Nordic Hydrology, 30 (2), 1999, 109-128

Mathematical Model of Hydrological Processes METQ98 and its Applications

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The mathematical model METQ98 for runoff simulation is described. The METQ98 is developed from the model METUL (Krams and Ziverts 1993). Input data for the model are daily mean values of air temperature, precipitation and vapour pressure deficit. The spatial variability of surface processes is represented by dividing the river basin into hydrological response units (HRUs) depending on the land cover. The analysis of the model parameters is based on hydrological and meteorological data of the Vienziemite Brook basin. Also the influence of drainage on the model parameters is analysed. The results of application of the model to the Daugava River basin are presented.

Introduction

During the last ten years several versions of the mathematical models of hydrological processes have been developed in Latvia – METUL (Krams and Ziverts 1993), METQ96 (Ziverts and Jauja 1996). These models can be classified as conceptual models (Bergström 1991), however, most of the parameters are physically based. The last version METQ98 is described in this paper.

A detailed analysis of parameters based on the observations in the Vienziemite basin ($A=5.92\ km^2$) is presented. Observations of hydrological processes have been carried out in the Vienziemite basin since 1947. This basin is unique because observations in it still continue after the installation of artificial drainage over most of the arable land in 1974. The model METQ98 allows to simulate conditions both before and after the drainage construction by changing the values of parameters which characterise the depth of natural drainage or artificial drainage. The runoff hydrographs for both conditions before and after the drainage are simulated for the Vienziemite basin.

The model METQ98 is successfully applied to a relatively large river basin – the Daugava River basin (A=81,000 km^2 at the Plavinas HPP). The Daugava River basin was divided into subbasins and each subbasin was then divided into 5 types of hydrological response units (HRUs): agricultural lowlands, agricultural hilly land, forest, swamps and lakes.

Structure of the Mathematical Model METQ98

The model METQ98 is a mathematical model for the simulation of the daily runoff and evapotranspiration for the rivers with different catchment areas. The scheme of the model METQ98 for the point scale is shown in Fig. 1. A more complete description of the model is presented by Krams and Ziverts (1993), here the description will focus on the main principles of the model structure and the changes in it made since 1993. The land surface in the METQ98 is represented with three layers. The upper layer is called the root zone and it does not have a precisely defined boundary. The primary mass of vegetative roots are found in this zone and evapotranspiration in the root zone during the period of vegetation is determined primarily by plant transpiration. The lower layer is the groundwater and capillary fringe zone which is divided in two sublayers.

The equation of water balance for the root zone is the following

$$SMS_e = SMS_b + RS - EA + CAP - RCH - Q_1 \tag{1}$$

where SMS_b and SMS_e is the water storage in the root zone at the beginning and the end of a day respectively, mm, RS is rain and snow melt water, mm/day, EA is evapotranspiration from the root zone, mm/day, CAP is the capillary rise, mm/day, RCH is the groundwater recharge, mm/day, Q_1 is the surface runoff, mm/day.

The water balance equation for the groundwater and capillary water layer is based on the following assumption: all soil pores under the water table are saturated with water, but above the water table one part of pores is filled with air, another – with capillary water and the rest is filled with water which is attracted to soil particles and is not influenced by the fluctuations of groundwater level. The equation of water balance for the groundwater and capillary fringe layer is the following

$$GW_e = GW_b - RCH + CAP + Q_2 + Q_3 + D\mathrm{PERC} \tag{2}$$

where GW_b and GW_e is the capacity of empty soil pores at the beginning and the end of a day, respectively, mm, Q_2 is the upper layer subsurface runoff, mm/day, Q_3 is the base flow, mm/day and *D*PERC is the deep percolation to the aquifers, mm/day.

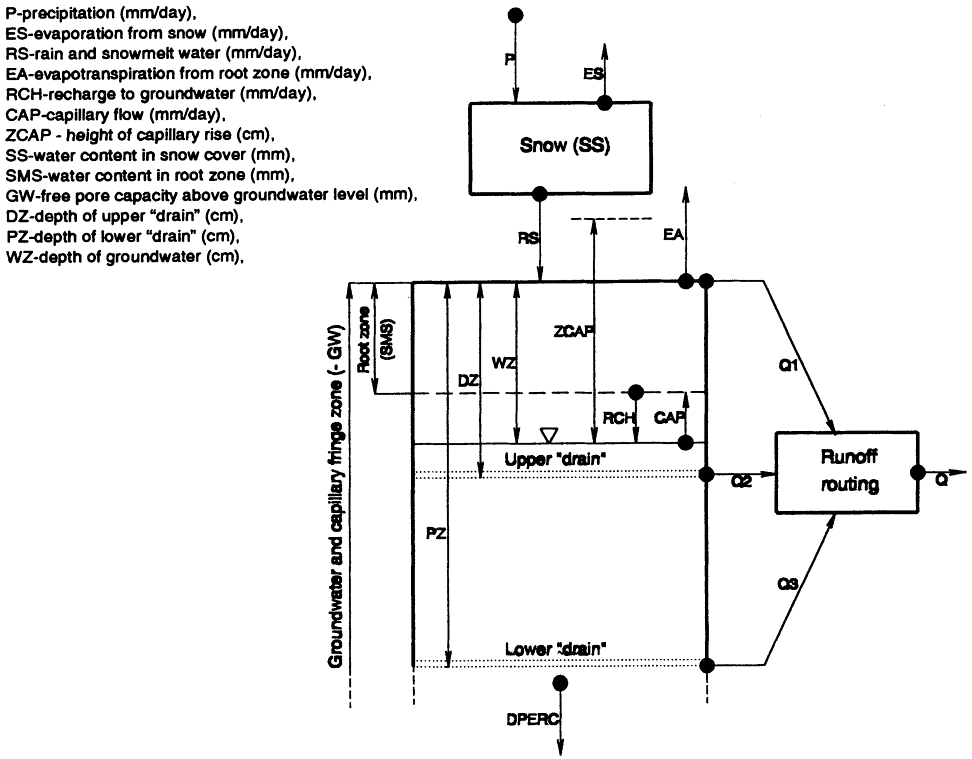

Fig. 1. Schematic presentation of the model METQ98.

