
'De Nieuwlanden'
Nieuwe Kanaal II
6709 PA Wageningen
The Netherlands

Department of Hydraulics and Catchment Hydrology

Application of the Pulse Model to the Hupselse Beek Catchment (Holland)

M.A.L. van Engelenburg
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APPLICATION OF THE PULSE MODEL
TO
THE HUPSELSE BEEK CATCHMENT
(HOLLAND)

Agricultural University Wageningen, Holland
Dept. of Hydraulics and Catchment Hydrology

PREFACE.

This report is the result of a 3-months-subject catchment hydrology at the Agricultural University Wageningen, Holland which formed a continuation to a 3-months-stay at the Swedish Meteorological and Hydrological Institute, Norrköping, Sweden.

This study was possible thanks to Sten Bergström (SMHI) who gave me the opportunity to take the PULSE model with me to Holland to apply it on a Dutch situation.

Furthermore I thank Piet Warmerdam for his support.

Jolijn van Engelenburg

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SUMMARY.

The PULSE model is a runoff model which can also be used for simulation of hydrochemistry developed by SMHI, Norrköping, Sweden.

The name 'PULSE' model was chosen because the input to the model is saved in a 'pulse' while for hydrochemistry residence time is of great importance. This is counted for by recalculating the hydrochemistry for each pulse for each day so to imply the effect of the period between the time of precipitation and the time of drainage to the chemical composition of the water.

The model is using rather simple formulations. This choice was made because using more complex formulations often increase the computing time to a greater extent than they improve the results.

Within the model several subroutines are used to finally calculate the discharge. The first step is formed by a snow routine which is calculating snow melt, refreezing and interception. After this the evaporation is counted for and the water is divided between supply to the soil moisture storage and contribution to the discharge in the soil routine. The amount of water that is to be drained is led through the response function which is generating the discharge. This generated discharge is guided through a transformation function in order to get the proper shape of the hydrograph.

To find out whether this model could be used in Holland the model was applied to the Dutch catchment area the 'Hupselse Beek'.

Sensitivity analysis was executed for the main parameters of the model. This led to the conclusion that several parameters show a dependency to other parameters, which is influencing the fitting procedure and consequently the results.

After simulation the water balance was checked by comparing the observed precipitation and discharge to the evaporation as estimated by the model. This led to an increase of the soil moisture storage in the period April '83 till March '84, which had an extremely wet winter period. Over the two other periods a negligible change of the storage occurred, which is assumed to be the normal situation.

The results of the simulation were relatively good. The main problem was the too slow reaction resulting in too low simulation of peaks and too slow recession. This is probably caused by the time of reaction which is only a couple of hours for the Hupselse Beek area while within the model the minimum value is one day.

An optimization procedure instead of manual optimization could improve the results though the dependency between some of the parameters could cause serious problems.

1 INTRODUCTION.

1.1 Purpose.

Since 1968 the Department of Hydraulics and Catchment Hydrology at the Agricultural University, Wageningen, Holland, has been measuring hydrological and climatological variables in a catchment area in the eastern part of Holland. Main purpose for these measurements was to try and develop a runoff model based on the hydrological processes occurring in a catchment area. In the past years the Wageningen-model was developed, which is still subject to efforts to improve the results or to describe the processes with more accuracy.

Comparison with runoff models developed by other institutes could add new ideas about how to describe a catchment area in general.

Recently the department obtained a model developed by the hydrological research group of the Swedish Meteorological and Hydrological Institute. This 'PULSE' model is a combination of a hydrological and a hydrochemical model.

The purpose of this research was to apply the hydrological part of the PULSE model to the Dutch research-area to find out whether this model could be of use in Holland.

1.2 Description of the catchment.

The catchment is called the Hupselse Beek catchment. The catchment covers an area of 6.5 km² and is situated in the eastern part of Gelderland, Holland (see fig.1.1).

The stream can be divided into a main stream (length 4 km) and 7 tributary streams each with a length varying between 300 and 1500 meters (see fig.1.2).

The altitude of the area is slightly changing from 24 meters above New Amsterdam Level in the western part to 33 in the eastern part.

1.2.1 Geology.

The catchment area is situated in a landscape merely consisting of ground moraines. On a depth varying between 0.4 and 8.0 meters below the surface an impermeable layer of Miocene clay is found. On top of this layer moderate to medium coarse sand and some fine to coarse gravel was deposited. Also some disturbing layers of loam occur. The surface layer consists of fine sandy deposits.



Fig.1.1: Situation of Hupselse Beek catchment in Holland.

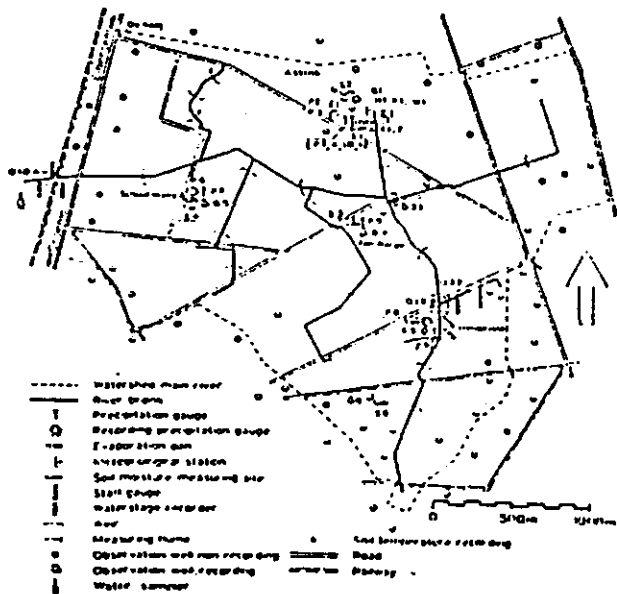


Fig.1.2: The Hupselse Beek catchment.

1.2.2 Land use.

The main activity in the Hupselse Beek area is agriculture. About 65 per cent of the area is in use as pasture, 20 per cent as arable land which is merely put under corn. Furthermore about 9 per cent of the area is covered with forest.

The 6 per cent left-over consists of built-up area and a camping site. The built-up area is formed by scattered farms and houses. No towns are situated in the area.

1.2.3 Hydrology.

The hydrological situation has been changed by human activities. About 50 per cent of the area is drained by pipes and the stream has been canalized and regulated.

The groundwater table is usually low in summer time (lower than 120 cm below surface) and above 80 cm during wintertime.

The hydrological base is formed by the Miocene clay layer. Hardly any groundwater nor surface water supply occurs from the surrounding area. Water leaves the area through one point of outlet at weir 10A (see fig.1.2).

Though the area has clear bounds there are still circumstances complicating the hydrological situation, such as the changing thickness of the aquifer, the disturbing loam layers and differences in altitude on short distance.

2 DATA AND WATER BALANCE.

2.1 Introduction.

In this chapter a short description of the determination and acquisition of precipitation, temperature, evapotranspiration and runoff data is given.

In order to understand more of the hydrological situation in the catchment and to be able to estimate the values of the parameters in the start situation as needed for the simulation calculation of the water balance is needed.

Also to be able to judge the quality of the data used it is wise to calculate a water balance. This calculation has been described in the last section of this chapter.

2.2 Precipitation.

The precipitation data have been measured at 'Assink', the meteorological station situated in the Hupselse Beek area. At this station different kinds of rain-gauges are used. The data used have been obtained by a recover-rain-gauge which is recording every 15 minutes. For this research the 24-hours total values were used, measured from 0.00 h to 0.00 h.

2.3 Temperature.

The temperature data also have been measured at 'Assink' and are daily mean values.

2.4 Evapotranspiration.

The potential evapotranspiration data have been recalculated from monthly mean data for evaporation of a water surface as determined by the Royal Dutch Meteorological Institute (KNMI) by using formula 2.1.

$$\begin{array}{l} \text{potential} \\ \text{evapotranspiration} \end{array} = 0.75 * \begin{array}{l} \text{evaporation of} \\ \text{open water} \end{array} \quad (2.1)$$

2.5 Runoff.

The runoff of the catchment is measured at the outlet of the area (weir 10A, see fig.1.2). The flume that is used is an H-flume. Every 15 minutes the height of the water level is recorded with an accuracy of 1.0 mm. These heights are calculated into discharge per 15 minutes by a known relation-

ship, between both variables. The assumption is made that the momentary height measured is representative for the last period of 15 minutes. These values are recalculated into 24 hours discharges.

2.6 Water balance.

2.6.1 Introduction.

The water balance is calculated according to formula 2.2.

$$\Sigma P = \Sigma Q + \Sigma E + \Delta S \quad (2.2)$$

where:

ΣP	=	total precipitation	[mm]
ΣQ	=	total runoff	[mm]
ΣE	=	total actual evapotranspiration	[mm]
ΔS	=	increase of storage in soil	[mm]

Re-arranging of formula 2.2 leads to formula 2.3.

$$\Delta S = \Sigma P - \Sigma Q - \Sigma E \quad (2.3)$$

While ΣP , ΣQ and ΣE are available ΔS can be calculated.

The Hupselse Beek area has no water supply from or loss to the surroundings, so usually an occurring increase or decrease of the water storage in the soil is caused by errors in the data. Assuming that the change of the storage is nil and that the precipitation and runoff data are correct because of the adequate method of measuring, usually the actual evapotranspiration is assumed to be the erroneous part in the calculation.

Within the model the water balance is checked daily as well as each month.

A daily check of the balance for the soil is executed within the soil routine (see 3.2.2 and app.A). In this check the change in soil moisture between two successive days is checked with the difference between the effective precipitation and the amount of water available for discharge. If certain limits for this difference are exceeded the program run will be terminated. This is merely a check of computing errors.

Each month the water balance is checked up on for the (sub)basin. This check is executed by comparing the amount of precipitation minus evaporation minus discharge to the difference of the amount of water that is stored in snow, interception and lake at between the last day of the former month and the last day of the present month as described in formula 2.5. The limit above which the program run is terminated is also given.

$$\text{DIFF} = \text{EP} - \Sigma \text{E} - \Sigma \text{Q} + (\text{IN} - \text{OUT}) \quad (2.5)$$

where:

DIFF = difference in water balance. If DIFF is [mm]
 positive water is disappearing. Limit=0.05;
 EP = precipitation summed over one month; [mm]
 ΣE = evaporation summed over one month; [mm]
 ΣQ = computed discharge summed over one month; [mm]
 IN = storage of water in snow, interception [mm]
 or in lake on last day of the month before;
 OUT = storage of water in snow, interception [mm]
 or in lake on last day of the present month.

2.6.2 Results.

In table 2.1 the water balance is given as follows from the model runs. Also the observed discharge and the change of the soil moisture storage over each period and over the entire period of three years are given.

Table 2.1: Results of the water balance.

Period	EP	ΣE _{com}	ΣQ _{com}	S _{com}	ΣQ _{obs}	S _{obs}
830401- 840331	845.5	451.1	436.6	-42.2	375.6	+18.8
840401- 850331	724.8	387.1	339.6	-1.9	340.9	-3.2
850401- 860331	761.7	443.3	322.5	-4.1	318.1	+0.3
830401- 860331	2332.0	1281.5	1098.7	-48.2	1034.6	+15.9

Some remarks can be made while looking at table 2.1.

Before discussing the results for each single period a remark should be made about the origin of the results. The evaporation data are the values as calculated by the final simulation run of each period. They are assumed to be a reasonable approximation of the actual evaporation. The observed discharge is compared with this actual evaporation to estimate the change of the soil moisture storage. To compare the results and to be able to verify the assumption that the calculated evaporation volume equal the actual evaporation these computed discharge volumes are also presented in table 2.1. These computed values can be erroneous.

The period 83/84 was very wet: a yearly precipitation of over 850 mm while this normally is approximately 750 mm. Looking at the precipitation data especially the winter period turned out to have more precipitation than usual. This could lead to an

increase of soil moisture over the year because during winter time hardly any evaporation is diminishing this storage. As shown in table 2.1 the storage indeed is increasing. The simulation of the first period resulted in too large a volume of discharge. According to this the evaporation volume probably is too low. If this volume was larger the increase of the storage would be smaller which would be more likely than the increase of 3 per cent of the precipitation input as is the present result.

