It is characterized by great diversity of land altitudes. The highest altitudes in Poland, reaching 2500 m above sea level, are found there. That basin is distinguished by considerable diversification of the annual mean total precipitation from 600 to 1600 mm and by the annual mean air temperatures from -0,8°C to 8,0°C.

The differential basin area between Zawichost and Warsaw, covering A = 34139 km^2, is characterized by uplands and lowlands. The Vistula is supplied at this part with small tributaries such as: Pilica, Kamienna, Wieprz. Annual total precipitation oscillates between 550 and 600 mm, whereas the annual mean air temperature for the longer period equals approx. 7,5°C.

The differential basin area between Warsaw and Kępa Polska is the largest singled out area covering A = 84024 km^2. North part of the basin is of a lake-type character, and the south part is of a lowland character. At this part the Vistula has the greatest tributaries Narew-Bug of joint basin area 74808 km^2. The annual precipitation ranges from 500 to 600 mm, and the annual mean air temperature varies between 6°C and 7,5°C.

The Vistula differential basin area between Kępa Polska and Tczew, extending for A = 25394 km^2 is a typical lowland basin with a small number of lakes and the depression zone at the river estuary. The Vistula is supplied at this part with some small tributaries. The annual total precipitation is from 500 to 600 mm, and the annual mean temperature of air equals approx. 7°C.

The division of the Vistula river basin into the differential basins and the location of the chosen meteorological stations is presented in Fig. 4.1.

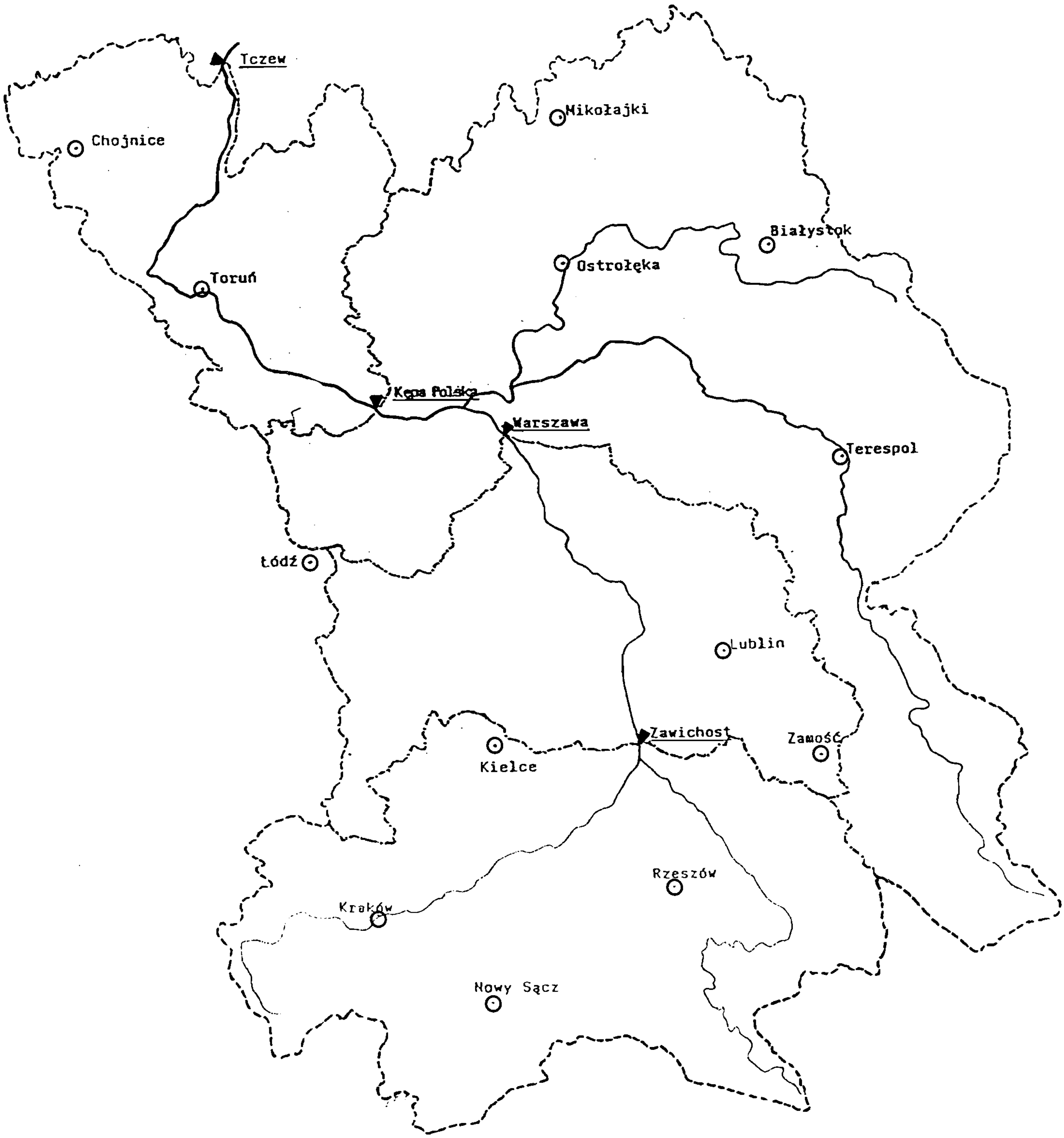


Fig. 4.1. The Vistula river basin with separated differential basins and meteorological stations used in the model.

The representativeness and the uniformity of the meteorological stations location on the river basin area were the principles guiding their selection. Table 4.1 presents the specification of meteorological stations, their geographic coordinates and altitudes above sea level.

Table 4.1.

Name of the station	Latitude	Longitude	Altitude above sea level
Nowy Sącz	49°37′	20°42′	292
Kraków	50°04′	19°57′	209
Rzeszów	50°06′	22°03′	200
Kielce	50°51′	20°37′	268
Zamość	50°42′	23°15′	212
Lublin	51°14′	22°34′	171
Łódź	51°44′	19°24′	187
Warsaw	52°09′	20°59′	106
Terespol	52°04′	23°37′	133
Ostrołęka	53°05′	21°34′	95
Białystok	53°06′	23°10′	148
Toruń	53°03′	18°35′	69
Chojnice	53°42′	17°33′	172
Mikołajki	53°47′	21°35′	127

The series of flows and meteorological elements in the years 1955-1981 were considered. The analysis of measurements series comprised the analysis of homogeneity of the following data:

a) the series of mean monthly flows for gauging stations: Zawichost, Warsaw, Kępa Polska and Tczew on the Vistula river,
b) the series of monthly total precipitation for the meteorological stations: Nowy Sącz, Kraków, Rzeszów, Kielce, Zamość, Lublin, Łódź, Warsaw, Terespol, Ostrołęka, Białystok, Toruń, Chojnice and Mikołajki,
c) the series of mean monthly air temperatures for the fourteen stations mentioned in point b).

The all measurement series mentioned above were tested from the point of view of accidental errors elimination and their homogeneity. The plots of the moving averages as well as of differences between the synchronous terms of the tested series and the series from the neighbouring stations were utilized for this purpose. The plots for the moving averages were drawn for the series from a single station and for the differences of observations between the considered station and the neighbouring ones. All calculations of the moving averages were performed for the period of averaging equal to 12 months. The analysis of the plots of moving averages allowed to detect trends or fluctuations in the investigated series, and the plots of differences - to accurately determine the time of disturbance or accidental errors occurrence.

The flow series, for each gauging station, was compared to the series from the neighbouring station as far as the conformity of hydrograms was concerned. Fundamentally, the compared hydrograms were consistent, with rare cases of negative increase in volume of flow. They were observed in these months when the flood (due to precipitation or snowmelt) proceeded along the river channel, and whose peak discharge was noticed at the end of a month. The same flood was observed in two different months by the neighbouring stations. That was a result of assuming a short (a month-long) water balance period. Therefore, the modelling of differential parts of a Vistula basin was abandoned in favour of the runoff models for the basin areas closed by the gauging stations: Zawichost, Warsaw, Kępa Polska and Tczew.

The series of monthly total precipitation for each of the fourteen meteorological stations were compared to monthly mean total precipitation from the neighbouring stations. The obtained plots did not warrant inferring about the occurrence of nonhomogeneity in the series of precipitation at the investigated stations. These plots were characterized by a high natural variability of the phenomenon. The variation may have included the changes caused by nonhomogeneity resulting, for example, from measurements themselves.

The series of monthly mean air temperatures for all meteorological stations were investigated in a similar way as the precipitation series. For three stations, namely: Zamosc, Bialystok and Lublin, abrupt changes on the plots of moving averages were observed. The plots of air temperature difference at the mentioned stations and the neighbouring ones proved that fact and enabled to establish the exact time of a disturbance (nonhomogeneity) occurrence. The noticed nonhomogeneities and the moment of their occurrence coincided with the times of relocations of the mentioned stations. The values of the observed disturbances, in the range 0.3-0.4°C, were introduced into the series of air temperatures for these stations.