Snow Accumulation and Melting

Snow accumulation is simulated by means of the following assumption – if the daily mean air temperature is lower than the threshold value (T_1 varies in the range from 0.0 to 0.5 °C), the precipitation is accumulated in the form of snow. The melting simulation procedure in the model version METQ96 (Ziverts and Jauja 1996) is similar to the one used in the HBV model (Bergström 1992). The degree-day method calculates the daily snow melt depth, M (mm), by multiplying the number of degree-days (T-T_2) by the degree-day ratio $CMELT$ (mm/°C)

$$M = CMELT\,(T - T_2) \qquad (3)$$

A degree-day is defined (Linsley *et al.* 1988) as a departure of one degree per day in the daily mean temperature T (°C) from the adopted reference temperature T_2 (°C).

One of the applications of the model version METQ96 was an estimation of the probable maximum flood generated mainly by snow melt for the reconstruction of the Daugava HPP cascade (Jauja 1998). During this study special attention was paid to the simulation of the snow melt process. It was concluded that there is a need to

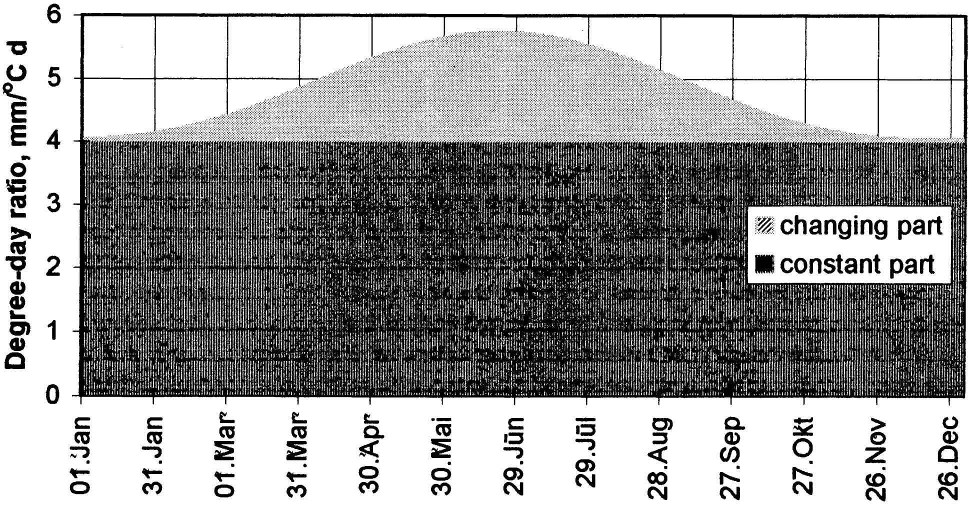

Fig. 2. Degree-day ratio for open areas depending on solar radiation.

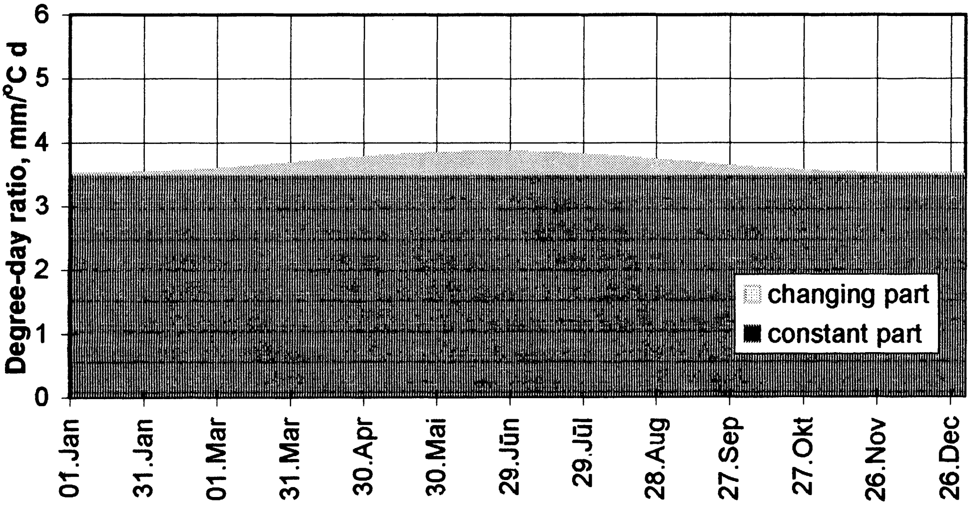

Fig. 3. Degree-day ratio for forested areas depending on solar radiation.

differentiate the values of the degree-day ratio for different periods of winter and spring – the degree-day ratio in April should be higher than in December. In the new model version METQ98 the degree-day ratio CMELT does not have a constant value, but it has a temporal difference depending on the daily potential insolation of each particular day. The degree-day ratio consists of two parts – the constant part and the changing part (radiation part) which depends on solar radiation

$$CMELT = CMELTB + AMELT \times I \tag{4}$$

where CMELTB – the constant part of the degree-day ratio, AMELT – conversion factor, I = potential insolation of each particular day for a completely clear atmosphere, MJ/m^2 day.

The influence of the radiation part to the total value of the degree-day ratio is higher in open areas than in the forest. It is shown in Fig. 2 and Fig. 3 where the daily values of the degree-day ratio for open areas and the forest are presented. The procedures of simulating the refreezing of melted water in the snow cover and the liquid water holding capacity of snow are the same as in the HBV model (Bergström 1992).

Storage

There are three types of water storage in the model METQ98: water storage in the snow cover, water storage in the root zone and groundwater and the capillary fringe storage. The amount of the storage characterises the basin in each moment. The actual evapotranspiration and runoff is calculated depending on the storage. The amount of water that can be stored in the root zone is limited by the threshold value WMAX. This value is a model parameter. The groundwater storage is characterised by the groundwater level and the fillable porosity of the aquifer ALFA which is a model parameter. If the water storage in the root zone is lower than the threshold value WMAX, precipitation in the form of rain or (and) melted water replenish the water storage in the root zone. If the threshold value of the water storage in the root zone is exceeded, the excess water percolates and replenishes the groundwater storage, and ,accordingly, the level of the groundwater rises. If the level of the groundwater reaches the surface then surface runoff occurs.

Evaporation and Evapotranspiration

It is assumed that water evaporates only from the upper layer of land, respectively, from the snow and root zone. Evapotranspiration is calculated by using the simple empirical method similar to the bioclimatic method developed by Alpatjev (1969). This method is based on the assumption that evapotranspiration is proportional to the vapour pressure deficit

$$ET = k \times DEF \tag{5}$$

where ET is evapotranspiration, mm/day; DEF is the daily mean air vapour pressure deficit, hPa; k is the bioclimatic coefficient which depends on the development of plants and climatic characteristics. The average value of the bioclimatic coefficient for the territory of Latvia is in the range of 0.53 ... 0.58 (Ziverts and Sauka 1976).