Comparing the computed to the observed discharge the observed volume is over-estimated by nearly 15 per cent which points to a bad simulation. Therefore the decrease of the storage as resulting from the calculation is not discussed further.

The period 84/85 was a bit dryer than normal and showed a lower volume of evaporation. Over this period the soil moisture storage decreased by less than half a per cent of the precipitation which is negligible.

The last period 85/86 had a normal amount of precipitation. Together with the observed discharge a negligible increase of less than 0.1 per cent is resulting.

While these last two periods had a 'normal' amount of precipitation the change of the soil moisture storage should be nearly nil, which means the water balances over these two periods are correct.

Summed together the three periods lead to a change of the storage for observed discharge of approximately 15 mm which is less than 1 per cent of the amount of precipitation over the entire period. This is negligible especially when the wet winter period of 83/84 is taken into account.

3 THE PULSE MODEL.

3.1 Introduction.

The PULSE model as developed by the Swedish Meteorological and Hydrological Institute is a combination of a hydrological and a hydrochemical model.

Main reason for the development of this combined model was to model the impact of acid rain to the hydrological system. Several attempts have been made to model this impact. Though the hydrological processes are influencing hydrochemistry a lot, usually choice is made to use a complex hydrochemical model in combination to a simplified hydrological model.

The PULSE model however is the reverse of this approach. By using an advanced hydrological model and a semi-empirical, simplified hydrochemical model, the importance of for instance the residence time is worked in into the model.

The name 'PULSE' model is chosen because of the approach used in the model: each day the amount of precipitation available for discharge is memorized in a 'pulse'. The reason for using this approach was to be able to implicate the influence of the residence time to the chemical composition of water by using pulses for each day and re-calculating the chemistry of each pulse every day.

The main routines of the hydrological model are described in the next section. Though the hydrochemical part has not been used in this research, a short description of this part is given in section 3.3. In the last section the optimization routine is described.

3.2 The hydrological model.

The hydrological model is a conceptual runoff model. While an increasing complexity of a model does not implicate as much extra information as it implicates extra computing time, choice was made to use simple formulations to describe the hydrological processes.

Before modelling can start, parameters describing the area such as the size of the area, altitude, size of forested and non-forested area, are needed. Also a description of the physical situation is needed, by for instance recession coefficients, maximum soil moisture and several threshold values for processes to start. Furthermore some parameters concerning the measuring stations for precipitation and temperature are needed.

Also a description of the state of the area at the first date is needed, for instance the soil moisture storage and the snow pack at that date.

The input variables of the model are daily precipitation and discharge, daily mean temperature in case the snow routine is

used and monthly mean values of potential evapotranspiration. Both precipitation and temperature can be measured at several stations.

Output of the model consists of daily values for several variables such as computed discharge, actual evapotranspiration, soil moisture, interception (rain and snow), snow pack and snow melt.

The output is calculated on a day-to-day-basis: For each day the model is run through completely. The state of the variables at the end of the day is saved for the calculation of the next day.

In fig.3.1 the basic structure of the model is represented. The hydrological processes are modelled in subroutines as described in the following sections.

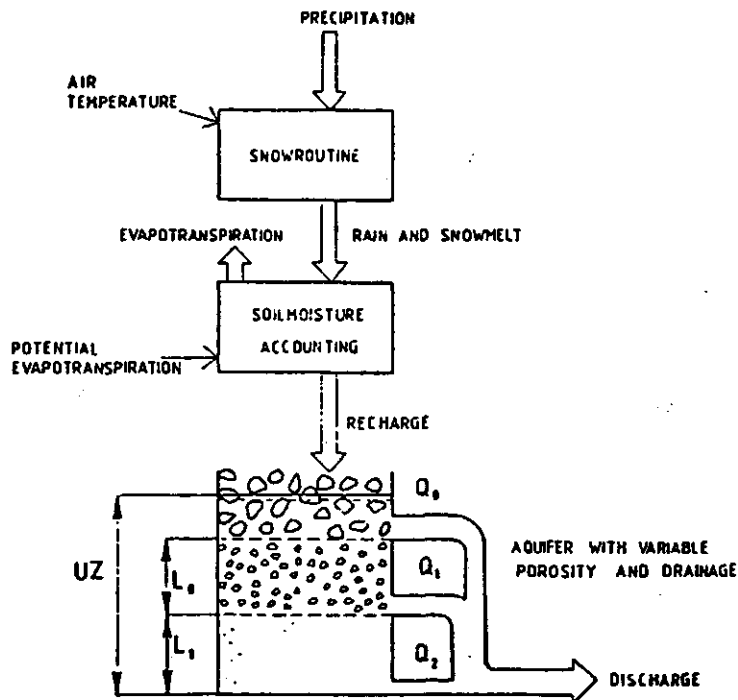


Fig.3.1: Basic structure of the hydrological model.
Source: ref.2.

3.2.1 The snow routine.

To simulate the process of snow melt numbers of models have been developed varying between complex and simple (ref.3). As mentioned before choice was made to use formulations as simple as possible.

The formulation used for snow melt is based on a degree-day approach. This means that the amount of snow melt is proportional to the difference between the daily mean air temperature and the temperature above which snow melt will occur. In formula 3.1 this is formulated.

$$M = C_o (T - T_o) \quad (3.1)$$

where:

M = snow melt [mm]
 (if $T < T_o$ then $M = 0$);
 C_o = degree-day melt factor; [mm/°C]
 T = surface air temperature; [°C]
 T_o = threshold value of the air temperature. [°C]

Because this approach is a simplified description of the snow melt process, it has been combined with several options so that the description is more physical.

One of these options is using the liquid water holding capacity of the snow, which delays runoff from melting snow until the snow is saturated up to 10 per cent. Another option is the differentiation of the area into forested and non-forested land and water, to account for differences such as in interception and the temperature above which snow melt will occur. Furthermore the option of using the elevation zone in combination with temperature and precipitation changes according to the height is used. The measured data are recalculated according to the elevation of the area and the meteorological station.

3.2.2 The soil moisture routine.

The generated recharge is mainly controlled by this routine. The soil moisture routine is run through twice for each day: for forested and non-forested land.

In the soil moisture routine the pulse of water contributing to this routine is distributed into a contribution to the soil moisture storage and a contribution to the response function. The contribution to the response function is supposed to be proportional to the quotient of the computed and the maximum soil moisture storage raised to a certain power. In figure 3.2 this is represented. In formula 3.2 this is formulated.

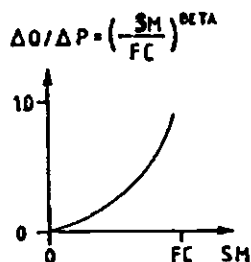


Fig.3.2: The soil moisture routine.
 Source: ref.5.

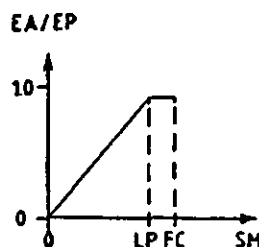


Fig.3.3: The evaporation function.
 Source: ref.5.

$$\Delta Q / \Delta P = \left(\frac{SM}{FC} \right) ** BETA \quad (3.2)$$

where:

ΔQ	= contribution to the response function;	[mm]
ΔP	= amount of precipitation;	[mm]
SM	= computed soil moisture storage;	[mm]
FC	= maximum soil moisture storage (field capacity);	[mm]
BETA	= empirical coefficient;	[-]

From formula 3.2 can be deduced that in case of a dry soil (low soil moisture storage) a smaller part of the precipitation will contribute to runoff than in case of a wetter soil with a higher soil moisture storage.

The amount of evapotranspiration influencing the soil moisture storage is estimated by a linear decrease of the potential evaporation below a certain storage level. If the storage has a value in between this level and the storage at field capacity, the actual evapotranspiration is supposed to be equal to the potential evapotranspiration. This means a decreasing soil moisture storage will lead to a decreasing actual evapotranspiration. Schematically this is represented in figure 3.3.

Capillary rise is supposed to be related to both the quotient of the soil moisture storage and field capacity and the amount of water contributing to the response function divided by the minimum amount. This is calculated for each pulse according to formula 3.3a and b.

$$CFLUX1 = CFLCAP * (1 - SM / FC) \quad (3.3a)$$

$$CFLUX = CFLUX1 * (1 - LZ / LZMIN) \quad (3.3b)$$

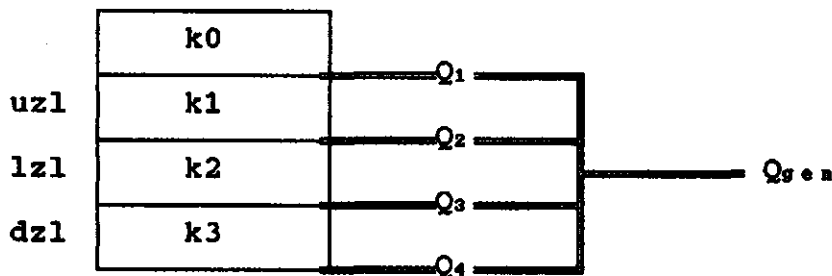
where:

CFLUX1	= Amount of cap.rise according to SM/FC;	[mm/d]
CFLCAP	= Maximum cap.rise;	[mm/d]
SM	= Soil moisture storage;	[mm]
FC	= Maximum soil moisture storage;	[mm]
CFLUX	= Final amount of cap.rise;	[mm/d]
LZ	= Amount of water in pulse;	[mm]
LZMIN	= Minimum amount of water in pulse.	[mm]

This amount in addition to the calculated soil moisture storage leads to the ultimate value for the storage. The final contribution to the response function is reduced by this amount of capillary rise.

3.2.3 The response function.

The response function generates the contribution to this function into runoff. The function is based on a subdivision of the soil into layers with variable hydraulic properties concerning porosity and drainage capacity as represented in figure 3.4. Each layer has a threshold value above which the layer is draining, and a recession coefficient determining the amount of discharge through that layer.



uzl = upper zone level; [mm]
 lzl = lower zone level; [mm]
 dzl = deep zone level [mm]
 (groundwater);
 k0,k1,k2,k3 = recession coefficient; [1/1000*d]
 Q1,Q2,Q3,Q4 = discharge per layer; [mm]
 Qgen = runoff generated by [mm]
 response function;

Fig.3.4 Subdivision in response function.

The water contributing to the response function is subdivided into pulses. After summing these pulses until the sum exceeds the lower threshold value of a layer, the water remaining is calculated into runoff by formula 3.4.

$$Q(\text{pulse}) = S(\text{pulse}) * k(\text{level})/1000 \quad (3.4)$$

where:

pulse = number of the pulse, [-]
 (between 1 and maximum);
 Q(pulse) = discharge of the pulse; [mm]
 S(pulse) = contribution of the pulse to [mm]
 the response function;
 level = number of the layer [mm]
 (between 1 to 4);
 k(level) = recession coefficient of [1/1000*d]
 the layer.

Generated runoff is formed by the sum of these discharges as calculated for each pulse and for each layer.

If a large open water body is situated in the catchment runoff as an effect of precipitation directly on the water and the evaporation of this water is calculated. This is added to the generated runoff.

3.2.4 The transformation function.

The generated runoff is routed through a function in order to get a proper shape of the hydrograph. This transformation function is a simple filter technique with a distribution of the weights as shown in fig.3.5.

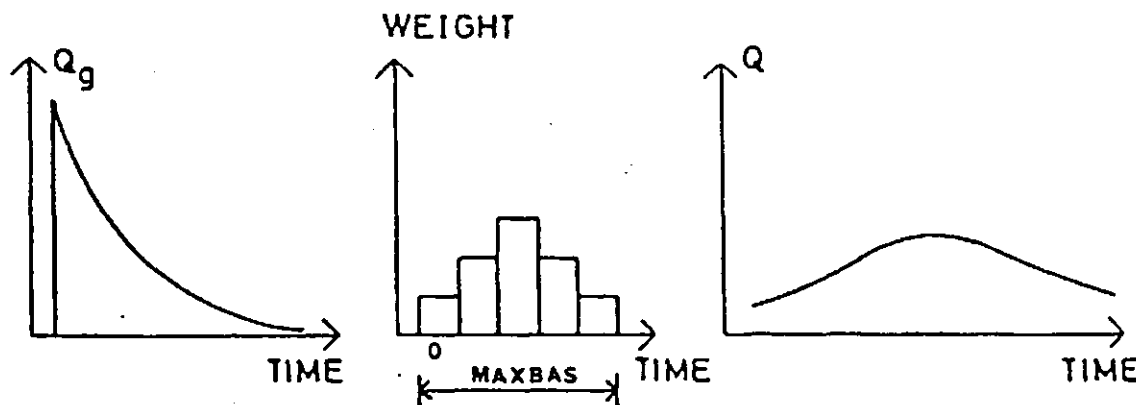


Fig.3.5 The transformation function.
Source: ref.4.