5. APPLICATION OF THE MODELS TO THE VISTULA RIVER BASIN

5.1. The way of input data preparation taking into account the scenarios of climatic changes due to doubling of CO_2 concentration in atmosphere

Simulation results of temperature and precipitation changes taken from GISS and GFDL models, are presented in the form of averaged (for longer periods), absolute increments of mean monthly temperature and procentage increments of total monthly precipitation. Numerical values of these increments are placed in the nodes of grid cells of a side equal to 0,5 degree of latitude and longitude.

As an input to the simulation model of monthly runoff, instead of avarage values from long period, the succesive monthly values of mean temperature and precipitation in subsequent years have been used. Observations from a number of meteorological stations, located in the area of a river basin, are averaged by the method of Thiessen polygons. Taking these facts into consideration, an algorithm of the input data preparation, including scenario of climatic changes, has the following form:

- it is assumed that each node of the grid, for which the simulation results from GISS and GFDL models are known, is placed in the middle of the area of a geodetic trapezoid of sides corresponding to 0,5 degree of latitude and longitude. An assumption is made that the values of temperature and precipitation increments calculated for a given node hold true for the entire geodetic trapezoid,
- each meteorological station, which serves as the source of historical data is tested as to its location in relation to the geodetic trapozoids. If a station is located close to the centre of trapezoid, the data for it will be modified by the values of

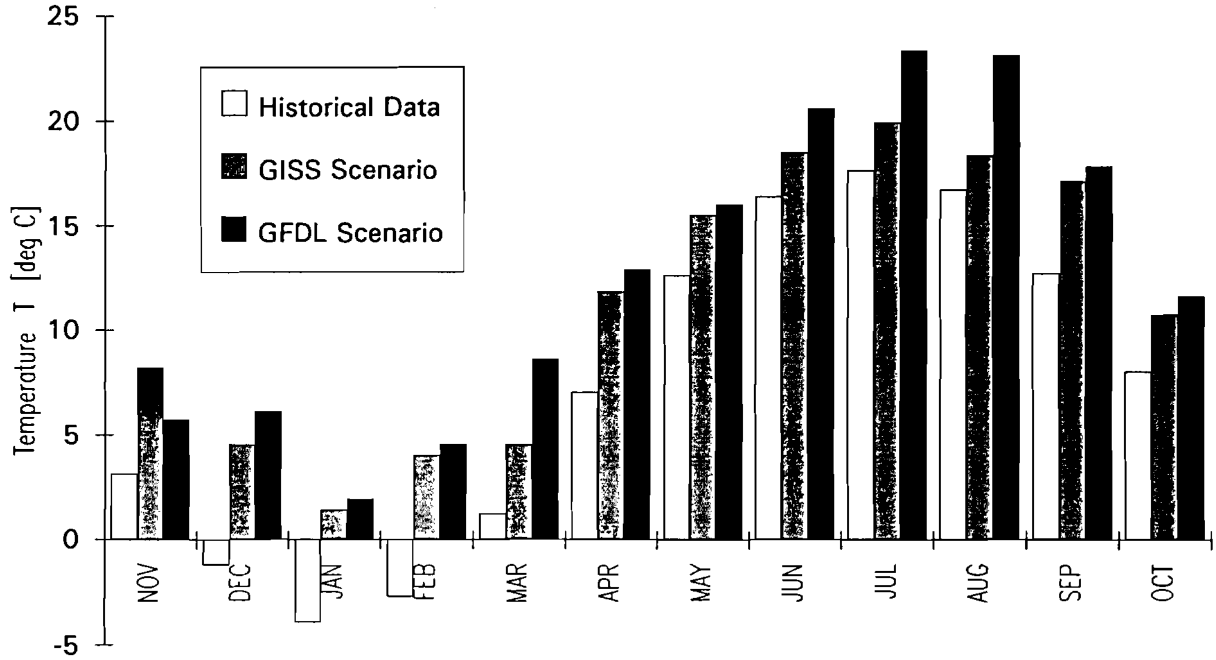
increments for the given trapezoid. If a station is located close to the middle of the boundary of two trapezoids, the mean values of increments from both trapezoids are taken as disturbance of data for this station. If a station is located close to the contact point of four trapezoids corners, the mean values of increments from all four trapezoids are assumed as the disturbance of the data for this station,

- for each meteorological station the historical data of the mean monthly temperatures and the monthly total precipitation is transformed by taking into consideration the increments for particular months (for a given station the sets of increments values each year are the same),
- input modified series for each station are used for calculation of mean values over river basin by the Thiessen polygon method,
- finally the results of the monthly runoff simulation and of other water balance elements are being averaged for the multi--annual period.

For all calculations carried out in this chapter appropriate computer programs have been developed. Results are presented in Table 5.1 and Fig. 5.1.

Table 5.1 Average increments of temperature and precipitation resulting from doubling CO_2 concentration for Vistula-Tczew basin

	GISS		GFDL	
months	ΔT [°C]	ΔP [mm]	ΔT [°C]	ΔP [mm]
NOV	5,2	15,2	2,7	4,2
DEC	5,7	1,1	7,3	15,8
JAN	5,3	4,1	5,8	4,4
FEB	6,7	6,8	7,2	9,2
MAR	3,3	9,2	7,4	5,3
APR	4,8	12,2	5,9	4,9
MAY	2,9	11,1	3,4	12,2
JUN	2,1	8,4	4,2	-8,4
JUL	2,3	14,5	5,7	13,6
AUG	1,6	14,6	6,4	32,8
SEP	4,4	-13,2	5,1	-0,2
OCT	2,8	12,5	3,7	-5,2



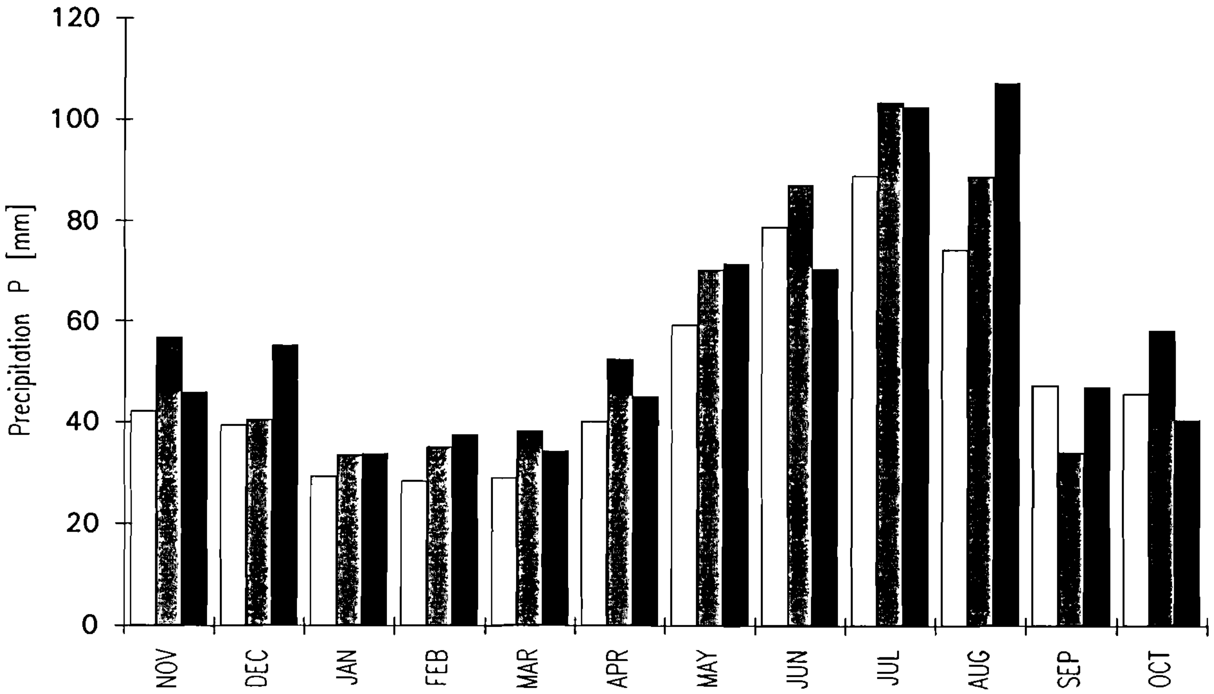


Fig. 5.1. Mean monthly temperature and precipitation computed on historical data, GISS scenario and GFDL scenario for Vistula-Tczew basin.

The monthly potential evapotranspiration index is estimated on the basis of the Schmuck formula [Dębski, 1959]:

$$E_{pi} = 30\ d_i \tag{5.1}$$

where: d_i - mean monthly deficit of air humidity.

The deficit of mean monthly air humidity is defined as a regional function of the mean monthly air temperature:

$$d_i = a\ (T_i + T0)^{b} \tag{5.2}$$

where:

$T0$, a, b - parameters of humidity deficit equation determined by the least square method, basing on the values of the mean air humidity deficit accessible for the given river basin,

T_i - mean monthly air temperature.