To keep the model structure as simple as possible the evaporation from snow *ES* is simulated by a similar empirical method as the evapotranspiration from vegetation and soil. The evaporation coefficient from snow *KS* is used instead of the bioclimatic coefficient

$$ES = KS \times DEF \tag{6}$$

The daily actual evapotranspiration from the root zone is estimated depending on the daily mean vapour pressure deficit, the water storage in the root zone, SMS_b, and the depth of the groundwater, WZ_b, at the beginning of a particular day. If $SMS_b = WMAX$, the actual evapotranspiration is equal to the potential evapotranspiration, which is calculated as follows

$$EA = KU \times DEF \tag{7}$$

where *EA* is evapotranspiration from the root zone, *KU* is the upper limit of the evapotranspiration coefficient which, in this case, is assumed equal to the bioclimatic coefficient.

If $SMS_b=0$ and $WZ_b \geq ZCAP$ (ZCAP is the height of capillary rise, cm), the actual evapotranspiration is calculated by using the lowest value of the evapotranspiration coefficient for a snowless period *KL*

$$EA = KL \times DEF \tag{8}$$

If the moisture content in the root zone is lower than *WMAX*, the actual evapotranspiration is estimated by interpolation between the limit values estimated by Eqs. (7) and (8). The interpolation formulas are the following

$$EA = \left(KU - \frac{WZ_b}{ZCAP}(KU-KL)\,(1 - \frac{SMS_b}{WMAX})\right) DEF\,, \quad \text{if } WZ_b \leq ZCAP \tag{9}$$

$$EA = \left(KU - (KU-KL)\,(1 - \frac{SMS_b}{WMAX})\right) DEF\,, \quad \text{if } WZ_b > ZCAP \tag{10}$$

Runoff

The total runoff from each of the elemental basins consists of three runoff components: surface runoff, subsurface runoff and base flow. Surface runoff occurs in two cases: 1) if the infiltration capacity of soil is lower than the amount of water which could possibly infiltrate per day (Horton 1940); 2) if the groundwater level reaches the ground surface (saturation excess runoff according to Dunne and Black 1970). The infiltration capacity of soil is characterised by three parameters for unfrozen soil (*RCHR*, *RCHR*2 and *ROBK*) and two additional parameters for the frozen soil (*RCHRZ* and *RCHR2Z*). The daily infiltration capacity of unfrozen soil is estimated as follows

$$Q_{\text{inf}} = RCHR + RCHR2 \tanh \frac{RCH-RCHR2}{RCHR \times ROBK} \tag{11}$$

and for frozen soil

$$Q_{\text{inf}} \equiv RCHRZ + RCHR2Z \ \tanh \frac{RCH-RCHR2Z}{RCHRZ\times ROBK} \tag{12}$$

The surface runoff according to Horton (1940) is simulated as follows

$$Q_H = P + M - Q_{\text{inf}}, \ \text{if} \quad P + M \leq 0 \quad \text{then} \quad Q_H = 0 \tag{13}$$

The saturation excess runoff according to Dunne and Black (1970) is simulated as follows

$$Q_D = -GW_e, \qquad \text{if} \quad GW_e \geq 0 \quad \text{then} \quad Q_D = 0 \tag{14}$$

The total surface runoff is

$$Q_1 = Q_H + Q_D \tag{15}$$

The subsurface runoff is calculated according to the height of the groundwater level above the upper level "drain"

$$Q_2 = A2\,(DZ-WZ)^2 \tag{16}$$

where $A2$ – intensity of the upper level "drain"; DZ – depth of the upper level "drain" (cm); WZ – depth of the groundwater level (cm).

For the areas with pipe drainage parameter DZ characterises the real depth of the pipe drainage and parameter $A2$ has the following explanation

$$A2 = \frac{A\,k}{E^2} \tag{17}$$

where k is hydraulic conductivity (m/day), E is the spacing between drainage pipes, A is correction factor. Parameters $A2$ and DZ cannot be directly measured in natural areas without artificial drainage, but we can assume that the upper level "drain" represents a very shallow drainage network.

The retention time for the base flow is longer than for the subsurface flow. The base flow is calculated depending on the height of the groundwater level above the level of lower level drainage

$$Q_3 = A3\,(PZ-WZ) \tag{18}$$

For areas without drainage we could imagine again that parameter PZ characterises the depth of the lower level "drain"; $A3$ characterises the permeability of the bedrock; for areas with artificial drainage PZ characterises the depth of collector ditches.

The additional parameter *D*PERC is introduced to characterise percolation to the deep aquifers which do not drain into the particular river basin. The value of *D*PERC can be negative in small river basins if there is drainage from confined aquifers.

Table 1 - Parameters of model METQ98 and methods of the parameters estimation.

Parameters	Description	Method of parameters estimation
1	2	3
WMAX	Threshold value of water storage in root zone	Previous experience. Estimation of value of WMAX in agricultural areas (30 mm) is based on the previous studies of irrigation regime in Latvia (Sauka, 1970). WMAX for swamps is 20 mm.
ALFA and ZCAP	Fillable porosity and height of capillary rise	Previous experience. Parameters can by estimated according to the hydrophysical characteristics of most common types of soils in Latvia.
A2 and DZ	Characterise the subsurface drainage	Calibration
A3 and PZ	Characterise the drainage capacity of deeper layers	Calibration
KU, KL and KS	Characterise the intensity of the evapotranspiration from the soil covered by vegetation or snow	Previous experience or calibration. Previous experience shows that values of parameters for river basins in Latvia territory and the Daugava River basin can be used the same as in Table 2, for other river basins these parameters should be calibrated.
CMELTB, AMELT	Characterise snow melting processes	Calibration
T1, T2, CFR and WHC	Characterise the snow accumulation and melting processes	Previous experience. Previous experience shows that values of parameters for river basins in Latvia territory and the Daugava River basin can be used the same as in the Table 2.
RCHR, RCHR2, RCHRZ, RCHRZ2, ROBK	Characterise the process of generating of surface runoff	Previous experience. Previous experience shows that values of parameters for river basins in Latvia territory and the Daugava River basin can be used the same as in the Table 2.
DPERC		Calibration

Methods of Estimation of Model Parameters

Methods of estimation of parameters are described in Table 1. The model METQ98 has 22 parameters and most of them can be kept constant for different river catchments. In this case parameters are estimated by a previous experience gained from the modelling of other river catchments or previous experience gained from other studies of water balance elements such as irrigation regime study done by Sauka (1970). Some parameters have to be calibrated for each particular river basin. Parameters which definitely change depending on the size and peculiarities of a river catchment are those who characterise the process of the runoff generation – *A*2, *DZ*, *A*3, *PZ* and *D*PERC. Also the degree-day ratio *C*MELT*B* and the correction factor *A*MELT must be calibrated. Actually, only 7 parameters are free parameters which change, but the rest of parameters are quite stable.