This transformation finally leads to the computed discharge.

3.2.5 Subbasins.

In the model the possibility of dividing a catchment into several subbasins is included. Subbasinwise modelling can be useful for instance in case of different elevation zones or soil characteristics in the catchment area.

For each subbasin the model parameters are needed. Also the direction of the flow through the subbasins is necessary (see fig.3.6).

In case of subbasinwise simulation discharge is calculated per subbasin after which the outflow is added to the inflow to the next basin.

The results can be given per subbasin as well as for the entire catchment.

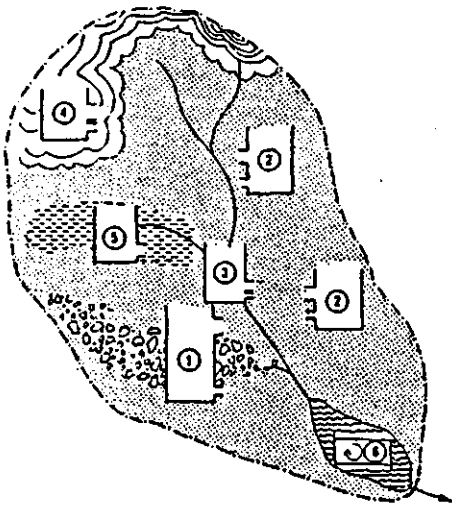


Fig.3.6 Catchment subdivided into subbasins.
Source: ref.2.

3.3 The hydrochemical model.

As mentioned in section 3.1 the main reason for the development of the PULSE model was to model the impact of acid rain to the hydrological system. For this reason mainly alkalinity and pH-values are simulated, though it also is possible to simulate for instance nitrate or chloride.

Acidity of precipitation is not taken into account except in case the precipitation is directly to water surfaces. Instead, assumptions were made that the water composition is adjusted by cation exchange in the humic layer and that water exchange occurs while the water is passing through the unsaturated zone. These assumptions are leveling out the effect of variations in the acidity of the precipitation and dry deposition.

In the model an average, fixed pH-value is used for the water passing through the organic zone. Percolating further through the soil the water will be subdued to cation exchange and weathering processes which will increase the pH-value of the water. This neutralizing effect is assumed to decrease with increasing pH-value. In the model this is taken into account by a decreasing neutralization rate with increasing residence time which is implying an increasing pH-value.

While carbon dioxide in the soil atmosphere is influencing the acidity by the possible dissolution in the soil water and is varying during the year, also a seasonal variation in the neutralization is used.

The pH-value is related to alkalinity. In formula 3.5 the definition of alkalinity is described.

$$\text{Alkalinity} = [\text{HCO}_3^-] + 2 [\text{CO}_3^{2-}] + [\text{OH}^-] - [\text{H}^+] \quad (3.5)$$

Because calculation of alkalinity is easier while it is not influenced by for instance the carbon dioxide pressure, the model simulates alkalinity which is recalculated into pH as a final step in the model.

(ref.2).

3.4 Optimization.

To fit the results to the measured data the set of model parameters should be optimised. Because the chemical modelling is based on the discharge modelling, a bad discharge simulation will cause erroneous results in the chemistry simulation. To avoid this one should optimize the discharge simulation before modelling chemistry.

In the next section optimization of the hydrological part is described. This optimization is executed by a manual trial-and-error procedure.

Within the model several optimization criteria are estimated to value the results of the optimization. In table 11 a summary of these criteria is given. All these criteria can be used for hydrological as well as for chemical variables.

In section 3.4.2 the main criteria to fit the model are described.

3.4.1 Optimization of parameter values.

The parameter file of the PULSE model is containing over 60 parameters. A part of these parameters should not be changed while another part is open for optimization. The main parameters which can be optimised are summarized in table 3.1.

A summary and a description of all parameters is given in table 3a and b.

Optimization of the model parameters should be executed step wise. Changing too many parameters at a time will lead to an indistinct change of the results: which change of parameter is causing which effect to the simulation will not be clear to see. The proper order of optimising is described in the following part together with an approximation of the value of the parameter and the effect to the simulation when the value is changed. If necessary this sequence should be repeated until the result is satisfactory.

The first step is to optimize the parameters in the snow routine (see 3.2.1). While this is of minor importance in the Dutch situation the influences of these parameters will be little.

Next step is optimization of the parameters in the soil moisture routine (see 3.2.2). If the catchment has been studied before and field capacity has been estimated this value should be chosen not to change. Field capacity is a soil property which is not likely to change in time. In case field capacity is unknown a value should be chosen between 100 and 300 mm. An increase of this value will usually lead to a decrease of the computed discharge volume.

The value of BETA should lie between 2 and 3. If the discharge peaks are too low in dry periods or too high in wet periods, an increase of BETA could improve the simulation.

A decrease of the limit above which potential evaporation is not reduced is smoothing the peaks in the computed discharge (a higher amount of evaporation leads to a lower amount of water available for discharge which causes lower peaks). The value of

lp/fc should lie between 0.6 and 0.9.

By optimising these three parameters (or two in case field capacity is known) the amount of computed discharge should be regulated. The following step, optimization of the parameters of the response function, merely influences the shape of the hydrograph.

Table 3.1 Summary of main parameters for optimization.

Routine	Name in chapter 3	Name in PAR.DAT	Description	Unit
snow routine	Co T ₀	csf	snow precipitation correction factor	[-]
		cmelt	degree-day factor	[mm/°C]
		ttmelt	threshold value above which snow melt will occur	[°C]
soil moisture routine	FC BETA	fc	field capacity	[mm]
		beta	empirical coefficient	[-]
		lp/fc	lp = limit above which potential evaporation is not reduced.	[-]
response function	CFLCAP	cflcap	maximum capillary rise	[mm/day]
	K0	k0	recess.coeff. layer 0	[1/1000*d]
	K1	k1	recess.coeff. layer 1	[1/1000*d]
	K2	k2	recess.coeff. layer 2	[1/1000*d]
	K3	k3	recess.coeff. layer 3	[1/1000*d]
	UZL	uzl	upper zone limit	[mm]
	LZL	lzl	lower zone limit	[mm]
DZL	dzl	deep zone limit	[mm]	
transform. function	MAXBAS	maxbas	time scale for distribution of discharge in time	[day]

The recession coefficient K0 effects the magnitude and recession of the peaks, K2 the recession of the base flow. Values of these coefficients can be roughly estimated as the negative slopes of the recession in a logarithmic plot of flow versus a linear time scale (see fig.3.7) if the basin has a short concentration time.

The lowest layer (with recession coefficient K3 and limited by DZL) has no really physical meaning and can be excluded by choosing both parameters nil if desired.

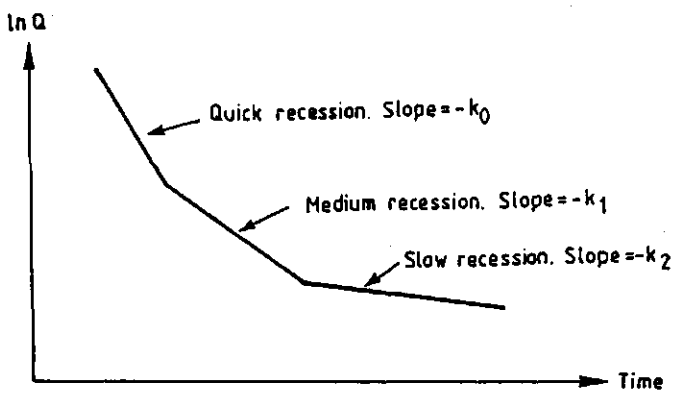


Fig.3.7 Estimation of recession coefficients.
Source: ref.4.

The last parameter to be optimised is MAXBAS in the transformation function (see 3.2.4). The parameter is stated in entire days and varies between 1 and 10 days. An increasing value will lead to a more inert reaction of discharge to precipitation. If the basin has a short concentration time MAXBAS should be chosen low.

3.4.2 Optimization criteria.

To value the results several criteria are used. The main criteria to fit the model are:

- visual inspection of the observed and computed hydrographs;
- a continuous plot of the accumulated difference between observed and computed discharge;
- the explained variance:

$$R^2 = 1 - \frac{\sum_{t=1}^n [X_{com}(t) - X_{obs}(t)]^2}{\sum_{t=1}^n [X_{obs}(t) - \overline{X_{obs}}]^2} \quad (3.5)$$

where:

R^2	= explained variance	[-]
$X_{obs}(t)$	= observed variable on time t	*
$X_{com}(t)$	= computed variable on time t	*
$\overline{X_{obs}}$	= mean value of variable	*
t	= time	[day]
n	= number of time-steps	[-]

* unit depends on which variable was chosen to be simulated.

To test the results of the optimization an independent set of data should be used.

3.5 Sensitivity analysis.

The PULSE model is using several parameters which should be optimised as described in section 3.4.1. To find out how the optimization criteria react to a change of the parameter value a sensitivity analysis can be carried out.

Within the model the sensitivity of a parameter can be tested. This analysis is executed by increasing the parameter value step-wise and re-run the program with the new value so to find the effect of this change to the results.

Another possibility of the sensitivity analysis is a test for dependency between two or three parameters. If a dependency exists between parameters this can cause problems while optimising the simulation results. In fig.3.8 two examples of dependency are given. The left picture shows a 100 per cent dependency between two parameters, the one to the right a lower but still clear dependency.

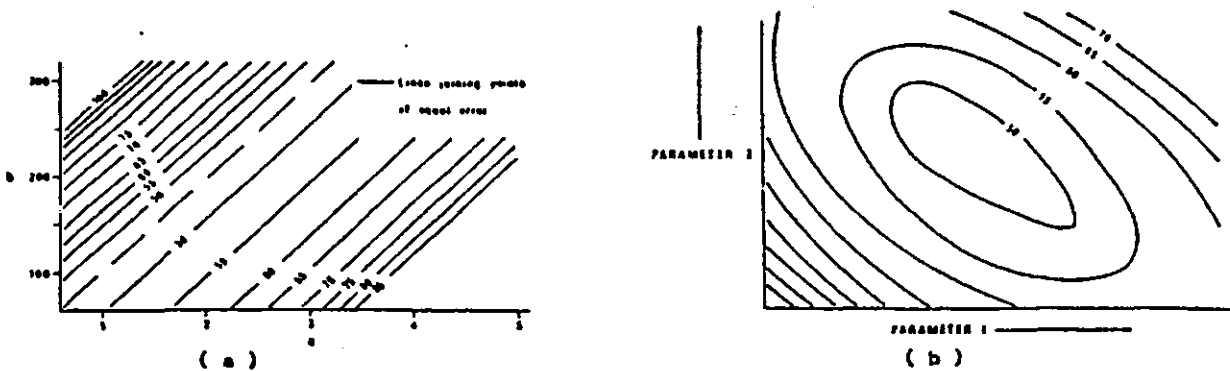


Fig.3.8 Examples of dependency:
a 100 per cent dependency;
b a frequent occurring dependency.

4 RESULTS AND DISCUSSION.

4.1 Introduction.

In this chapter the results of the application of the PULSE model to the Hupselse Beek catchment are presented and discussed.

In section 4.2 results of a sensitivity analysis (see 3.5) and a dependency test of the main parameters (see 3.4.1) are presented and discussed.

In section 4.3.1 the final results of the simulation are presented together with a description and discussion of the optimum parameter values. In section 4.3.2 the simulation results are discussed.

4.2 Results of the sensitivity analysis.

Before testing the dependency between the main parameters the sensitivity of each parameter was tested. In fig.4.1 the results are presented of analysis for each period.