5.2. Identification of the conceptual model BCM

The above described model of monthly runoff contains six parameters whose values are obtained in the process of identification:

k_g - runoff parameter from active storage ($0 < k_g < 1$),
k_s - parameter characterizing maximum storage capacity of a river basin ($k_s > 0$),
k_w - runoff parameter in the winter season ($0 < k_w < 1$),
k_e - parameter characterizing the current evapotranspiration process ($k_e > 0$),
$T1$ - parameter defining the lower limit temperature, below which the snow melting process does not occur ($T1 < 0$),
$T2$ - parameter defining the limit temperature, below which the process of water accumulation as a snow cover may begin ($T2 > 0$).

Values of the above mentioned parameters may be obtained as a result of calibration by means of the trial-and-error method or by automatic optimization with the following objective function:

$$F_c = \frac{1}{n} \sum_{i=1}^{i=n} \left(R_{ci} - R_{oi} \right)^2 \tag{5.3}$$

where:

n - number of time intervals (months),

R_{oi} - observed runoff,

R_{ci} - computed runoff,

The application of the latter method is certainly much more convenient but in that case some quite serious difficulties may arise. The hypersurface $F_c(k_g, k_s, k_w, k_e, T1, T2)$ is very irregular, having numerous deflections and local minima. This is caused mainly by the step-like changes of the runoff model structure. From among various optimization methods reported in the literature [Kręglewski and all, 1984], the gradient methods are quite useless, and nongradient methods do not ensure correct results either. Nevertheless, it has been decided that the popular and usually quite effective Rosenbrock's method will be used for the purpose of the model's parameters identification. In order to improve the efficiency of identification, the repeated optimization with various sets of initial parameters values is suggested. The simulated (R_c) and obesrved (R_o) mean monthly runoff for Vistula-Tczew basin are presented in Table 5.2 and Fig. 5.2.

Table 5.2 Results of calculations by BCM for Vistula-Tczew basin (historical data).

months	T [°C]	P [mm]	R_o [mm]	E [mm]	S [mm]	A [mm]	R_c [mm]
NOV	3,0	41,6	12,5	16,2	100,0	2,7	12,1
DEC	-1,2	39,4	14,1	1,1	104,2	21,9	15,0
JAN	-3,9	29,4	13,2	0,0	97,1	45,5	12,9
FEB	-2,7	28,3	14,8	0,0	103,5	52,2	15,3
MAR	1,2	29,0	21,7	0,0	132,9	29,8	22,0
APR	7,0	40,2	26,5	18,0	159,1	0,0	25,8
MAY	12,6	59,2	17,7	64,6	135,7	0,0	18,1
JUN	16,4	78,8	14,6	76,3	122,8	0,0	15,4
JUL	17,6	88,8	13,7	77,8	118,8	0,0	15,0
AUG	16,7	74,2	14,2	71,6	107,9	0,0	13,5
SEP	12,7	47,2	10,5	53,1	90,0	0,0	12,1
OCT	8,0	45,6	11,9	33,9	91,2	0,0	10,5

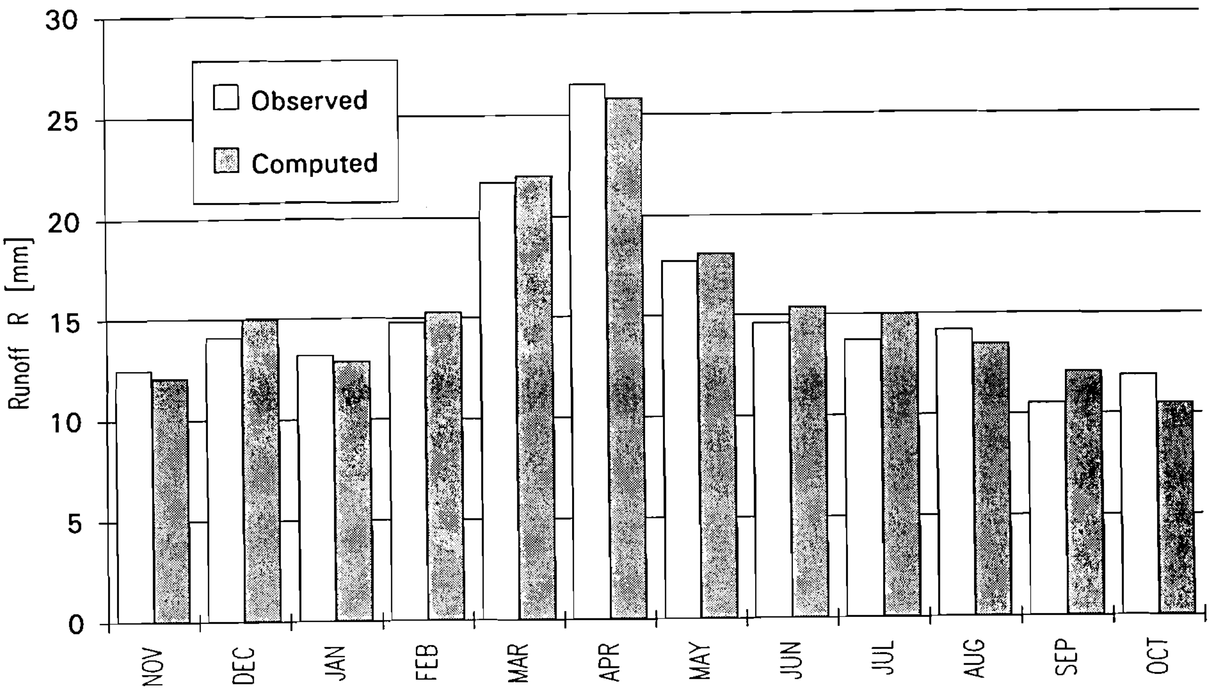


Fig. 5.2. Mean monthly runoff observed and computed by BCM for Vistula-Tczew basin.

5.3. Identification of the regression model RRM

The runoff model (3.1) was tested by splite-sample procedure. The data (precipitation, temperature and runoff) for the Vistula catchment divided into two equal parts were used for this purpose. The first part of the data set was used to estimate the smoothing factors and the second half was used as a basis for model verification.

As an indication of goodness of fitting between the observed and computed runoff values, the correlation coefficient r and the standard error s were calculated. The s value is defined by

$$s = \sqrt{\frac{1}{n-p}\sum_{i=1}^{n}(R_{ci}-R_{oi})^2} \qquad (5.4)$$

where:

n - number of observations,

p - number of model parameters (in this case p=5),

R_{oi} - observated runoff [mm],

R_{ci} - simulated runoff [mm].

From the numerical results it is determined that for the data set used in the estimation process r = 0,9308 and s = 3,1 mm, while for the data used in the verification r = 0,7405 and s = 6,4 mm. A splite-sample experiment shows that the nonparametric regression model (3.1) gives quite accurate computed results for the verification stage.

Based on the entire historical data set, the smoothing factors were estimated, and the simulation of runoff was carried out.

The observed (R_o) and computed (R_c) mean monthly runoff are presented in Table 5.3 and Fig. 5.3, which shows a good fitness between them.

Table 5.3 Results of calculations by RRM for Vistula-Tczew basin (historical data).

months	T [°C]	P [mm]	R_o [mm]	F [mm]	R_c [mm]
NOV	3,1	42,2	12,7	39,2	14,3
DEC	-1,2	39,4	14,1	17,9	13,8
JAN	-3,9	29,4	13,2	4,1	13,1
FEB	-2,7	28,3	14,9	19,9	14,7
MAR	1,2	29,0	21,7	51,9	20,6
APR	7,0	40,2	26,5	75,5	26,5
MAY	12,6	59,3	17,7	59,3	17,6
JUN	16,4	78,8	14,6	78,8	15,5
JUL	17,6	88,8	13,7	88,8	13,8
AUG	16,7	74,2	14,2	74,2	13,1
SEP	12,7	47,2	10,5	47,2	11,1
OCT	8,0	45,6	11,9	45,6	11,8

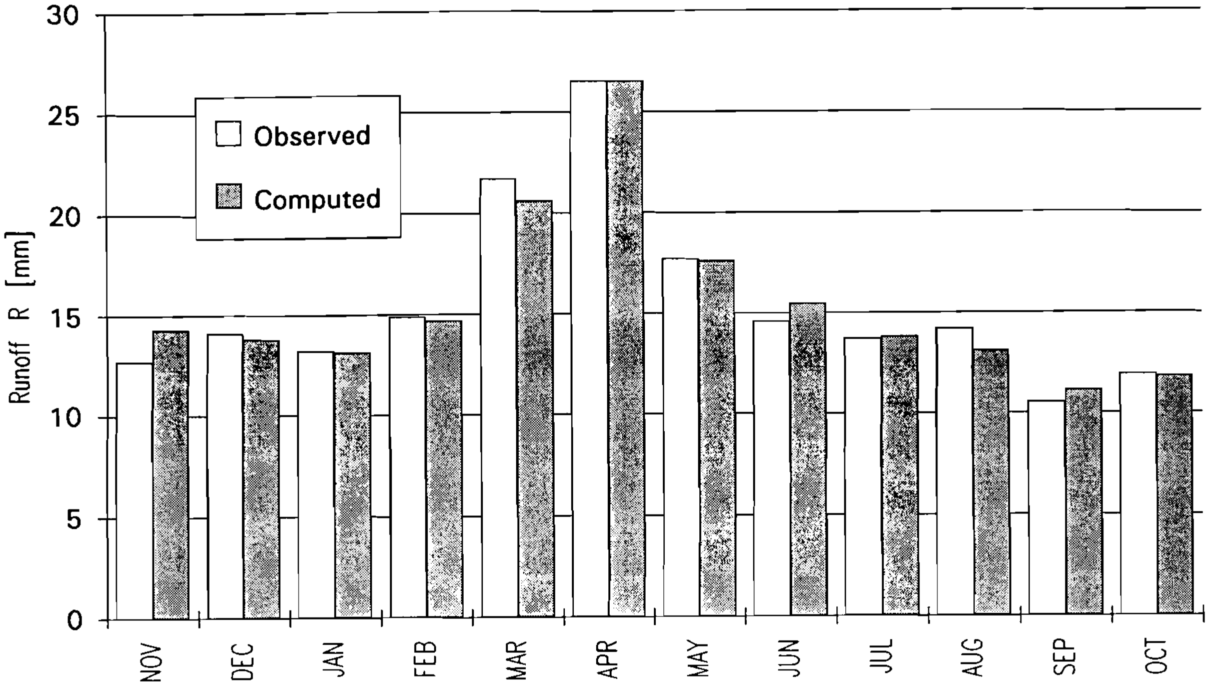


Fig. 5.3. Mean monthly runoff observed and computed by RRM for Vistula-Tczew basin.