Calibration of the model parameters is made by a manual trial and error technique, during which the relevant parameter values are changed until an acceptable agreement with observations is obtained. The judgement of the performance is supported by the statistical criterion R^2 according to Nash and Sutcliffe (1970). The principle of calibration procedure was determined by the character of the model application. The model was applied to the estimation of the probable maximum flood for the Daugava River basin. Therefore it was necessary to concentrate on a good agreement between simulated and observed flood peaks for the whole available observation period. For the Daugava River basin model was calibrated for the whole 39-year period. Hence, there is no validation of the model carried out for the Daugava River. The comparison of observed and simulated discharges with high return periods estimated by Gumbel distribution is used as an additional calibration criteria for this particular study.

Development for the Wide Range of the Spatial Scale

METQ98 is developed for the simulation of the hydrological processes at various spatial scales: point scale (up to 10 km^2), watershed scale (10 km^2-2,000 km^2) and large scale (such as the Daugava River – 81,000 km^2 at Plavinas HPP).

To consider the runoff spatial heterogeneity in runoff processes the watershed and large-scale river basins are divided in hydrological response units (HRU) characterised by a relative homogeneity with respect to the most important parameters, which include slope, vegetation and soil characteristics. There are five types of HRU in METQ98: agricultural lowlands (naturally shallow drained), hilly agricultural lands (naturally deeply drained), forests, swamps and lakes. There is no need to divide the watershed scale river basins into subbasins and runoff routing can be simulated by simple hydrological methods, such as modifications of the unit hydrograph approach. However, if there is a lake in the river basin which considerably influences the hydrological regime of the river then there is the need for hydraulic runoff routing schemes even in a small river basin.

Large-scale river basins must be divided into subbasins. Division into subbasins depends on the physiography of the basin and available meteorological and hydrological information about different parts of the basin. The runoff is simulated for each subbasin and then routed through the river bed and plains. Different kinds of methods could be used for the runoff routing. The simplest of them could be the method of linear reservoirs and more complicated could be hydraulic runoff routing methods. Selection of a method for the runoff routing depends on the peculiarities of each particular river bed and plain. There is experience to couple the model METQ98 with the hydraulic runoff routing model based on a simplified solution of unsteady water flow equations for the runoff routing in the Lubana Lowland (the Daugava River basin) (Sēne and Ziverts1991).

Analysis of Model Parameters at the Vienziemite Basin

The previous version of the model METQ96 was applied to several river basins with different sizes, and the simulation results were satisfactory. The main reason of simulation errors is considered to be a lack of good meteorological data to characterise the river basin. Therefore we searched for a river basin with dense meteorological and hydrological observations. The Vienziemite basin was chosen for an objective evaluation of the model performance.

The Vienziemite basin area is 5.92 km^2 (Fig. 4) and it is a part of the so called Baltic runoff (water-balance) station which was established in 1946 to carry out continuous measurements of elements of water balance such as precipitation, evaporation, evapotranspiration and runoff. Also soil moisture at various depths, groundwater level, piezometric pressure head, depth of snow, depth of frozen soil are measured at several places in the basin. The observation data are published in Russian in "Материалы набюдений Прибалтийской стоковой (водобалансовой) станции" (Observations of the Baltic runoff (water-balance) station) (1946-1985).

The territory of the Vienziemite basin is hilly. The height of hills is typically 5 to 10 m. Total difference in elevations within the basin is 78 m. In 1974 most of the agricultural land (2.78 km^2) and 0.22 km^2 of forests were drained by installing the tile drainage and ditch systems. The meteorological station Zoseni and precipitation gauge N1 are located 100 m to the west from the runoff gauging station (Fig. 4). There are two rain gauges (N8 and N12) in the central part of the Vienziemite basin and one rain gauge N13 in the upper part of the basin.

In order to divide the Vienziemite basin into hydrological response units, 1:2000 scale maps were used. There are 46% of hilly agricultural land, 16% of agricultural lowlands, 33% of forests and 5% of swamps in the Vienziemite basin. The rain gauges are located only a few km from each other, however, often the observed amount of precipitation has a significant difference. Therefore, to characterise the Vienziemite basin observations from all four rain gauges are used. The weight of each rain gauge is estimated according to the elevation zones characterised by each gauge: rain gauge N1 – 0.11, rain gauge N 8 – 0.39, rain gauge N12 – 0.21 and rain gauge N13 – 0.29. This distribution of weights gives the best correspondence be-