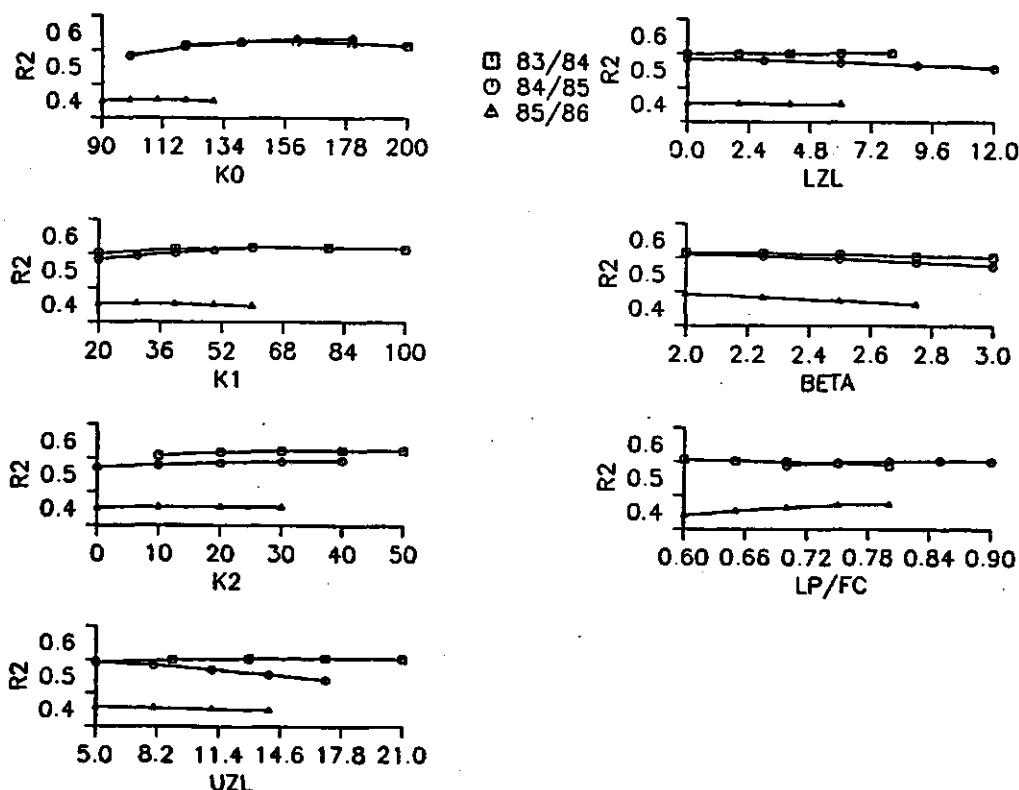


Fig.4.1 Graphical presentation of sensitivity analysis of some parameters per period of simulation:
 k0,k1,k2 = recession coefficients layer 0,1,2;
 uzl = upper zone limit (between layer 0 and 1);
 lzl = lower zone limit (between layer 1 and 2);
 beta = empirical coefficient;
 lp/fc = limit above which the potential evaporation is not reduced.

For most of the parameters the explained variance is reacting in a similar way for the three periods, though the optimum variance is often reached at different values.

Remarkable is the effect of BETA to the variance: for all three periods the maximum is reached at a value of BETA = 2. This could point to a relation between this parameter and the hydrological situation of the catchment to which the model is applied and only little influence of the meteorological situation.

LP/FC reacts differently for the period 83/84. This could be caused by the fact that this period was extremely wet compared to the other periods: a low value for LP/FC leads to a high evaporation rate which can only occur if enough water is available for evaporation.

In fig.7 of the appendices the results of the dependency test are presented.

Most of the parameters have a certain dependency on some of the other parameters. A clear example of this is given in fig.4.2 a: the dependency between the recession coefficients of the upper two layers for the period 84/85. Fig.4.2 b and c respectively show the dependency between the recession coefficient of the upper layer and the limit for potential evaporation (LP/FC) and between this coefficient and the limit of the upper zone, both for the period 85/86. These figures show a relatively low dependency between this parameters. Especially fig.4.2 c shows that the value of K0 is more or less independent to the limit of the upper zone.

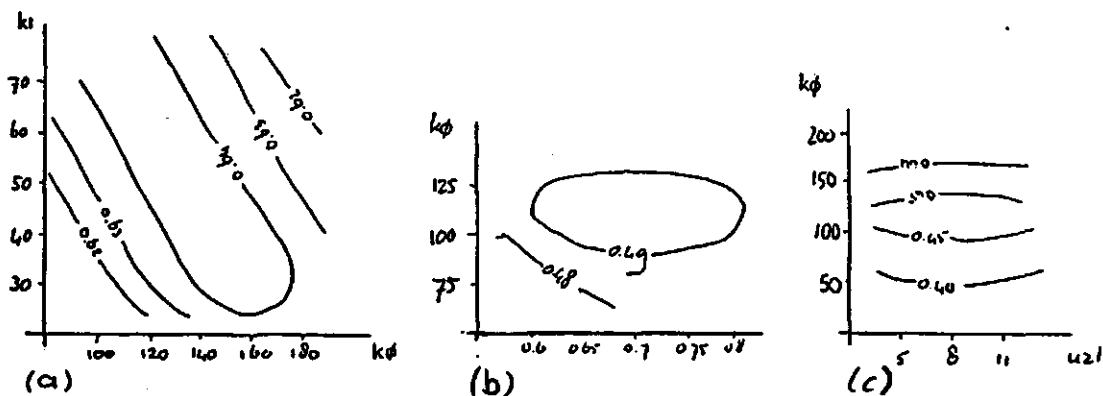


Fig.4.2 Examples of the results of the dependency test:
a K0 and K1, period 84/85;
b K0 and LP/FC, period 85/86;
c K0 and UZL, period 85/86.

While there is a dependency between most of the main parameters it is hard to find the optimum combination of parameters. This effects the results of the simulation.

4.3 Results and discussion of the simulation.

4.3.1 Simulation results.

In fig.1, 2 and 3 of the appendices the results of the simulation for each period are presented. Each figure shows next to the computed and observed discharge some other variables: precipitation, temperature, soil moisture storage, evapotranspiration and the accumulated difference between observed and computed discharge.

In table 4.1 a summary is given of the values of the main parameters as used for the final result of the simulation for each period. Also a summary is given of the values of some criteria.

Table 4.1 Optimum parameter sets and optimization results.

Parameter		Set 1	Set 2	Set 3
		830401- 840331	840401- 850331	850401- 860331
FC [mm]	Field capacity	150	150	150
BETA [-]	Empirical coeff.	2.0	2.0	2.0
LP/FC [-]	Limit pot.evap.	0.6	0.6	0.6
CFLCAP [mm/d]	Max.cap. rise	1.5	0.4	1.5
K0 [1/1000*d]	Recess.coeff. 0	170	180	110
K1 "	" " 1	20	30	20
K2,K3 "	" " 2,3	0	0	0
UZL [mm]	Upper zone limit	5	11	5
LZL,DZL [mm]	Lower and deeper zone limit	0	0	0
MAXBAS [d]	Time base	1	1	1
Results per period:				
Qcom [mm/d]	Comp.disch.(mean)	1.19	0.93	0.88
Qobs [mm/d]	Obs.disch.(mean)	1.03	0.93	0.88
Qcom/Qobs [-]	Comp./obs.disch.	1.14	1.00	1.00
acdif [mm]	Accumulated diff.	+59.00	-1.28	+4.50
R ² [-]	Explained var.	0.68	0.65	0.49
Results for the entire period:				
Qcom [mm/d]	Comp.disch.(mean)	0.89	1.09	0.93
Qobs [mm/d]	Obs.disch.(mean)	0.94	0.94	0.94
Qcom/Qobs [-]	Comp./obs.disch.	0.93	1.15	0.98
acdif [mm]	Accumulated diff	-63.11	+160.80	-16.49
R ² [-]	Explained var.	0.59	0.60	0.60

It is interesting to find out whether these sets of parameters are related to the period for which the set was optimised or that the sets can be used for other years too. The results of a simulation for the entire period of 83-04-01 until 86-03-31 are graphically presented in fig.4, 5 and 6 of the appendices, while some of the criteria are summarized in table 4.1.

About the final parameter sets some remarks can be made.

- The choice of the values of the parameters was among others based on the results of the sensitivity analysis. Also the effects of a change of a parameter value to the simulation of the hydrograph were studied.
- The parameters of the soil routine have the same value for each period. As mentioned in section 3.4.1 choice of a known value for field capacity is preferable. In this case field capacity was estimated before on 150 mm. The values of the other soil parameters were chosen to be of the same value for each period while they are assumed to be characteristic for a catchment area. As can be seen in the results of the sensitivity analysis in fig.7 the final values lead to an optimum of the explained variance for the first two periods and is near the optimum for the last period.
- Remarkable is the different value for the capillary rise in the second period. This could be influenced by the fact that this period was dryer than is normal in the Dutch situation, though there is only a small difference of 25 mm less than normal. The effect of this low maximum capillary rise is discussed in the next section.
- For this simulation it was chosen only to use the upper two layers because this agrees with the hydrological situation in the catchment: a fast reacting upper layer and a slow reacting, rather constant base-flow.
- The recession coefficient for the upper layer for the last period is smaller than for both other periods. This is also clear while studying the results of the dependency test. A reason for this is hard to find.
- The recession coefficients for the slow reacting layer are of the same order for all three periods.
- The limit between the two zones is chosen higher for the period 84/85 than it is for the other periods. Though the sensitivity analysis showed an optimum at a low value, the simulation results improved while increasing this value.
- The time base for the transformation function cannot be chosen smaller than one day. While the catchment has a very small time of reaction this time base was set on the lowest possible value.

4.3.2 Discussion.

While looking at the results for each period several remarks can be made.

- The simulation of the period 83/84 (fig.1) resulted in the highest value for the explained variance of all three periods. This even though the volume of computed discharge was nearly 15 per cent over-estimating the observed volume. As mentioned in

section 2.6.2 this period was extremely wet. This could be the cause of this over-estimation.

While looking at the accumulated difference it is clear to see that the strongest increase occurs in December '83 and January '84. During these months the computed discharge reacts too slow: the peaks are too low and the decrease afterward is too slow. This is a consequence of the transformation function (see section 3.2.4): the reaction time is one day. The Hupselse Beek catchment is characterized by a very fast reaction especially in wet circumstances. In these periods the reaction time can be only a couple of hours with high peaks and a fast recession afterwards.

The over-estimation in this winter period is very high because the discharge peaks are occurring in a fast sequence. Between the peaks the computed discharge is decreasing too slow and is not reaching the low value of the base-flow before the next peak starts as it does after the peak in February '84. Therefore the total amount of computed discharge is much bigger than the observed amount in these months.

- The result of the simulation of the period of 84/85 was an explained variance of 0.65 while the computed discharge volume was equal to the observed.

While looking at fig.2 it should be noticed that the peaks are often too low but the recession afterwards resembles the observed very good. Looking at the accumulated difference the main increase is in September '84. Probably the soil moisture storage increased too fast which too early caused an increasing reaction to precipitation.

In the second half of January '85 the accumulated difference decreases strongly because the occurring peaks are hardly simulated at all. These high peaks have been measured in a short period of thaw after a long period of frost. They could be caused by melting of ice or snow accumulated above or close to the outlet.

- The period 85/86 was simulated rather poorly. The explained variance was only 0.49 though the observed and computed volume fit exactly. While looking at fig.3 there are two periods during which the accumulated difference changes very fast: in June '85 and in January '86.

June '85 was a rather wet month after two dry months. The discharge peaks in June are hardly simulated. This could for instance be caused by too high an evaporation rate during the dry months which leads to a low amount of water available for soil moisture supply of discharge. Probably the soil moisture storage is decreasing too fast during these months which leads to a lower discharge when the wet period starts.

In January '86 as well as in December '85 the peaks are simulated too low and the decrease afterwards too slowly. This is the same problem as described while discussing the simulation of 83/84 and is probably caused by the reaction time of the model which is too high for a wet situation in the Hupselse Beek catchment.

While studying the results of application of the optimum parameter set to the entire period some remarks can be made.

- The explained variance is for all three sets nearly the same, circa 0.60. Looking at the results points out rather clear differences in the simulation.