It should be added that the sums of calculated and observed values of runoff are very similar $\sum_{j=1}^{12}(R_{cj}) = 185{,}9$ mm and $\sum_{j=1}^{12}(R_{oj}) = 185{,}7$ mm.

5.4. Computational results of the conceptual model BCM

The calculations have been carried out for the whole Vistula basin closed by the gauging station Tczew. To check the model's behaviour in river basins of diverse sizes, calculations have been also carried for three inner basins closed by gauging stations: Zawichost, Warsaw and Kępa Polska. The paper provides printout of results for the Vistula basin at gauging station Tczew only. This results are presented on Fig. 5.4 and Fig. 5.5. and in Tables 5.4 and 5.5, where ΔR means increment of mean monthly runoff resulting from doubling CO_2 concentration.

Table 5.4 Results of calculations by BCM for Vistula-Tczew basin (GISS scenario).

months	T [°C]	P [mm]	E [mm]	S [mm]	A [mm]	R_c [mm]	ΔR [mm]
NOV	8,2	56,8	31,2	96,2	0,0	8,9	-3,2
DEC	4,5	40,5	23,0	100,0	2,0	11,6	-3,4
JAN	1,4	33,5	8,4	103,0	9,6	14,6	1,7
FEB	4,0	35,1	7,3	117,1	5.6	17,7	2,4
MAR	4,5	38,2	18,8	121,0	3.5	17,5	-4,5
APR	11,8	52,4	35,1	124,5	0,0	17,5	-8,3
MAY	15,5	70,3	68,4	111,9	0,0	14,4	-3,7
JUN	18,5	87,2	77,7	108,5	0,0	12,9	-2,5
JUL	19,9	103,3	83,2	114,3	0,0	14,4	-0,6
AUG	18,3	88,8	76,6	112,9	0,0	13,6	0,1
SEP	17,1	34,0	71,5	62,7	0,0	12,7	0,6
OCT	10,7	58,1	31,8	81,0	0,0	7,9	-2,6

Table 5.5 Results of calculations by BCM for Vistula-Tczew basin (GFDL scenario).

months	T [°C]	P [mm]	E [mm]	S [mm]	A [mm]	R_c [mm]	ΔR [mm]
NOV	5,7	45,8	21,2	79,7	0,5	7,5	-4,6
DEC	6,1	55,2	24,5	99,8	0,9	10,3	-4,7
JAN	1,9	33,8	11,2	101,6	7,5	14,2	1,3
FEB	4,5	37,5	10,2	115,2	4.5	16,6	1,3
MAR	8,6	34,3	32,4	105,9	0.0	15,7	-6,3
APR	12,9	45,1	52,6	86,5	0,0	11,9	-13,9
MAY	16,0	71,4	57,4	90,5	0,0	9,9	-8,2
JUN	20,6	70,4	77,9	72,9	0,0	10,2	-5,2
JUL	23,3	102,4	78,5	87,1	0,0	9,7	-5,3
AUG	23,1	107,0	85,4	97,1	0,0	11,6	-1,9
SEP	17,8	47,0	67,2	66,0	0,0	10,9	-1,2
OCT	11,6	40,4	35,0	63,9	0,0	7,6	-2,9

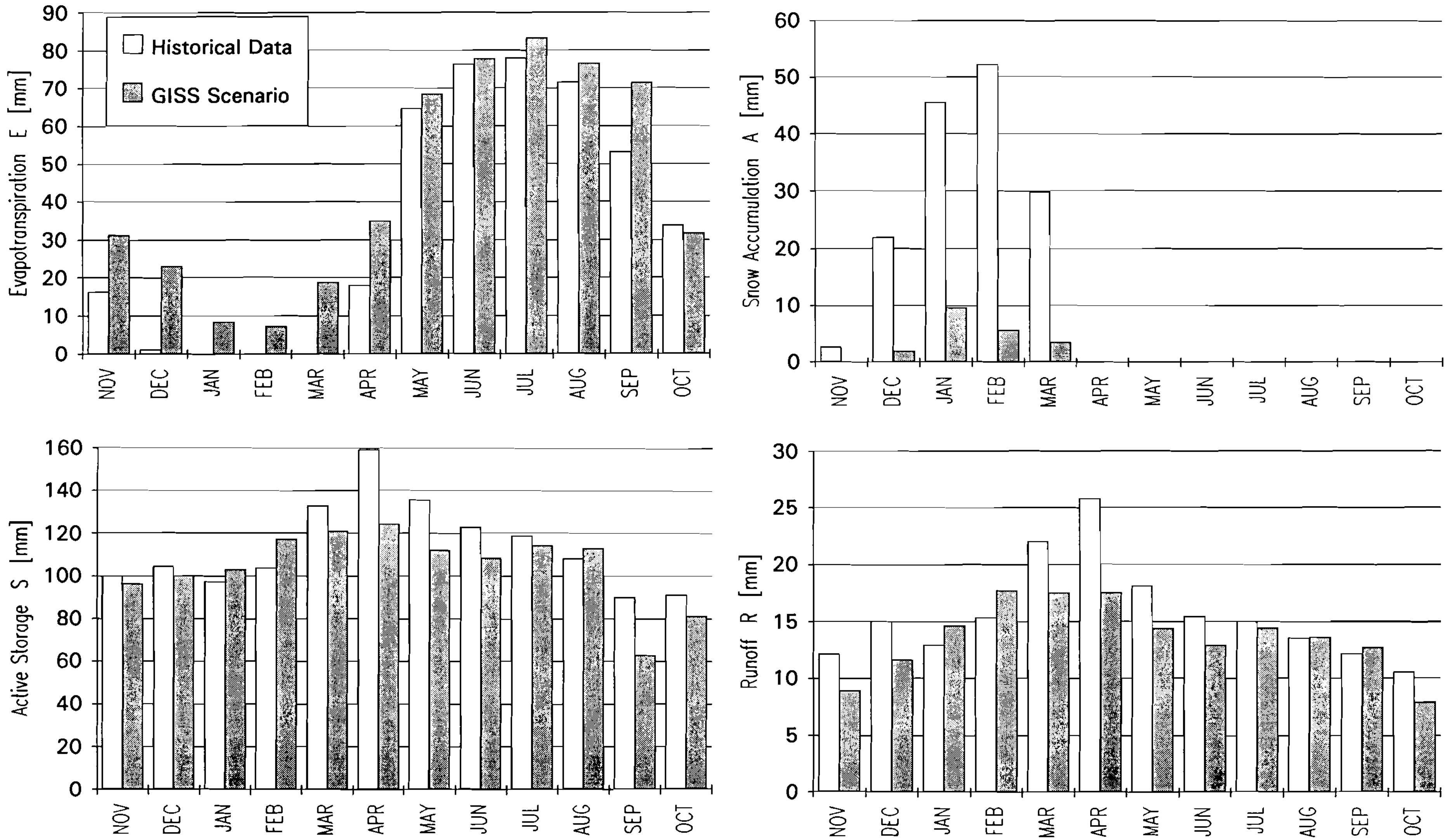


Fig. 5.4. Results of calculations by BCM for Vistula-Tczew basin (GISS scenario).