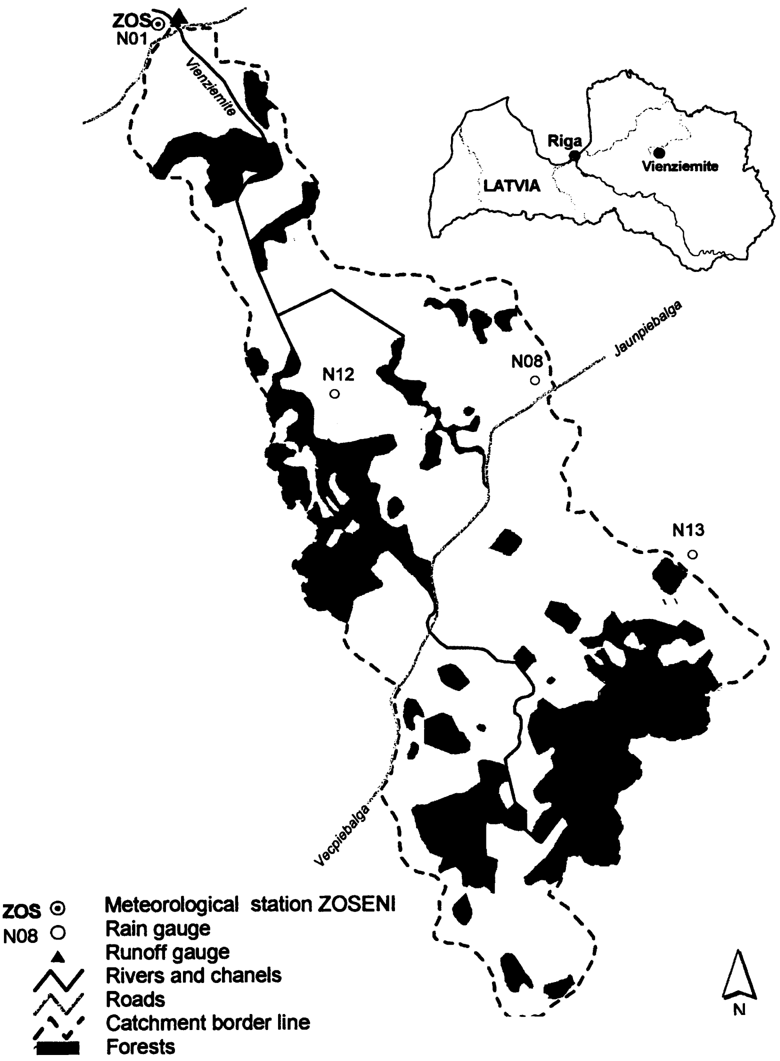

Fig. 4. Basin of Vienziemite Brook (A=5.92 km^2).

tween the observed and simulated discharges.

The calibration procedure of the model METQ98 parameters was done for two periods: the first is a 15-year period before the drainage construction from January 1,1956 till October 31,1970; the second is an 8-year period after the drainage construction from January 1,1975 till December 31,1982. The observed and simulated hydrographs simulated with a parameter set before the drainage construction for the period 1956-1958 are shown in Fig. 5 and hydrographs simulated with a parameter set after the drainage construction for the period 1979-1981 are shown in Fig. 6. The

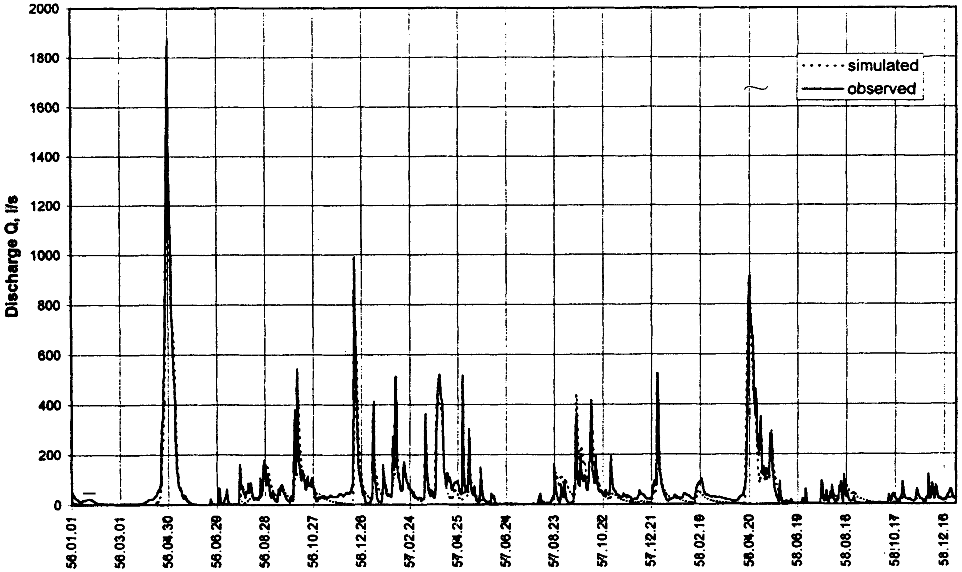

Fig. 5. Simulated and observed hydrographs at Vienziemite Brook (A=5.92 km^2) in 1956-1958 (without artificial drainage).

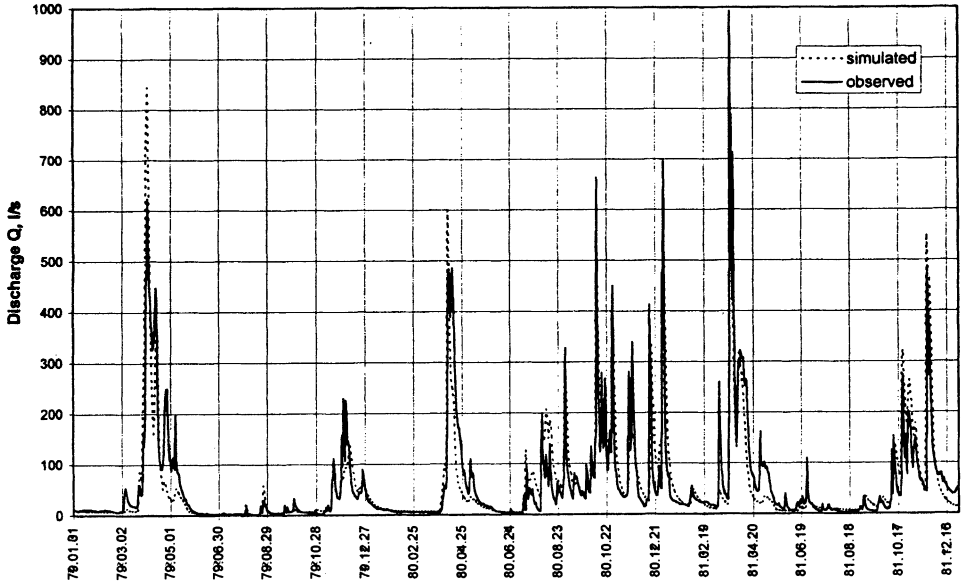

Fig. 6. Simulated and observed hydrographs at Vienziemite Brook (A=5.92 km^2) in 1979-1981 (artificial drainage installed).

Table 2 – The model parameters for the Vienziemite brook basin.