- Using parameter set 1 (see table 4.1) to the entire period leads to an under-estimation of the total volume of discharge of 7 per cent, while the volume of the period 83/84 was over-estimated by 15 per cent.

This could be caused by the value for the maximum capillary rise, CFLCAP. In comparison to the second parameter set, of which application resulted in an over-estimation of 15 per cent of the volume for the entire period, the main difference is the value of CFLCAP. Though in the third parameter set CFLCAP has the same value as in the first set and in that case only leads to a small undervaluation of the volume, the assumption can be made that the correct value lies in between the fixed values of 0.4 and 1.5 mm per day.

Another cause could be the value of the limit between the zones because a higher limit leads to a retarded reaction of the discharge and a smaller amount of discharge. This influence to the over-all volume however is relatively small (1 or 2 per cent) and could not result in the differences in the volumes as found in this simulation.

The value of the recession coefficient of the slowly reacting component is, though in the same order, 50 per cent higher in parameter set 2 than it is in the other sets. This leads to a higher amount of base-flow, but while the limit is higher too the contribution of the fast component will be smaller. For this reason the effect to the total volume will be small.

- While looking at the simulation results it is obvious that all parameter sets lead to an over-estimation of the winter period of '83. This points out the extraordinary character of this very wet and warm winter time.

- All parameter sets lead to a similar under-estimation of especially the high peaks. The recession part of the peaks is sometimes over-estimated, especially while using parameter set 1 and 3 and correct when applying parameter set 2.

- Using parameter sets 1 and 3 leads to a comparable under-estimation of the second period between April '84 and March '85. This could be caused by the difference in the value of the maximum amount of capillary rise between this year and the first and the last period.

- The over-estimation of the winter period of '83 is extremely high while using parameter set 2. While looking at the accumulated difference this over-estimation is the main cause of the error in the over-all volume of discharge. During the rest of the simulation the difference stays on the same level with only little increases and decreases. The amount of capillary rise seems to be sufficient for these last periods. The wet character of 83/84 clearly needs a higher amount of capillary rise to decrease the volume of discharge.

- The former two points support the assumption that the capillary rise should be smaller than the value in parameter set 1 and 3.

5 CONCLUSIONS AND RECOMMENDATIONS.

5.1 Conclusions.

Summarized the following conclusions can be drawn.

- The parameters in the PULSE model show a certain dependency. This crosses attempts to find an optimum set of parameters.
- The results of the manually optimised simulations are relatively good though the values of the optimization criteria are rather low.
- The parameters field capacity and the empirical coefficient BETA as used in the soil routine seem to be characteristic for the catchment area and only little influenced by the meteorological situation of the period simulated. If the meteorological character of a period is extraordinary the limit for potential evaporation could be influenced a lot.
- The value chosen for the maximum amount of capillary rise is influencing the computed volume of discharge to a great extent.
- The influence of the values of the recession coefficients merely consists of an effect to the form of the peaks and only little effect to the total amount of discharge.
- Application of optimum parameter sets to other periods leads to a result comparable to the results of the simulation of the period for which the set was optimised.
- The minimum time base of one day as can be used in the PULSE model is too large for the Hupselse Beek catchment especially in wet periods as often occurring in winter time.

The final conclusion to be drawn from this research is that the PULSE model can be applied in Holland with tolerable results though the model should be adjusted a little to the Dutch situation.

5.2 Recommendations.

Some recommendations can be made to improve the results of the Hupselse Beek simulation:

- Using an optimization routine instead of a manual optimization.
- Choosing another type of transformation function. For instance a different time base or a different form with a fast increase towards the peak and a slow decrease afterwards.
- Check of the course of the evaporation and the soil moisture storage.

Suggestions for further research are:

- Application of the hydrochemistry part of the PULSE model to simulate the chemical composition of the discharge. Especially the measurement series for the Hupselse Beek which are available could be simulated.
- Application of the PULSE model to other catchment areas. Probably areas with a high time of reaction could lead to good results.
- Subbasinwise simulation of an extended and differentiated area.

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Appendix A

The simulation program.

The most important part of the program is JOMAIN. Within this part several files are called. Before the program can be executed all these files need to be available.

The structure of the main program and the relations to the files are represented schematically in section A1. The scheme is refined step-wise in the next sections.

Altogether the files related to the main program can be subdivided in four categories:

Subroutines:

FORTTRAN-files. Each subroutine is linked to the main program and can be called from the main program or another subroutine. A summary in combination with a short description of the function of each subroutine is given in section A2.

Input files:

DATA-files. Each input file is containing data of a different kind: for instance observed hydrological or chemical data and values for parameters used in the model. In section A3 all data-files are summarized and described.

Output files:

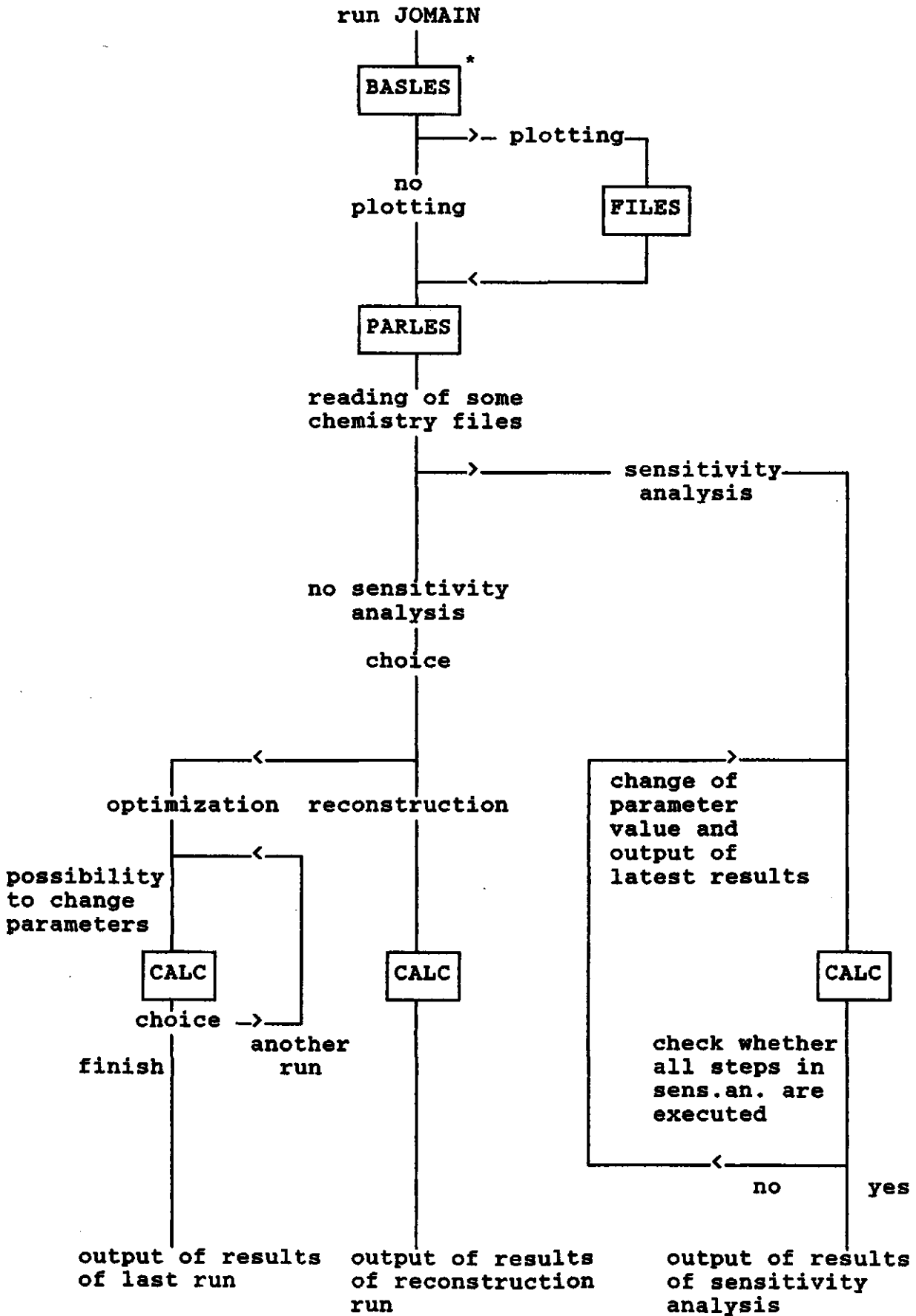
TEMPORARY-files. These files are containing output data, merely used by the plot program (described in appendix B). In section A4 these files are shortly described.

Declaration files:

INCLUDE-files. These files are containing declarations for variables needed in the different subroutines and the main program. A summary of which files are included in each subroutine is given in table 9.

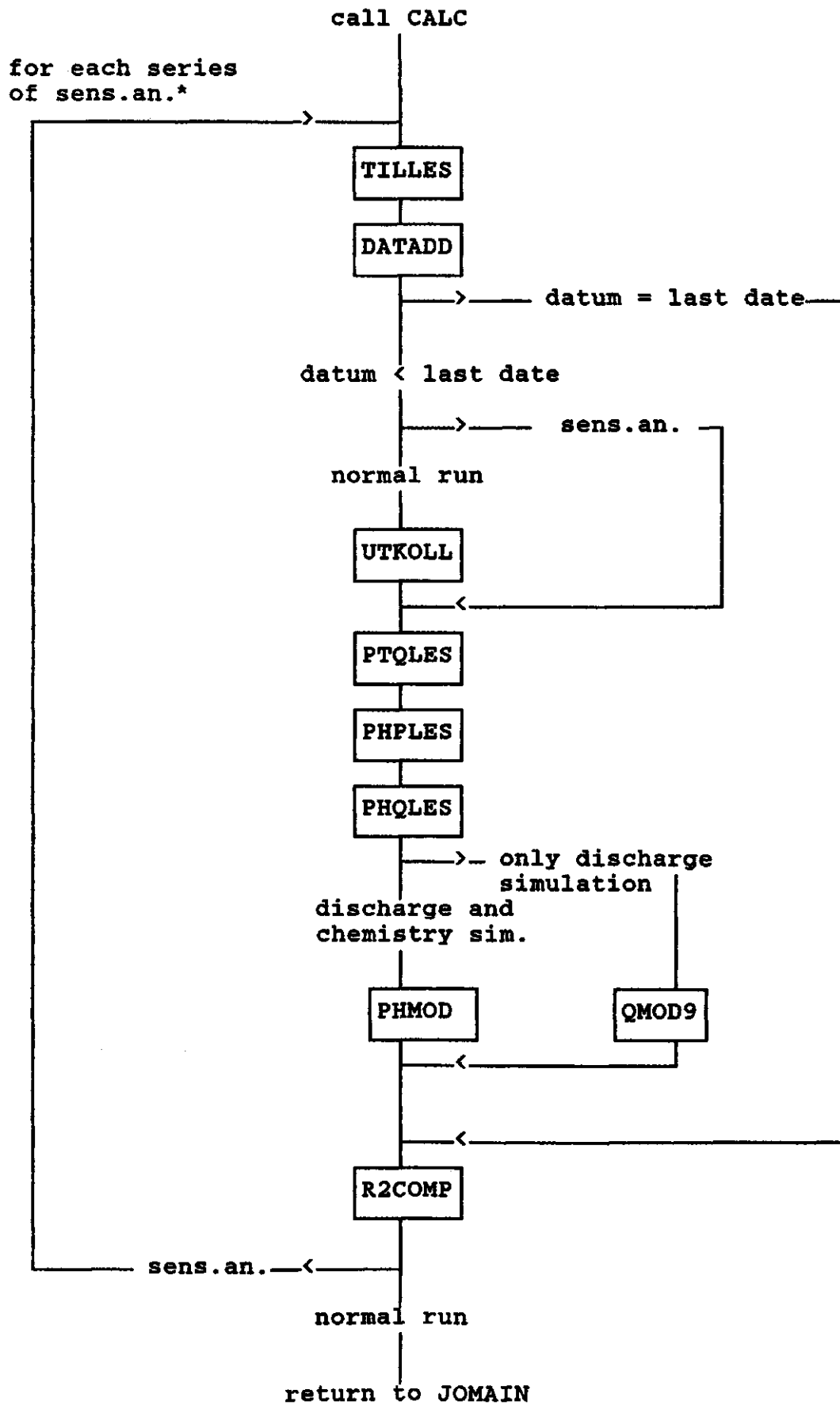
In appendix D a summary of most of the variables used in the model is given.