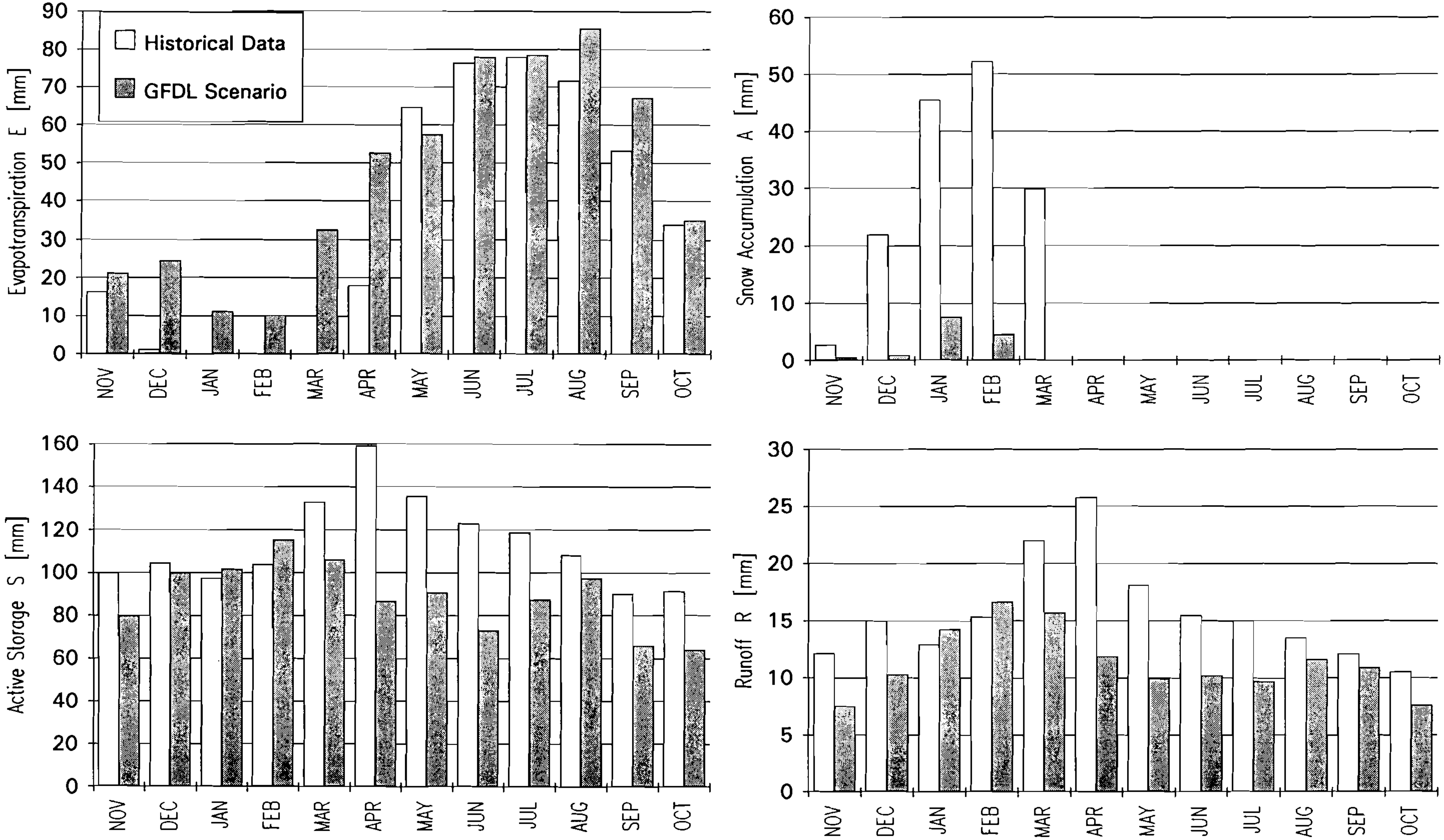


Fig. 5.5. Results of calculations by BCM for Vistula-Tczew basin (GFDL scenario).

5.5. Computational results of the regression model RRM

The calibrated model (3.1) was used for the computation of runoff for scenario of the GISS and scenario of the GFDL climate models. The numerical runoff values are presented in Table 5.6 and 5.7 and Fig. 5.6 and 5.7.

These results allow to anticipate that the simulated runoff of GISS and GFDL climates scenarios in winter periods (December-February) will be higher than in the history. In the spring it will be lower than the historical values. The lower runoff of the GFDL climate scenario $\sum_{j=1}^{12}(R_{cj}) = 149{,}5$ mm than the GISS climate scenario $\sum_{j=1}^{12}(R_{cj}) = 161{,}2$ mm can be anticipated.

It should be stressed that these results are not a forecast of future runoff from the Vistula river catchment, but only runoff scenarios conditioned by the assumed changes of climates.

Table 5.6 Results of calculations by RRM for Vistula-Tczew basin (GISS scenario).

months	T [°C]	P [mm]	F [mm]	R_c [mm]	ΔR [mm]
NOV	8,2	57,8	57,8	13,2	-1,1
DEC	4,5	40,5	38,2	13,7	-0,1
JAN	1,4	33,5	24,9	15,0	1,9
FEB	4,0	35,1	39,6	15,6	0,9
MAR	4,5	38,2	40,6	16,1	-4,5
APR	11,9	52,4	56,5	13,2	-13,3
MAY	15,5	70,3	70,3	12,3	-5,3
JUN	18,5	87,2	87,2	12,7	-2,8
JUL	19,9	103,3	103,3	13,5	-0,3
AUG	18,3	88,8	88,8	13,2	0,1
SEP	17,1	34,0	34,0	11,3	0,2
OCT	10,7	58,1	58,1	11,4	-0,4

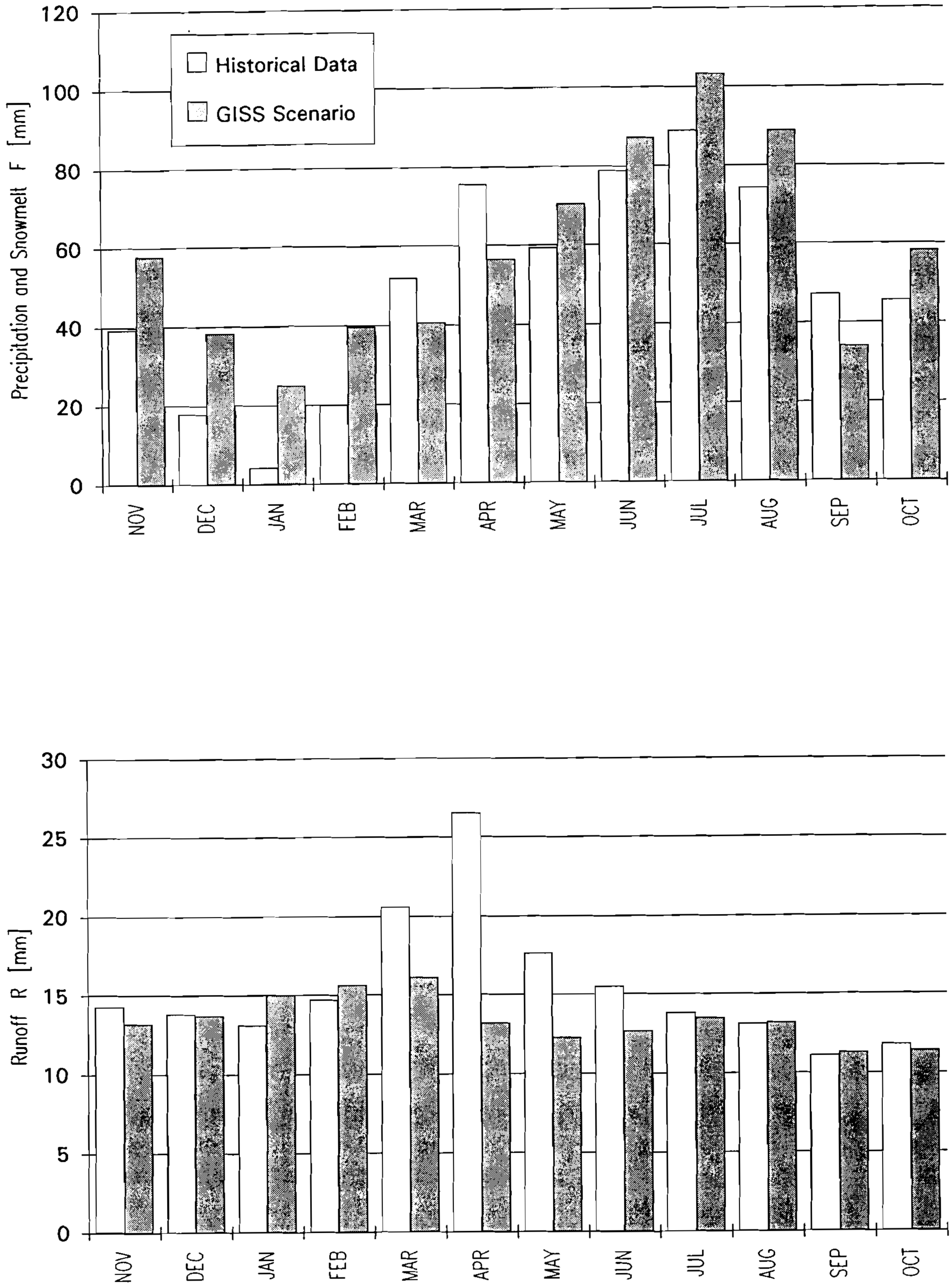
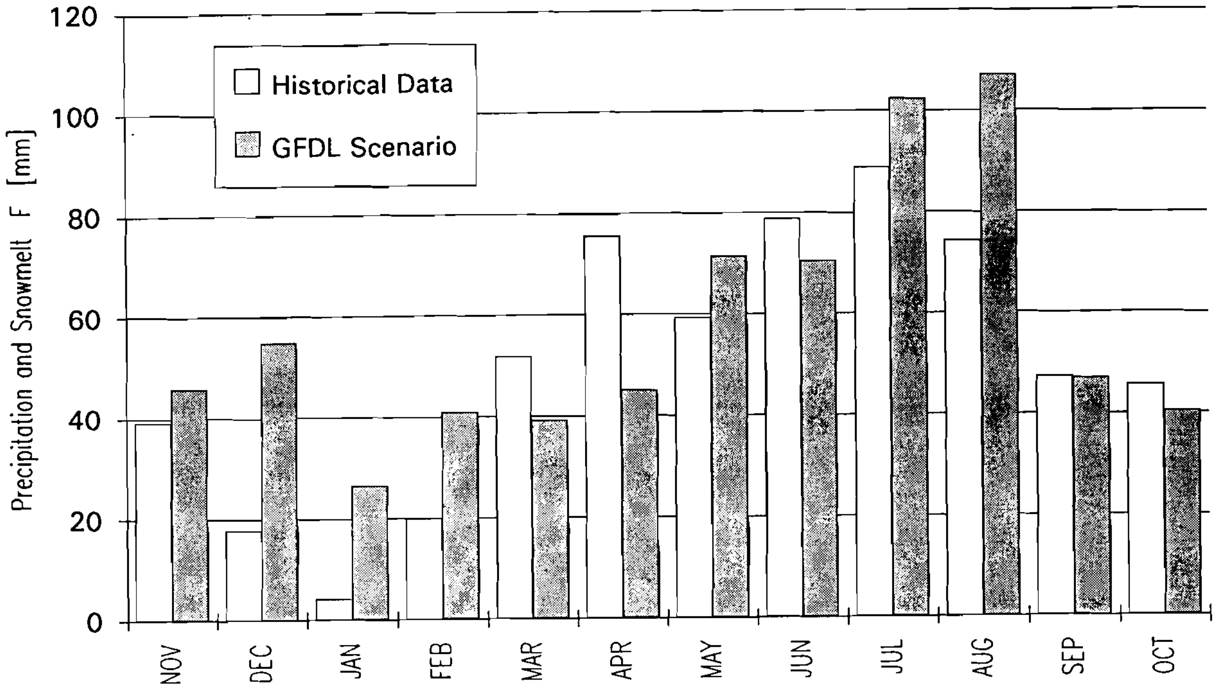