Parameters	Hilly agricultural land		Agricultural lowlands		Forests		Swamps	
	Before drainage	After drainage	Before drainage	After drainage	Before drainage	After drainage	Before drainage	After drainage
WMAX, mm	30	30	30	30	30	30	20	20
ALFA	0.05	0.05	0.05	0.05	0.10	0.10	0.15	0.15
ZCAP	200	200	250	150	200	200	60	60
A2	0.0004	0.0004	0.0004	0.001	0.0004	0.0004	0.0004	0.0004
DZ, cm	80	85	40	115	30	50	40	40
A3	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006
PZ, cm	120	250	115	220	100	200	50	90
KU	0.57	0.58	0.57	0.58	0.58	0.58	0.58	0.58
KL	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
KS	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
CMELTB	4.0	4.0	4.0	4.0	3.5	3.5	4.0	4.0
AMELT	0.07	0.07	0.07	0.07	0.01	0.01	0.07	0.07
T1, ^{0}C	0.5	0.5	0.5	0.5	1.0	1.0	0.5	0.5
T2, ^{0}C	-0.1	-0.1	-0.1	-0.1	0.1	0.1	-0.1	-0.1
CFR	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
WHC	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
RCHR, mm/d	5	5	15	15	20	20	25	25
RCHRZ, mm/d	1	1	10	10	6	6	6	6
RCHR2, mm/d	30	30	20	20	30	30	25	25
RCHR2Z, mm/d	6	6	5	5	3	3	4	4
ROBK	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
DPERC, mm/d	0.1	0.09	0.07	0.07	0.08	0.08	0	0

model parameters estimated for the Vienziemite basin are shown in Table 2.

The efficiency criteria R^2 shows good coincidence between the observed and simulated discharges. The R^2 by the model METQ98 for an 8-year period after the drainage construction is 0.796. The R^2 by the model METQ98 for a 15-year period before the drainage construction is 0.830. The performance of the model METQ98 was compared with the model METQ96 which does not have the modification of the degree-day method depending on incoming solar radiation. The efficiency criteria R^2 by the model METQ96 for the same time period of 15 years (1956-1970) before the drainage construction is 0.799. Conclusion is that the modified degree-day method gives some improvement in the modelling of snow melt. That can be detected by looking at the simulations of the spring flood peaks. Fig. 7 shows simulated flood peaks by both versions of the model METQ96 and METQ98 for the spring flood event in 1958.

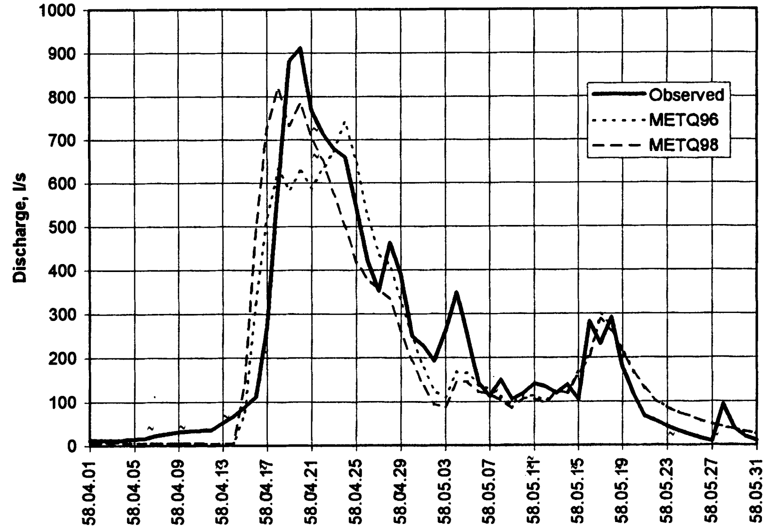

Fig. 7. Comparison of observed and simulated flood peaks in spring 1958 in Vienzimite Brook (A=5.92 km^2).

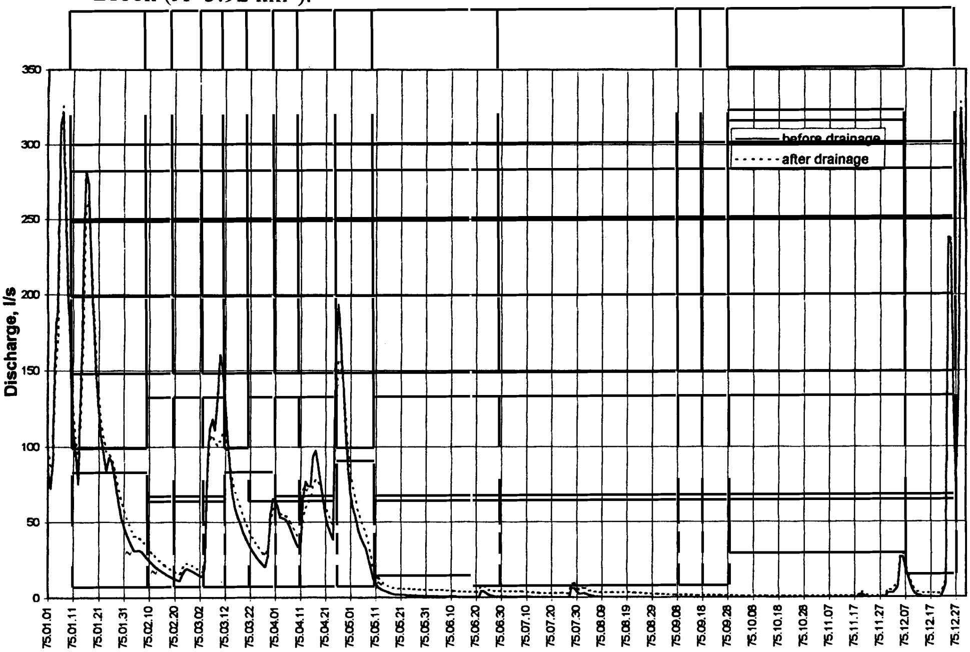

Fig. 8. Simulated runoff for both conditions before and after the drainage in Vienziemite basin (1975)

The values of parameters are estimated for both conditions before and after the drainage construction. The most considerable difference between the values of parameters before and after the drainage construction have parameters which characterise the drainage intensity and the depth of drainage. The value of parameter *DZ* (depth of upper "drain") before and after drainage in agricultural lowlands is 40 and 115 cm, respectively. It may be explained that mainly agricultural lowlands were drained in 1974. The value of parameter *PZ* (depth of lower "drain") increased after the drainage in all types of HRUs. However, the most considerable increase was observed in hilly agricultural land from 120 cm to 250 cm.