A1 The main program.



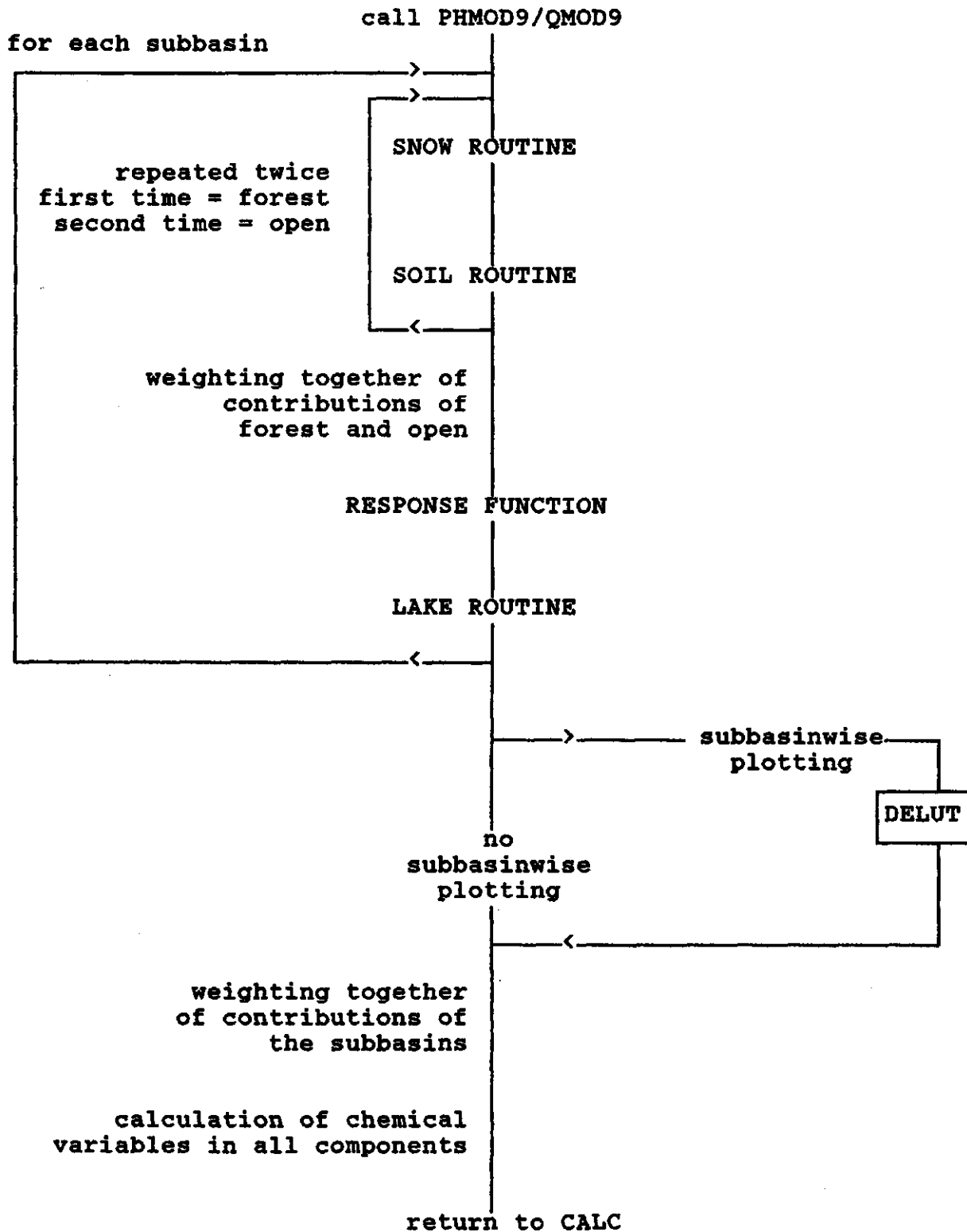
* = subroutine.

A1.1 Subroutine CALC

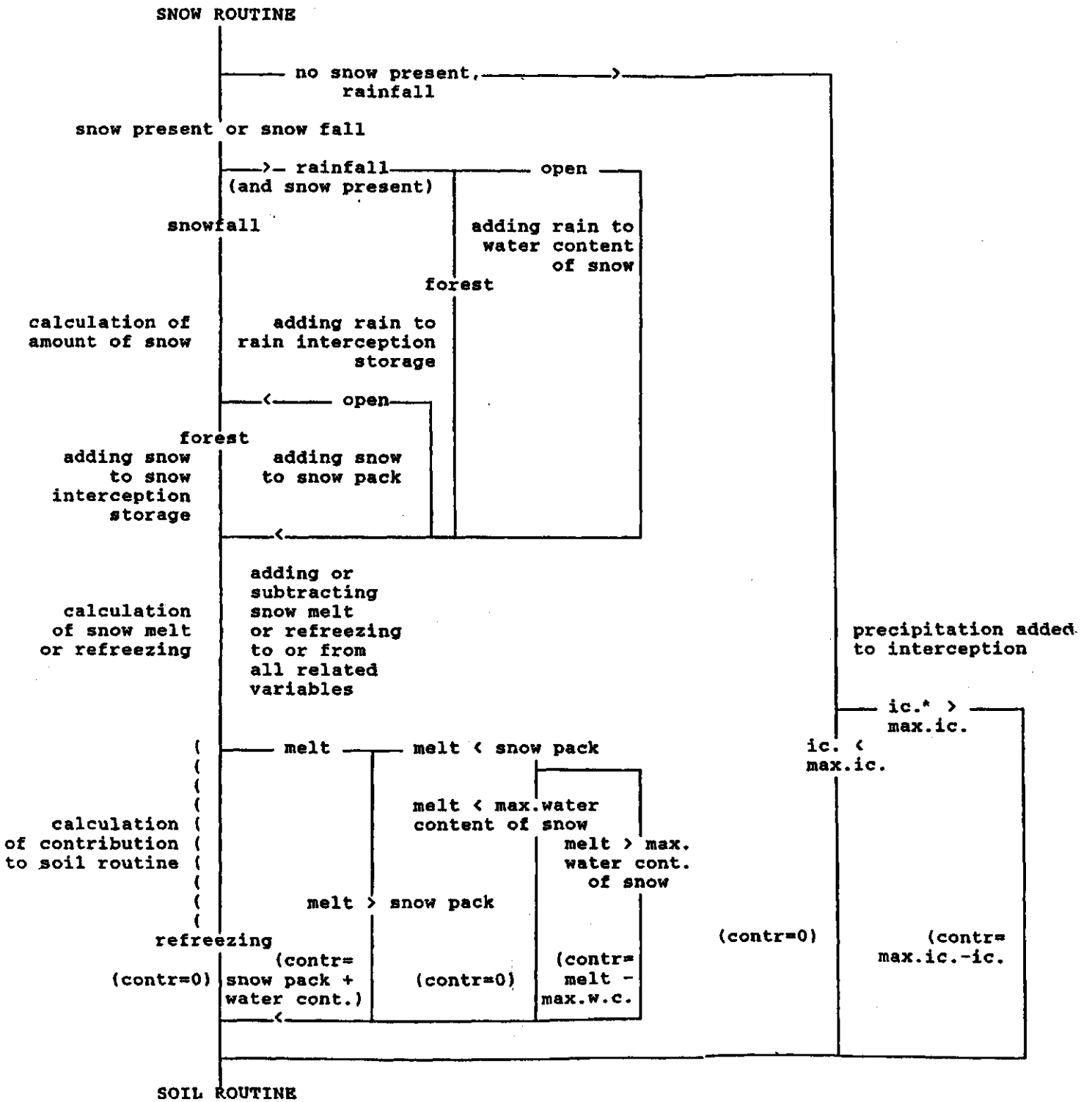


* sens.an. = sensitivity analysis

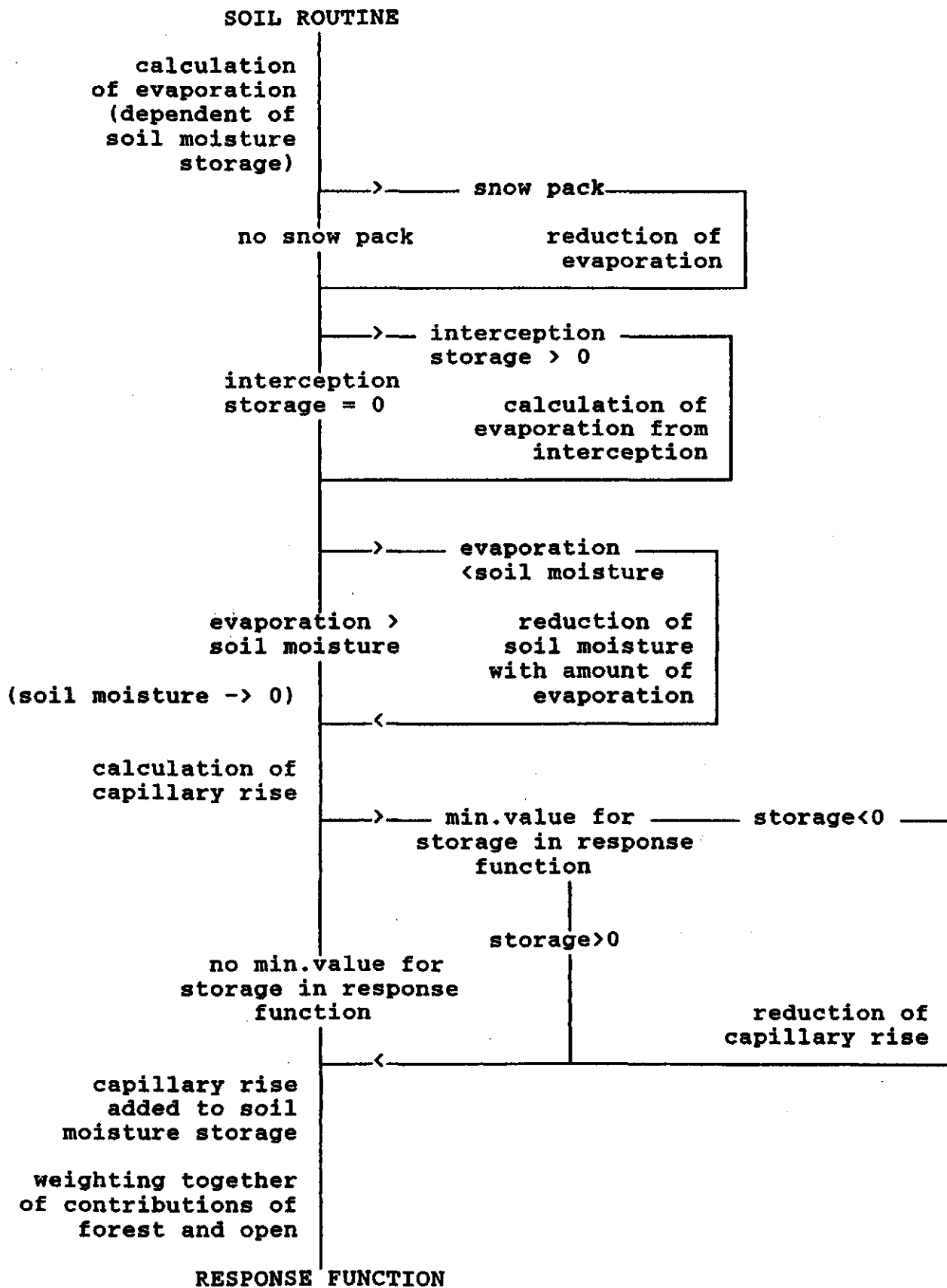
A1.1.1 Subroutine PHMOD9/QMOD9.