Fig. 5.6. Results of calculations by RRM for Vistula-Tczew basin (GISS scenario).

Table 5.7 Results of calculations by RRM for Vistula-Tczew basin (GFDL scenario).

months	T [°C]	P [mm]	F [mm]	R_c [mm]	ΔR [mm]
NOV	5,7	46,5	45,9	11,9	-2,4
DEC	6,1	55,2	54,8	14,9	1,1
JAN	1,9	33,8	26,4	15,9	2,8
FEB	4,5	37,5	40,9	16,0	1,3
MAR	8,6	34,3	39,2	13,8	-6,8
APR	12,9	45,1	45,1	11,3	-15,2
MAY	16,0	71,4	71,4	11,1	-6,5
JUN	20,6	70,4	70,4	10,9	-4,6
JUL	23,3	102,4	102,4	11,4	-2,4
AUG	23,1	107,0	107,0	11,9	-1,2
SEP	17,8	47,0	47,0	10,7	-0,4
OCT	11,6	40,4	40,4	9,7	-2,1



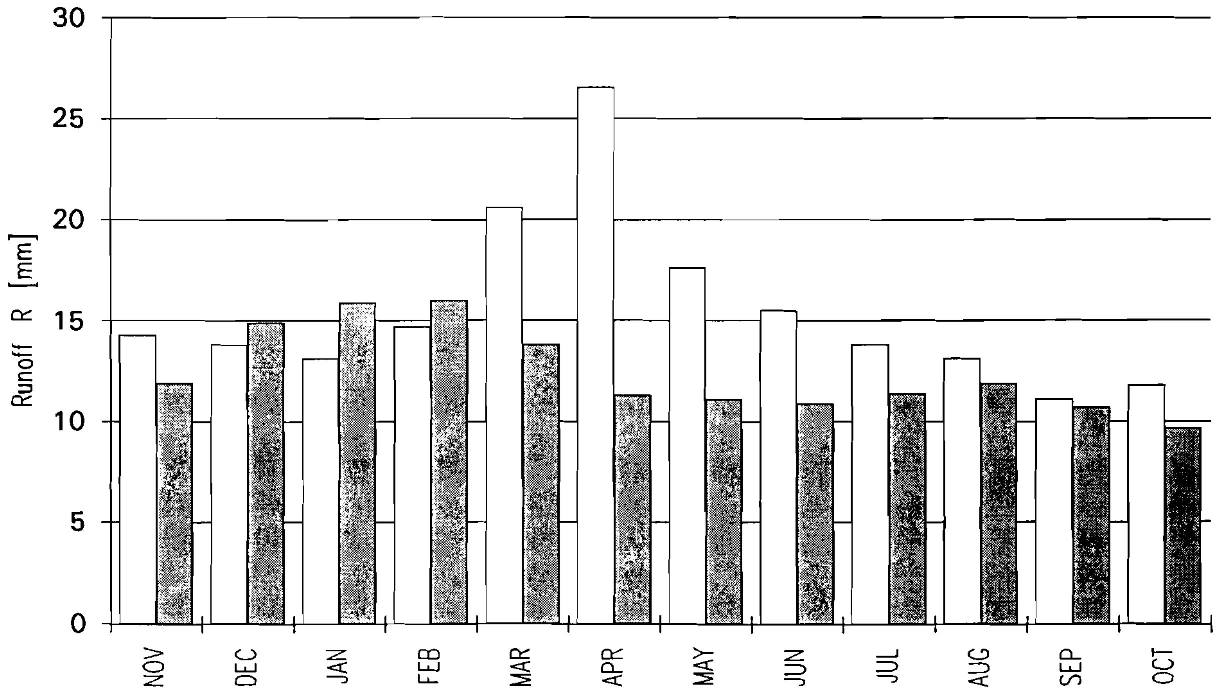


Fig. 5.7. Results of calculations by RRM for Vistula-Tczew basin (GFDL scenario).

6. CONCLUSION

The models of monthly runoff presented in this Study should be looked at as two possible solutions in the situation when input data are precipitation and air temperature only (derived from climate change scenarios).

These models, like others built for the same purpose, assume that the relationship between components of the land phase of hydrological cycle do not change under climate changes. This assumption is not a realistic one. Until now there are no serious investigation of climate - induced changes of relation between hydrological elements. For example, we assume that evapotranspiration will not change, that means the vegetation cover will be as now but it is certainly not true.

The comparison between these two models is rather difficult because their scientific bases are quite different. The second of them uses only statistical information incorporated the measurement series of precipitation, air temperature and runoff. But the first model uses in addition also the physical information incorporated in the water balance equation and the relationship among air temperature, air humidity and evaporation.

Each of the models has been calibrated for four parts of the Vistula basin closed by gauging stations: Zawichost, Warsaw, Kępa Polska, Tczew. This way we can compare the results obtained from these two models in four different parts of Vistula basin. The values of the correlation coefficient r and the standard error s for BCM and RRM model are presented in Table 6.1. These results show that the "goodness" of the BCM model is almost the same for the data used both for identification ($\bar{r}$=0,856, Tczew r=0,857) and verification ($\bar{r}$=0,790, Tczew r=0,813). The RRM model has very high correlation coefficients ($\bar{r}$=0,948, Tczew r=0,931) for data used for calibration and much smaller correlation coefficients obtained in the verification process ($\bar{r}$=0,771, Tczew r=0,741). As far as the standard deviation is concerned, comparison between models shows similar, but increasing, tendency.

These models are alternative each other. The choice one of them depends on the user. If one wants to have more phisically based model, i.e. model based on the mass conservation law as a form of water balance, it should be chosen the conceptual model (BCM). However, if statistical relatinship is sufficient it could be chosen the regression model (RRM).