The model is run by both parameter sets before and after the drainage for the same 49-year period (1946-1994). It allows to compare the runoff simulated by the same meteorological input data, but for different conditions in the river basin. Simulated discharges for both conditions for one year (1975) are shown in Fig. 8. The simulated mean annual runoff for an artificially drained basin was higher in comparison with natural drainage conditions by 3.3% for the 49-year simulation period. Simulated runoff during the dry seasons increased after the drainage construction. On the other hand, the simulated maximum discharges decrease a little after the drainage installation. The same tendencies also have been measured. For the period 1947-1973 during 20 summers the Vienziemite Brook dried up, but after the installation of drainage drying up has never been observed.

Application of the Model to the Daugava River Basin

The Daugava river is one of the biggest rivers in the basin of the Baltic Sea (Fig. 9). The area of the basin is 86,500 km^2. The annual precipitation varies in the range from 600 to 800 mm. The headwaters of the Daugava river are in the Valdaya highland in the western part of Russia. The river flows from the east to the west and crosses the northern part of Byelorussia. The lower part of the Daugava river basin, however, is located in Latvia, and there the Daugava flows into the Gulf of Riga. The main peculiarity of the Daugava River basin is the small difference of elevation within the basin. The main part of the basin has an elevation between 100 and 200 m above the sea level , except some hills which are higher than 250 m above the sea level.

METQ98 is run using the historical data from the Daugava River basin for a 39-year period (1956-1994). Meteorological data (daily precipitation, air temperature and vapour pressure deficit) from 16 meteorological stations are used as the input data to the model. The Daugava river basin is divided in 22 subbasins, and each subbasin is characterised by the data from one up to four meteorological stations (average, two meteorological stations). The total number of the subbasin-metorological station units is 44. The total amount of HRU is 44 units multiplied by 5 types of HRU which gives 220 HRU (Ziverts and Jauja 1998a, 1998b). The model parame-

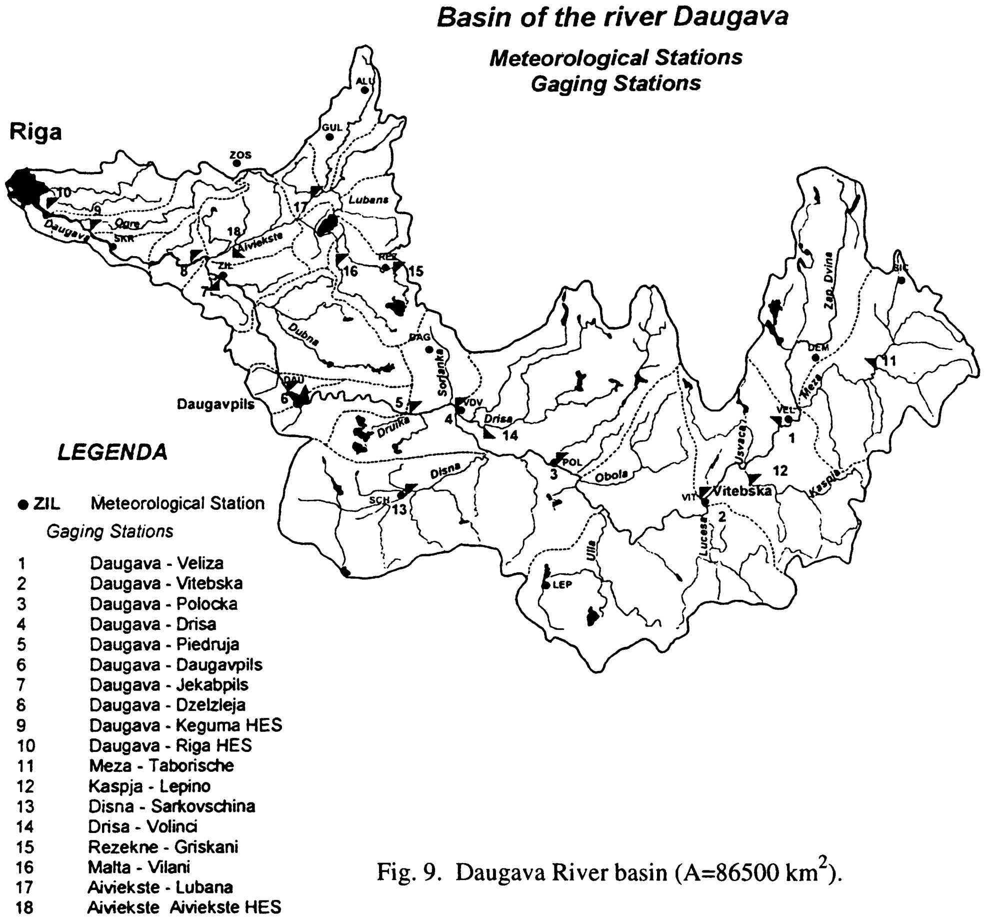

Fig. 9. Daugava River basin (A=86500 km^2).

ters estimated by calibration for the Daugava River simulations are given in Table 3.

The runoff from each subcatchment then is routed through the channel. The channel routing for the Daugava river is calculated by using the linear reservoir model. The river channel is represented by a series of $n = 43$ linear reservoirs. The runoff is simulated for 15 sites along the Daugava River including Plavinas HPP.

The runoff routing in the Lubana lowland and the river Aiviekste basin is estimated by using different approaches (Sēne and Ziverts 1991). The peculiarity of the river Aiviekste basin is that the flood-detention storage capacity of the Lubana lake and the whole Lubana lowland is very large. Simulated inflow into and outflow from the Lubana lowland (A=7,270 km^2) are shown in Fig. 10. During the flood peaks the maximum inflow discharges into the Lubana lowland are approximately three times larger than the outflow discharges. For the runoff simulation at the Lubana lowland the conceptual model METQ98 is coupled with the unsteady flow model developed for the Lubana lowland simulations in the previous years (Sēne and Ziverts1991).

Table 3 – The model parameters for the Daugava basin.