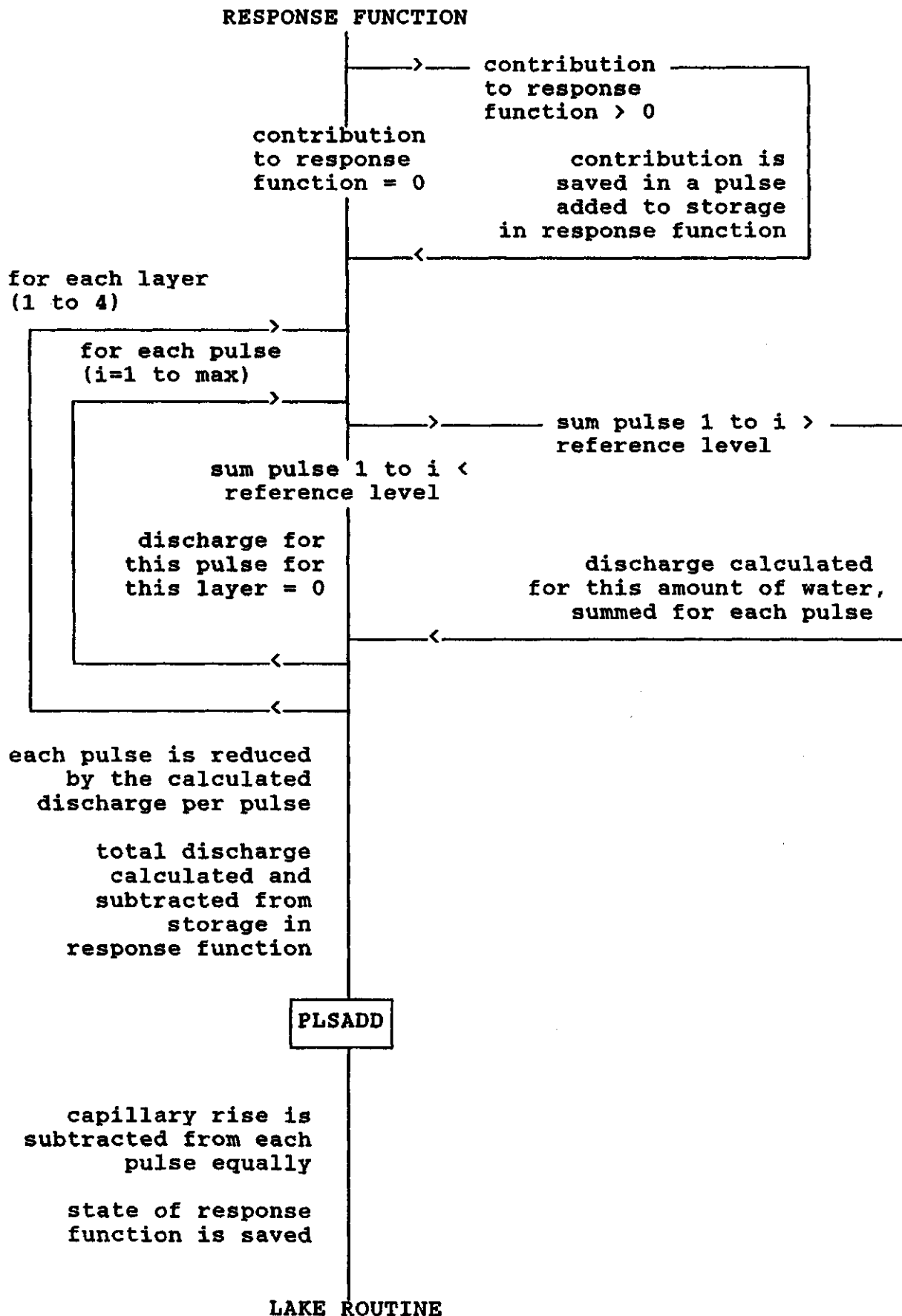
A1.1.1 a The snow routine.



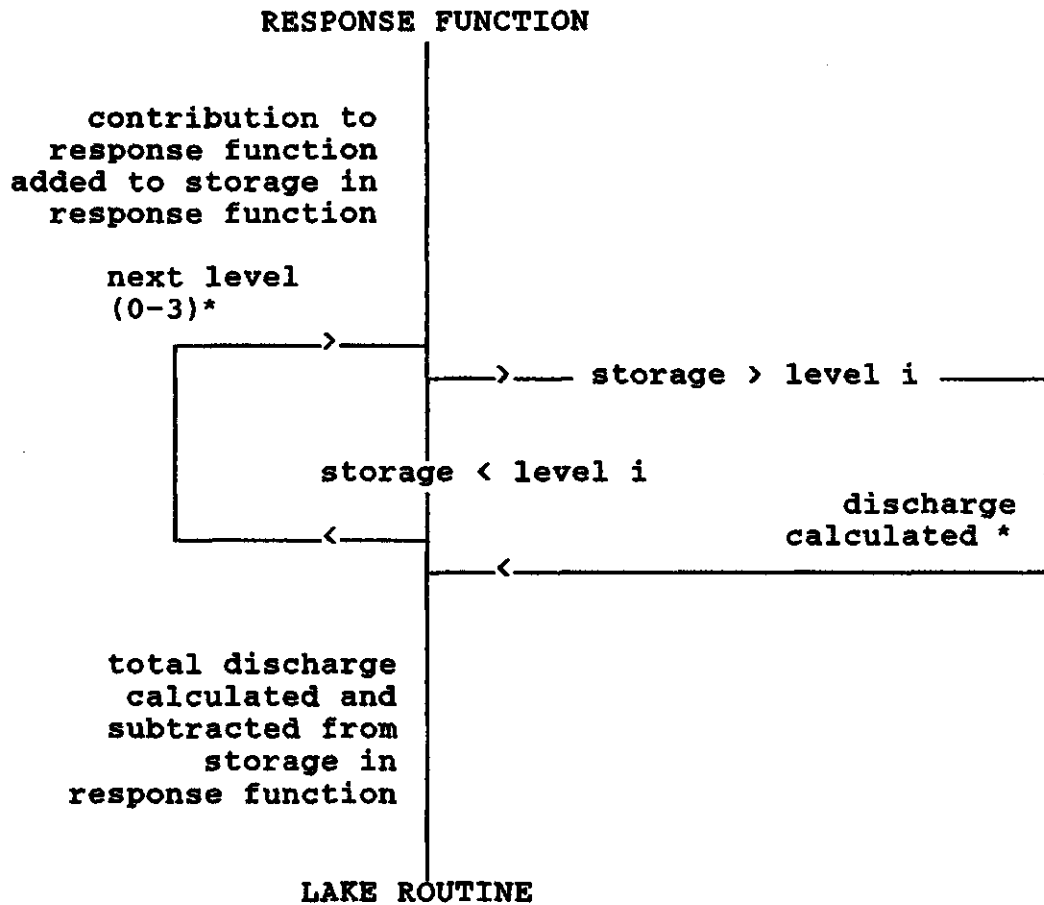
A1.1.1 b The soil routine.



A1.1.1 c1 The response function (PHMOD9).



A1.1.1 c2 The response function (QMOD9).



* see page ix

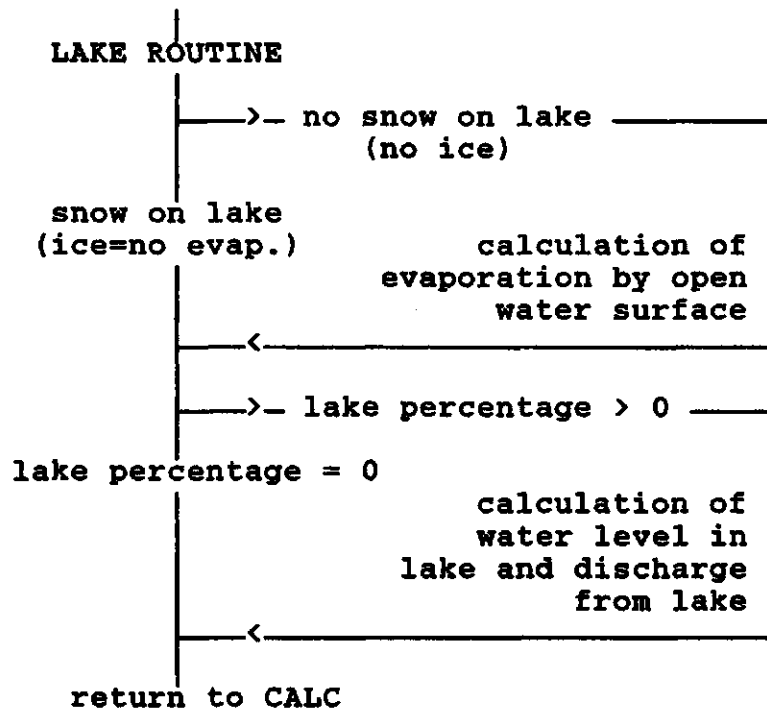
*
 surface _____
 k(0)
 level 0 _____
 k(1)
 level 1 _____
 k(2)
 level 2 _____
 k(3)
 level 3 _____

discharge of layer n: $\sum_{i=0}^n k(i) * (\text{storage in layer}(n))$

Note:

The subroutine QMOD9 is only simulating discharge while PHMOD9 is also simulating chemical variables. The calculation of the discharge is varying only in one way from PHMOD9: in QMOD9 the contribution to the response-function is added to the storage in the contribution function without saving the value of this contribution in a 'pulse' as is done in subroutine PHMOD9.

A1.1.1 d The lake routine.



A2 Summary of subroutines.

In this section a summary of all program elements in FORTRAN is given. All subroutines are described shortly. Some of the subroutines have been represented schematically in the former section.

AVBRYT In case of an occurring error this subroutine is called to stop the program run;

BASLES Subroutine for reading of data from BAS.DAT (see section A3b);

CALC Subroutine (part of main program JOMAIN) for calculation of results (see section A1.1);

DATADD Subroutine for changing the date with a number of days;

DELUT Subroutine for output of calculated data subbasinwise. For each variable a separate file is created (see section A4);

FILES Subroutine used for creating or deleting output files;

JOMAIN The main program (including CALC; see section A1);

NYDAG Subroutine for calculation of the date of the next day;

NYDAT Subroutine for calculation of a date;

PARLES Subroutine for reading data from PAR.DAT (see section A3c);

PHMOD9 Subroutine for simulation of discharge and transport of a chosen chemical variable;

PHPLES Subroutine for reading data of chemical composition of precipitation from KEM85.DAT (see section A3f, not used anymore);

PHQLES Subroutine for reading data of chemical composition of discharge from KEM80.DAT (see section A3f);

PTQLES Subroutine for reading data of precipitation, temperature and discharge from PTQ.DAT (see section A3a);

PLSADD Subroutine for summing of pulses smaller than a certain level;

QMOD9 Subroutine for simulation of only discharge (comparable to PHMOD9);

R2COMP Subroutine for calculation of several optimization criterions;

SOIL Subroutine for calculation of the amount of water available for drainage from the effective precipitation. Also a check of the water balance of the soil;

TILLES Subroutine for reading data from TILL.DAT (see section A3d);

UTKOLL Subroutine for output of monthly values including a monthly check of the water balance.

A3 Input files.

Before running the main program is possible a number of input files should be available. In this section a summary is given to the required input files, in which also the unit numbers of each of these files is given. In the next sections a short description of most of these files is given.

Table A1 Input files.

File name	Unit	Contents	Section
PTQ.DAT	14	measured input data	A3a
BAS.DAT	19	data for simulation	A3b
PAR.DAT	12	parameter values for model	A3c
TILL.DAT	17	initial state	A3d
UD.DAT	26	if necessary values for updating the measured data	A3e
KEM85.DAT	23	chemical data for precipitation, daily measured	A3f
KEM80.DAT	24	chemical data for discharge, daily measured	A3f
**MISU.DAT	30+	monthly mean values for concentration in precipitation	A3g

All input files have a special format. In order to prevent problems while running the program it is important not to change the form of the files unless the program itself has been changed.

A3a PTQ.DAT.

In the PTQ-files the daily measured data are stated for P (precipitation), T (temperature) and Q (discharge) as well as the date. The possibility of using more than one measuring station is implied in this file by a variable stating the number of stations. Furthermore a station number of the discharge station is required.

The order of the data in the file and an example of data are given in table 1.

All data must be integer values. To accomplish this both precipitation and temperature data are multiplied by a factor 10. The discharge is stated in mm per day multiplied by 1000.

In case of missing values these should be stated as '-9999'. These values are neglected in the program.

A3b BAS.DAT.