Table 6.1 Results of identification and verification of the conceptual model (BCM) and regression model (RRM)

Station	Data used for identification 1955-68				Data used for verification 1969-81			
	BCM		RRM		BCM		RRM	
	r	*s*	*r*	*s*	*r*	*s*	*r*	*s*
Zawichost	0,840	8,74	0,946	5,47	0,766	10,07	0,810	9,03
Warsaw	0,865	5,84	0,958	3,43	0,776	6,36	0,741	7,25
Kępa Polska	0,862	4,53	0,959	2,61	0,807	5,90	0,794	5,66
Tczew	0,857	4,28	0,931	3,12	0,813	5,76	0,741	6,40
mean value	0,856	5,84	0,948	3,65	0,790	7,02	0,771	7,08

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BASIN CONCEPTUAL MODEL (BCM)

THE SIMULATION MODEL OF THE MONTHLY RUNOFF

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BASIN CONCEPTUAL MODEL (BCM)
THE SIMULATION MODEL OF THE MONTHLY RUNOFF

1. Purpose and basic assumptions of the model BCM

The model BCM is to serve for simulation of the monthly runoff changes caused by the increase of CO_2 in the earth's atmosphere. Climatic changes are simulated by means of the so-called Global Circulation Models (GCM) from which, at the assumption of a certain increase of CO_2 concentration in the atmosphere, averaged (for longer periods) monthly temperature and precipitation increases are obtained. That data is basically the only information which may be utilized in the simulation model of the monthly runoff. Such a restricted input data is the factor which extremely influences the choice of simulation model type. Other factor, none the less important, is the requirement of its parameters limitation. In the specification process of the model the following assumptions have been made, taking into consideration the above mentioned restrictions [Ozga-Zielińska and all, 1992]:

a) Input to the simulation model will be made of historical, multi-annual series of mean monthly temperatures and monthly total precipitation disturbed by increments resulting from the scenarios determined by means of Global Circulation Models, but the monthly potential evapotranspiration index is estimated on the basis of any external model (for example Thornthwaite or Penman method).

b) The model should satisfy the law of conservation, what in practice resolves itself into the construction of a model which satisfies the equation of continuity being the simplified form of the water balance equation for each successive month.

c) Each process of water exchange in a river basin will be simulated using simple conceptual models, including possibly the least number of parameters.

d) Identification of model's parameters will be performed on the basis of historical data. Optimum values of parameters will be estimated as a result of the minimization of the sum square differences between the calculated and the observed values of monthly runoff.

2. Description of the model's structure

In accordance with the assumptions presented above the conceptual model of the monthly runoff consists of the following elements:

Equation of continuity

The water balance equation in a river basin during each successive i-th monthly period has been assumed as follows:

$$S_{i-1} + A_{i-1} + P_i = E_i + R_i + S_i + A_i \qquad (1)$$

where:

P - total monthly precipitation,

E - monthly evapotranspiration,

R - monthly runoff,

S - active storage in the river basin at the end of i-th month,

A - snow accumulation at the end of i-th month.

Model of snow accumulation and melting process

The model of snow accumulation and melting process is two-parameteric. Both parameters $T1$ and $T2$ are of temperature dimension . The value of $T2$ parameter takes into account the separation of precipitation into liquid - rainfall ($T_i \geq T2$) and solid - snowfall ($T_i < T2$), where T_i is the mean temperature in i-th month. The value of $T1$ parameter determines the lower limit temperature of the snow cover melting process. If $T_i \leq T1$, then only the process of snow accumulation takes place.

In the model of the snow cover melting process it has been assumed that the process proceeds according to the following:

$$M_i = \alpha_i \; (A_{i-1} + P_i) \qquad (2)$$

where:

$$\alpha_i = \begin{cases} 0 & \text{for} \quad T_i \leq T1 \\ 1 & \text{for} \quad T_i \geq T2 \\ (T_i - T1)/(T2 - T1) & \text{for} \quad T1 < T_i < T2 \end{cases} \qquad (3)$$

M_i - water from snow melting process,
T_i - mean temperature for i-th month,
P_i - total precipitation for i-th month,
A_{i-1} - accumulation of snow from the previous month.

The process of snow accumulation in *i*-th month is described as:

$$A_i = (1 - \alpha_i)\ (A_{i-1} + P_i) \qquad (4)$$

Taking into account that data used for the model pertain to hydrological year, it may be presumed that the initial accumulation of snow $A_0 = 0$.

The distinction of the winter season in a given year is made if the following condition has been satisfied:

$$(A_{i-1} > 0) \vee (T_i < T2). \qquad (5)$$

If in *i*-th month the above condition is not satisfied, it is assumed that this month belongs to the summer season. This condition operates as a switch of the model structure, because the model takes into consideration the divergencies of processes occurring during winter and summer seasons.

Model of evapotranspiration process

The current evapotranspiration is determined in each *i*-th time step according to the formula:

$$E_i = E_{pi}\left[\ 1 - \exp(-k_e\ S_{i-1})\ \right] \qquad (6)$$

where:
E_{pi} - index of potential evapotranspiration,
S_{i-1} - active river basin storage at the end of the previous month,
k_e - parameter of the evapotranspiration model.

The monthly potential evapotranspiration index E_p is estimated on the basis of any external model (e.g. Thornthwaite or Penman method).

During winter season the values of the current evapotranspiration, calculated from the formula (6) are very small and one should expect that they are considerably smaller than the anticipated error of evapotranspiration model. Owing to this, in the runoff model an assumption has been made that during winter season the evapotranspiration process can be neglected ($E_i = 0$).

Model of runoff process

During winter season, when condition (5) is satisfied, the runoff is calculated for each month from the relation:

$$R_i = k_g S_{i-1} + k_w M_i \tag{7}$$

where:

R_i - monthly runoff during winter season,
S_{i-1} - active storage at the end of the previous month,
M_i - water from snow cover melting,
k_g - parameter of runoff from the active river basin storage,
k_w - parameter of surface runoff during winter conditions.

During summer season, when condition (5) is not satisfied, the runoff for each month is determined from the relations:

$$R_i = \begin{cases} k_g S_{i-1} + \dfrac{(P_i - I_i)^2}{P_i + 4I_i} & \text{for} \quad (P_i - I_i) > 0 \\ k_g S_{i-1} & \text{for} \quad (P_i - I_i) \le 0 \end{cases} \tag{8}$$

where:

$$I_i = \begin{cases} 0,2\left(\dfrac{1}{k_s} - S_{i-1}\right) & \text{for} \quad \left(\dfrac{1}{k_s} - S_{i-1}\right) > 0 \\ 0 & \text{for} \quad \left(\dfrac{1}{k_s} - S_{i-1}\right) \le 0 \end{cases} \tag{9}$$

R_i - monthly runoff during summer season,
R_{i-1} - active storage at the end of the previous month,
I_i - index of monthly total initial losses,

k_g - parameter of runoff from the active river basin storage,
k_s - parameter describing the maximum river basin storage capacity.

The form of the function describing the surface runoff process has been taken from the SCS method used for effective precipitation calculation. Elements of this function have undergone appropriate modification for the monthly runoff.

3. Identification of the model BCM

The above described model of monthly runoff contains six parameters whose values are obtained in the process of identification:

- k_g - runoff parameter from active storage ($0<k_g<1$),
- k_s - parameter characterizing maximum storage capacity of a river basin ($k_s>0$),
- k_w - runoff parameter in the winter season ($0<k_w<1$),
- k_e - parameter characterizing the current evapotranspiration process ($k_e>0$),
- $T1$ - parameter defining the lower limit temperature, below which the snow melting process does not occur ($T1<0$),
- $T2$ - parameter defining the limit temperature, below which the process of water accumulation as a snow cover may begin ($T2>0$).

Values of the above mentioned parameters may be obtained as a result of calibration by means of the trial-and-error method or by automatic optimization with the following objective function:

$$F_c = \frac{1}{n} \sum_{i=1}^{i=n} \left(R_{ci} - R_{oi} \right)^2 \qquad (10)$$

where:
n - number of time intervals (months),
R_{oi} - observed runoff,
R_{ci} - computed runoff,

The application of the latter method is certainly much more convenient but in that case some quite serious difficulties may arise. The hypersurface $F_c(k_g, k_s, k_w, k_e, T1, T2)$ is very irregular, having numerous deflections and local minima. This is caused mainly by the step-like changes of the runoff model structure. From among various optimization methods reported in the literature [Kręglewski and all, 1984], the gradient methods are quite useless, and nongradient methods do not ensure correct results either. Nevertheless, it has been decided that the popular and usually quite effective Rosenbrock's method will be used for the purpose of the model's parameters identification. In order to improve the efficiency of identification, the repeated optimization with various sets of initial parameters values is suggested.

4. Computer programs to be implemented on the IBM PC

The computer programs have been written in the Turbo--Pascal. The required configuration of an IBM PC XT/AT computer is as follows:

- numerical coprocessor,
- EGA/VGA graphic card,

There are six files on the disk enclosed:

IDENT.EXE - executable version of the program for automatic identification of parameters of the BCM by Rosenbrock's method,

MODEL.EXE - executable version of the program BCM for simulation of mean monthly runoff,

TCZEW.PAR - sample file contaning optimal values of parameters for VISTULA-TCZEW basin.

TCZEW.DAT - sample file containing historical data for VISTULA--TCZEW basin.

TCZEW1.DAT - sample file containing data prepared according to GFDL scenario[1] for VISTULA-TCZEW basin.

TCZEW2.DAT - sample file containing data prepared according to GISS scenario[1] for VISTULA-TCZEW basin.

The sample data files contain data we have supplied for you to use when practicing with Basin Conceptual Model. Before you can use IDENT.EXE or MODEL.EXE program for another basin, you have to prepare your own data file.

---

[1] Suitable increments of temperature and precipitation (located in grid cells of a side equal to 0.5 degree of lattitude and longitude) were obtained from IIASA in 1991.

6. Preparing of data file *name*.DAT

Name of data file may contain up to eight characters with standard extension DAT. This file is standard ASCII text file and consists of header and four (for identification) or three (for simulation) data blocks (see sample data TCZEW.DAT, TCZEW1.DAT or TCZEW2.DAT).