Parameters	Hilly agricultural land	Agricultural lowlands	Forests	Swamps
WMAX, mm	30	30	30	20
ALFA	0.05	0.05	0.10	0.15
ZCAP	200	250	200	60
A2	0.0002	0.0002	0.0002	0.0002
DZ, cm	85	120	70	40
A3	0.0006	0.0006	0.0006	0.0006
PZ, cm	500	300	500	90
KU	0.58	0.58	0.58	0.58
KL	0.25	0.25	0.25	0.25
KS	0.05	0.05	0.05	0.05
CMELTB	3.5	3.5	2.5	3.5
AMELT	0.06	0.06	0.01	0.06
T1, ^{0}C	0.5	0.5	1.0	0.5
T2, ^{0}C	-0.1	-0.1	0.1	-0.1
CFR	1.2	1.2	1.2	1.2
WHC	0.1	0.1	0.1	0.1
RCHR, mm/d	5	15	20	25
RCHRZ, mm/d	1	10	6	6
RCHR2, mm/d	30	20	30	25
RCHR2Z, mm/d	6	5	3	4
ROBK	1.5	1.5	1.5	1.5
DPERC, mm/d	0	0	0	0

The measured and simulated discharge in the Daugava River basin for the 5-year period (1983-1987) at Plavinas HPP is shown in Fig. 11. The correlation coefficient between the measured and observed daily discharge for that 5-year period is 0.94. The statistical criterion R^2 (Nash and Sutcliffe 1970), which characterises the coincidence between the measured and observed daily discharge for a 39-year period (1956-1994) is 0.814. The main source of difference between the simulated and observed runoff values is the shortage of precipitation input data to characterise the spatial and temporal distribution of precipitation. For such a large basin 16 points of observations are not enough. For the 39-year period the methods of precipitation measurement have changed at least twice and the correction factors of precipitation are also unstable during such a long period.

The simulated mean annual runoff at Plavinas HPP on the Daugava River for the whole 39-year simulation period is 232 mm and the observed mean annual runoff for the same period is 228 mm.

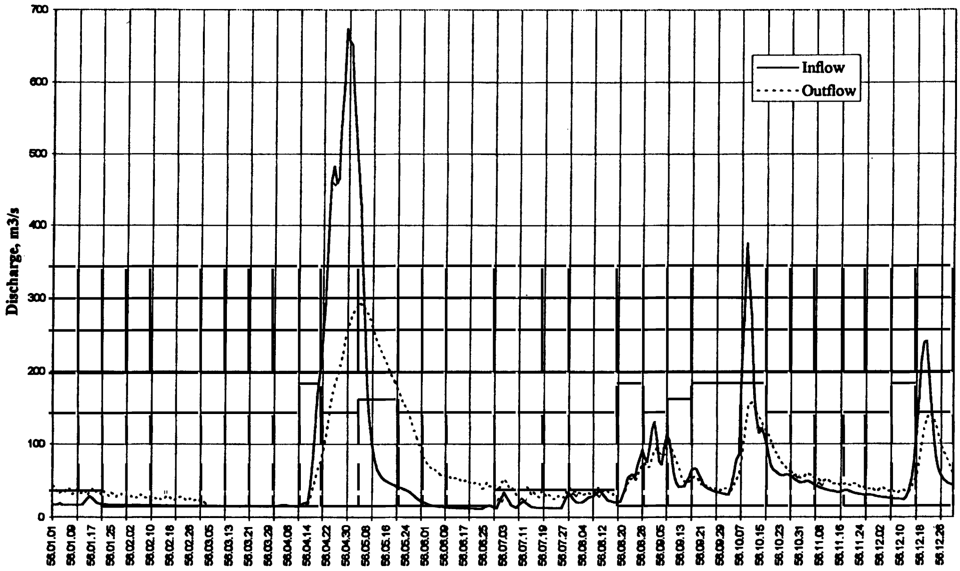

Fig. 10. Simulated inflow into and outflow from the Lubana lowland in 1956

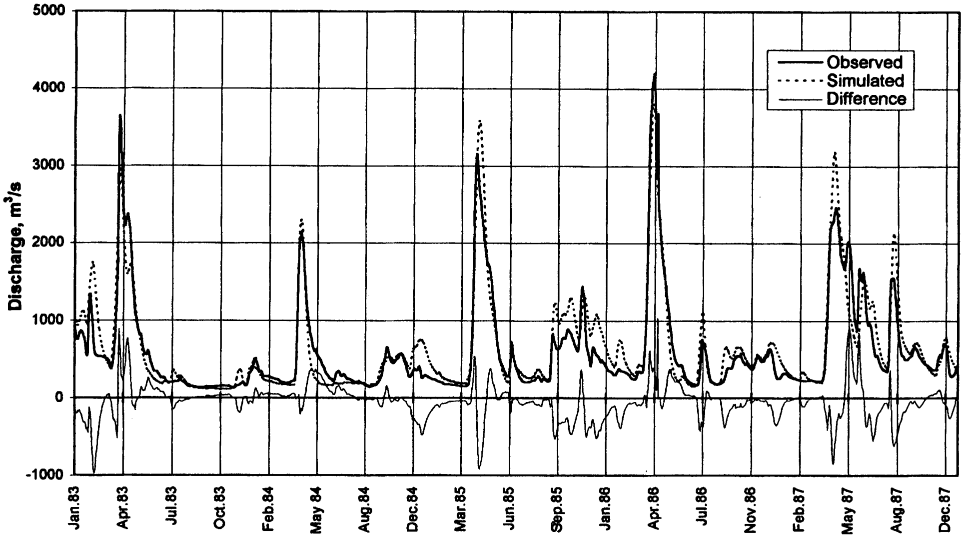

Fig. 11. Simulated and observed discharges at Plavinas HPP on the Daugava River (1983-1987)

Conclusions

1) The new version METQ98 is developed from the mathematical model METUL. METQ98 is applied to river basins with different catchment sizes (from a some km^2 to almost hundred thousand km^2).
2) For modelling large river basins, the catchment must be divided in subbasins. Each subbasin can consist of five types of hydrological response units: (agricultural lowlands, agricultural hilly land, forest, swamps and lakes).
3) For the description of a hydrological response unit the model METQ98 uses 22 parameters. 15 parameters are rather stable and the same values might be used for the majority of the river basins in Latvia. The rest of parameters have to be calibrated for each river basin separately.
4) The analysis showed that depending on daily potential insolation a temporally changing degree-day factor gives better snow melting simulation results than the traditional degree-day factor.
5) The model METQ98 allows to analyse the runoff changes caused by the installation of artificial drainage. According to both simulated and observed runoff data the smoothing out of the runoff hydrograph can be observed after the installation of drainage in the Vienziemite Brook basin. The minimum discharges are increasing and maximum discharges are decreasing after the drainage installation.

Acknowledgements

The application of the model to the Daugava River basin was carried out in co-operation with Consulting Company "Nara". The authors gratefully thank the director of this Company Anna Egle for the possibility to use the results of the study in this paper. We also appreciate the helpful and constructive comments provided by the two anonymous reviewers.

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Received: 26 October, 1998
Revised: 14 January, 1999
Accepted: 21 January, 1999

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