Header is as follow (see Fig. 1.):

Line 1: Name of basin

Line 2: Name of parameters file with standard extension PAR

Line 3: Name of scenario (for example: Historical or GISS)

Line 4: Number of years *n*

```
VISTULA-TCZEW
TCZEW.PAR
Historical data
27
```

Fig. 1. Example of header of data file.

Each data block is as follow (see Fig. 2.):

Line 1: Name of data, comment or empty line

Line 2: Names of months (short of english name - three characters only) in calendar year or hydrological year order

Line 3: First year (full) and data for each month

Line 4: Next year and data for each month

⋮

Line n+2: Last year and data for each month

You have to type data blocks in specific order. This order is as follow:

1. Mean monthly temperature T [deg C],
2. Monthly precipitation P [mm],
3. Factor of mean monthly potential evapotranspiration E_p [mm],
4. Monthly runoff R [mm] - for identification only.

All program and data files should be placed in the disk default directory.

Monthly temperature [deg C] (average for basin area)												
	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT
1955	2.2	2.0	-3.4	-3.3	-1.3	4.3	10.9	15.4	18.6	18.4	14.1	8.2
1956	2.9	0.3	-1.7	-12.6	-1.6	5.7	12.6	17.2	17.1	15.3	12.2	7.7
1957	-1.2	-1.0	-1.5	2.2	2.0	8.0	10.6	17.7	18.6	16.1	11.7	8.2
1958	3.9	-1.6	-3.2	-0.2	-2.9	4.3	15.1	15.2	18.3	17.1	12.6	9.4
1959	3.7	0.9	-1.4	-2.5	4.0	8.2	12.8	16.4	20.6	18.0	11.1	6.9
1960	2.3	-1.2	-3.6	-3.9	1.2	6.3	12.7	17.0	16.9	16.5	11.7	9.0
1961	4.9	2.6	-4.0	1.0	4.8	9.7	11.6	17.8	16.3	16.2	13.8	10.2
1962	3.6	-4.0	-0.6	-2.8	-2.2	10.0	10.9	14.3	15.8	16.6	12.0	7.5
1963	4.0	-4.8	-12.1	-8.4	-1.7	7.7	15.2	16.9	19.7	18.9	14.4	8.0
1964	6.3	-4.3	-4.8	-5.2	-3.2	7.2	12.7	19.8	18.5	15.7	12.9	7.5
1965	3.3	-0.9	-1.9	-6.3	0.2	5.9	10.1	16.0	16.3	15.1	14.1	6.9
1966	-1.2	-0.0	-5.4	-0.3	2.4	8.4	13.3	16.7	18.1	16.7	12.1	11.1
1967	2.4	-0.8	-5.4	-0.5	4.5	7.4	13.8	16.0	19.0	17.0	15.8	10.9
1968	3.7	-2.0	-4.8	-1.0	2.6	9.0	11.9	18.0	16.7	17.3	13.4	7.9
1969	3.6	-4.3	-7.0	-4.5	-2.2	6.2	14.4	16.2	18.1	16.4	13.2	7.8
1970	5.2	-8.2	-6.0	-5.7	0.2	6.9	12.1	16.5	17.0	16.7	11.8	7.1
1971	4.3	0.3	-3.8	-0.5	-0.5	7.4	15.0	15.5	17.9	18.6	10.9	7.8
1972	2.0	2.5	-7.7	-0.7	3.3	7.7	13.3	16.7	20.0	16.7	11.4	5.7
1973	3.9	-0.6	-2.8	0.9	3.1	6.8	12.5	15.8	17.6	17.0	12.6	6.2
1974	1.2	-1.3	-1.5	1.7	3.9	6.7	11.1	14.4	15.7	17.7	13.4	6.3
1975	3.2	1.8	2.1	-1.1	4.1	6.8	14.3	15.9	18.6	18.0	15.4	7.8
1976	1.1	0.1	-3.2	-5.2	-1.5	7.3	11.8	14.8	18.0	15.0	12.6	6.8
1977	4.2	-1.5	-2.3	-0.1	4.7	6.1	12.6	16.7	16.1	16.0	10.8	8.6
1978	4.6	-1.5	-2.2	-4.4	3.1	6.1	11.4	14.9	15.8	15.6	10.9	8.3
1979	4.2	-4.4	-6.1	-5.7	1.9	6.4	14.1	18.9	14.8	16.6	13.2	5.8
1980	2.5	1.2	-6.7	-1.8	-1.1	6.0	9.3	15.4	16.4	15.9	12.3	8.3
1981	1.4	-0.9	-4.2	-1.5	3.7	5.5	13.9	16.9	17.7	16.3	13.7	8.7

Fig. 2. Example of data block in data file.

7. Program IDENT.EXE

Program IDENT.EXE executes an automatic identification of the Basin Conceptual Model as well as it presents the results of preliminary verification. You can run this program in command-line mode, then execution of the program is performed by specifying its name together with the data file(s) *name* as a command-line parameters (with extension DAT or without), e.g.:

IDENT *name name1 name2*

Alternatively you can run this program by specifying its name without any command-line parameter:

IDENT

In this case you will be asked for name of the data file *name*.DAT.

The initial values of the optimized parameters have to be placed in the *name*.PAR file specified in the second line of header of the data file. Alternatively, if *name*.PAR file don't exist then program IDENT.EXE creates this file with default initial values of the parameters. The results of identification are written to the same file (see Fig. 3.). After the identification has been terminated, its results in the graphic form are displayed on VDU. In order to improve the efficiency of identification, the repeated optimization with various sets of initial parameters values is suggested.

```
Parameters of BCM used for Vistula-Tczew basin
INITIAL DATA:
  55.77        ;R0 - initial value of active storage
   0.00        ;S0 - initial value of snow accumulation
PARAMETERS:
   0.00960144  ;ke - evapotranspiration parameter
   0.00172953  ;ks - the reciprocal of maximum active storage
   0.21203487  ;kw - surface runoff parameter in winter season
   0.10214284  ;kg - parameter of runoff from active storage
  -3.95031331  ;T1 - lowest temperature of snowmelt process
   3.29999999  ;T2 - initial temperature of snow accumulation

----Parameters optimized by Rosenbrock's method----
Minimum value of criterion = 2.10155855358333E+0001
```

Fig 3. Example of parameters file.

8. Program MODEL.EXE

Program MODEL.EXE carries out runoff simulation for the historcal data included in the *name*.DAT file as well as the modified data according to scenarios determined by Global Circulation Models, e.g. GISS or GFDL (see sample data files TCZEW.DAT, TCZEW1.DAT and TCZEW2.DAT). It displays the results in numerical and graphical form (bar graphs) and introduces them in the numerical form to *name*.RES file (see Fig. 4.). You can run this program in command-line mode, then execution of the program is performed by specifying its name together with the data file(s) *name* as a command-line parameters (with extension DAT or without), e.g.:

MODEL *name name1 name2*

Alternatively you can run this program by specifying its name without any command-line parameter:

MODEL

In this case you will be asked for name of the data file *name*.DAT.

The optimum values of model's parameters must be included in the *name*.PAR file specified in header of the data file.

RESULTS OF SIMULATION

Catchment: VISTULA-TCZEW
Scenario: Historical
Data file name: TCZEW.DAT
Period of observations: 1955-1981

months	T [°C]	P [mm]	Ep [mm]	E [mm]	S [mm]	A [mm]	Rc [mm]
NOV	3.0	41.6	41.1	14.4	106.2	3.6	12.3
DEC	-1.2	39.4	28.9	0.0	111.1	23.0	15.1
JAN	-3.9	29.4	22.6	0.0	105.4	45.3	12.9
FEB	-2.7	28.3	25.6	0.0	111.5	52.2	15.3
MAR	1.2	29.0	35.5	0.0	140.5	30.0	22.3
APR	7.0	40.2	55.6	13.3	170.6	0.0	26.8
MAY	12.6	59.2	82.6	65.7	146.4	0.0	17.7
JUN	16.4	78.8	105.4	78.0	131.9	0.0	15.3
JUL	17.6	88.8	113.1	79.4	126.4	0.0	14.9
AUG	16.7	74.2	107.3	72.8	114.6	0.0	13.2
SEP	12.7	47.2	83.3	54.0	96.1	0.0	11.7
OCT	7.9	45.6	59.8	34.7	96.7	0.0	10.3

T - mean monthly temperaure;
P - mean monthly precipitation;
Ep - mean monthly potential evapotranspiration;
E - calculated mean monthly evapotranspiration;
S - calculaded mean active storage (for the end of month);
A - calculated mean monthly snow accumulation;
Rc - calculated mean monthly runoff;

Fig. 4. Example of results of simulation.

References

Kręglewski T., Rogowski T., Ruszczyński A., Szymanowski J., 1984. *Metody optymalizacji w języku FORTRAN.* PWN, Warszawa.

Ozga-Zielińska M., Brzeziński J., Feluch W., 1992. *DEVELOPMENT OF A MESO-SCALE HYDROLOGICAL MODEL FOR CLIMATE IMPACT ASSESSMENT.* Institute of Environmental Engineering. Warsaw University of Technology. (Workpaper for IIASA)