This file is containing the basic information for the program run. The file can be divided into four parts. The first part is concerning how the model should be run, the next part is concerning the sensitivity analysis and the third part is stating how the output and plots should be arranged. The last part whether some of the parameters as stated in the PAR-

file (see section A3c) should be changed during the simulation period.

The first part is containing information about the simulation, for instance which period, which kind of simulation should be made, whether a sensitivity analysis or plots should be made.

The second part of the BAS-file is containing information about sensitivity analysis. If in the first part is stated that sensitivity analysis should be executed this second part is used, otherwise these lines are neglected by the program.

For each parameter mentioned in this part a start value, a step size, the number of steps, the number of subbasins and for which of the subbasins the analysis should be executed is required.

The third part is a matrix containing information about output and plotting. Each line is containing this information for a hydrological or chemical variable. In BASFIL.INC (see section A5) default-values are stated. Only if different values are needed this should be stated here.

The last part is optional. If in the first part is stated that no parameter change should occur the program will neglect this part.

For each parameter change a date, a parameter name, the new value and the subbasin numbers for which the change should be executed are required. Only the changes within the simulation period are used.

In table 2a an example of a BAS-file is given. The variables used in the first and the third part are summarized and described in table 2b.

A3c PAR.DAT.

In this file values for several parameters are stated. If chosen, parameter values can be stated for several subbasins. If more columns are stated than there are subbasins the remaining columns are not read.

In table 3a an example of a PAR-file is given. While this file is important for optimization of the model simulation the parameters are also described separately in table 3b. The list of parameters is in the same order as the file.

A3d TILL.DAT.

This input file is containing several initial states for different start dates. The subroutine TILLES (see section A2) is repeating reading initial states until the start date matches the date of the state that was read. If this date is not available the program run will be interrupted and a message will be written to the screen that the initial state is missing.

In table 4 a complete example of an initial state is given.

The first two lines of each state should not be changed except for the date and the name of the catchment (maximum 12 characters).

In table 4 the variables are stated for seven subbasins. In case of less subbasins than stated only the first few columns are used.

The variables mentioned are described in the variable list (appendix D).

A3e UD.DAT.

This file is only needed in case the measured data should be updated. This is stated in BAS.DAT (see section A3b).

The format of this file is stated in table 5.

A3f KEM80.DAT and KEM85.DAT.

In these files chemical data are stated. In KEM80 the composition of the discharge is stated, in KEM85 of precipitation. Each line is containing results of sampling on one day. If a value is missing of a chemical parameter within a sample, this value should be stated as '-9999'. If the sampling did not take place each day the days without sampling should not be stated at all. As in the PTQ-file all values should be integer values.

In table 6 an example of some data of KEM80.DAT is given. KEM85.DAT should have the same composition.

A3g **MISU.DAT.

These files, for instance ALKMISU.DAT or PHMISU.DAT, are containing monthly mean value for the concentration of a chemical variable in precipitation (ALKMISU=alkalinity, PHMISU=PH) for several years.

In table 7 an example of PHMISU is given. The other **MISU-files should have the same composition.

A4 Output files.

Most of the output files are temporary files. If necessary they can be saved by changing this in subroutine FILES (see section A2). The output files are mainly used for the plot program.

If choice was made to plot the results (in BAS.DAT, see section A3b) a special output file is created: PULS_52.TMP. If this file is missing the plot program cannot be used.

The remaining output files can be subdivided into three kinds containing:

- daily results for the whole catchment;
- monthly mean values of the results for the whole catchment;
- results per subbasin for one variable.

Each kind can be subdivided further into hydrological or chemical results.

In table A2 a scheme is given for the unit numbers of the files, which are also used in the name of the files (PULS_*.TMP).

Table A2 Unit numbers of the output files.

	Daily	Monthly	Subbasinwise
Hydrological	53	55	60 + 1/20
Chemical	54	56	90 + 1/16

In table 8 the order of two series of input/output variables is given. Each line of the output files with daily or monthly output for the whole catchment is stating the variables in order of table 8. The subbasinwise output files are each containing the results for one of these variables (unit 61=precipitation, unit 69=amount of melt water, unit 91=pH in precipitation, unit 102=generated pH in discharge, etc.)

The program is also creating some output files that are not temporary files. Depending of the choice of sensitivity analysis or not files can be created. If yes a file RESSENS.DAT will be created containing all results of the analysis. If not a file RES.DAT will be created containing lines with the values of some of the parameters from the PAR-file and some results. The number of lines depends on the number of optimization runs (see section C1).

A5 Declaration files.

When the program elements are compiled some of these declaration files are included in some of them. Most of the files are containing declarations of variables. In table 9 an overview of which files are included in the subroutines, the main program and the plot program is given.

One of the declaration files has a different content: VLISTA.INC is containing a variable list in which most of the variables are described. This list is given in appendix D.

Appendix B

The plot program.

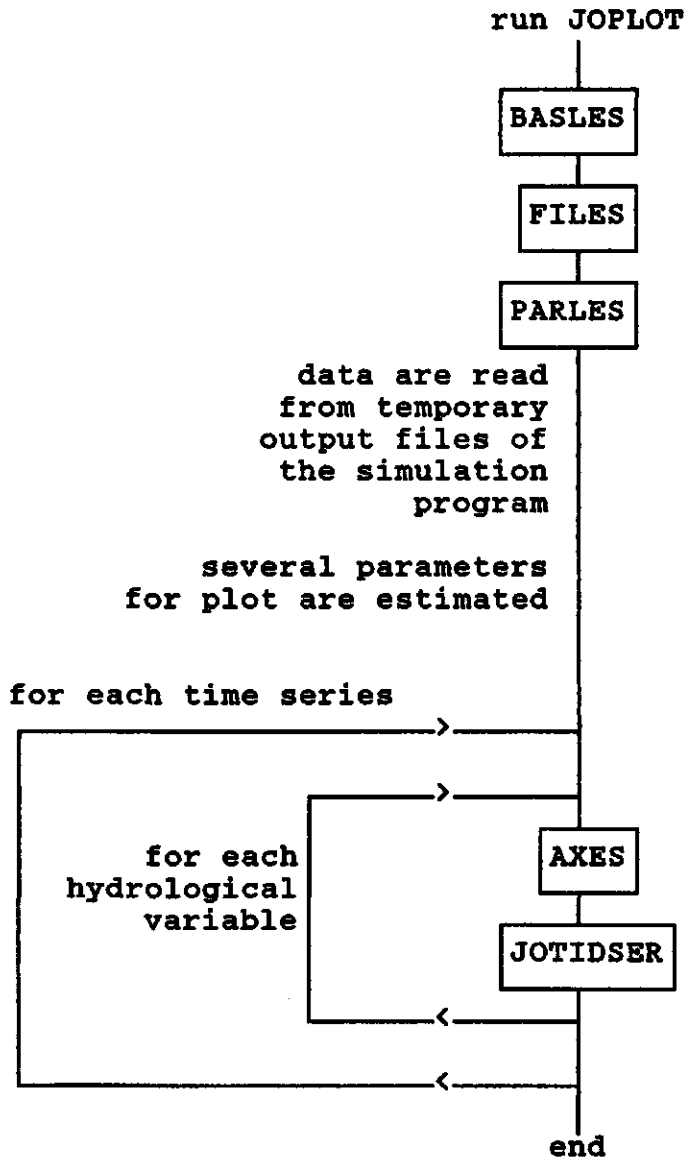
The main part of the plot program is formed by JOPLLOT. In section B1 the program structure is represented schematically.

A number of subroutines is needed in this program, some of them are also used in the simulation program. For the plot program two special subroutines are needed. These are described in section B2.

In section B3 the input files are summarized. In section B4 the output of the program is described. The declaration files are described in section B5.

Most of the variables used in the plot program are described in the variable list (appendix D).

B1 The main part of the plot program.



B2 Summary of the subroutines.

Because part of the subroutines used by the plot program are also used in the simulation program, these are not described here. For a description of these is referred to section A2.

AXES Subroutine for writing a title to the plot, plotting and scaling of the axes and writing the unit of the Y-variable;
BASLES See section A2;
FILES See section A2;
JOTIDSER Subroutine for plotting of the time series;
NYDAG See section A2;
PARLES See section A2.

B3 Input files.

The input files for the plotting program are partly the same as used by the simulation program and partly formed by output files created by the simulation program.

In table B1 the input files are summarized and referred to the section in appendix A in which these files are described.

Table B1 Summary of input files for plot program.

File name	Section
BAS.DAT	A3b
PAR.DAT	A3c
PULS_**.TMP	A4

B4 Output.

The plot program has two possibilities for output: output can be sent to the screen of the Computerterminal.

If 'screen' is chosen the program will plot the first page of the plot on the screen. After erasing the graph this plot can only be re-obtained by re-running the program.

If 'Computerterminal' is chosen result files called DATA.PLT and UNIPRNT.DAT will be created. These files can be used to make a plot on the plotter at the Computerterminal. How this can be done is described in appendix C.

Also a file PAR.LAS is created in which the changed parameters in comparison with the former model-run are saved.

B5 Declaration files.

In the plot program only one declaration file is different from the declaration files used by the simulation program: PLOT.INC. Furthermore the same files are used. In table 9 also an overview is given for the plot program.

Appendix C

How to run the programs.

In this appendix the most important information is given about how to run the program. In section C1 running the simulation program is explained, in section C2 running the plot program. In section C3 suggestions are made how to change some things in the program.

C1 Running the simulation program.

Before the model can be run all program elements should be compiled and linked to the main program. Therefore two COMMAND-files are created as described in table 10 (CMAIN.COM and LMAIN.COM).

To run the model another COMMAND-file is needed (START.COM, table 10) in which the input files are given a default name and the model run is started. As soon as these default files have been created the command 'RUN JOMAIN' will be sufficient.

If sensitivity analysis is chosen the model will run without any questions to the user. The results are written both to the screen and to the result file RESSENS.DAT (see section A4).

If no sensitivity analysis is chosen some choices have to be made during the model run. The first question is whether to make a reconstruction run or more runs with a possibility to change parameters values.

If reconstruction is chosen the program will be run through once and end after this run.

If more runs are chosen the user has to choose a subbasin for which parameter should be changed. The program will be run through each time the user chooses to go on. Every time the program is re-run the user can choose new values for a number of parameters. The results of all changes are saved in the result file RES.DAT (see section A4).

C2 Running the plot program.

As well as for the simulation program all program elements should be compiled and linked together before a program run can be made. In table 10 the required COMMAND-files are given (CPLOT.COM and LPLOT.COM).

Before the program can be run the following command should be given:

```
$ USE UNIRAS,SILENT
```

When the plot program is run choice can be made between 'screen'(device LT4107) or 'Computechnion'(device PC1039). If the program is used on a different system as is available at the Agricultural University of Wageningen, Holland, one should be aware that the device needed can be different from the one used in the program. This can easily be changed by changing the device in JOPLLOT.

If 'screen' is chosen the program will plot the first page of the plot on the screen. After erasing the graph this plot

can only be re-obtained by re-running the program.

If 'CompuTechnion' is chosen result files called DATA.PLT and UNIPRNT.DAT (see section B4) will be created. These files can be used to make a plot on the plotter at the CompuTechnion. The commands needed are:

```
$ USE PLOT,SILENT (only once)
$ PLOT DATA.PLT
```

To check whether the plot is made one can use:

```
$ SHOW QUEUE SYSSPLOT
```

If the username is in this queue the plot will be made. If not an error was detected by the program. In file UNIPRNT.DAT this error can be found.

C3 How to change the programs.

In this section tips are given if a change in the program is required.

* Changes in the program or in the subroutine (without changing variable names or length of arrays):

- 1 Compile the changed file;
- 2 Link all program elements (use @LMAIN or @LPLOT, see table 10);

* Change the device in the plot program:

- 1 Change JOPLLOT.FOR:
 - Change the device in 'CALL GROUTE(select *****;exit)';
- 2 Compile JOPLLOT.FOR;
- 3 Link the program;

* Changes in data files:

- 1 Change the file and run the program;

* Changes in BAS.DAT:

- 1 Change BAS.INC:
 - If necessary change IBAS (=number of elements in BAS-vector);
 - Declare the new variable as 'integer';
 - Put the new variable in the right place in common block '/basdat/';
- 2 Change BASFIL.INC:
 - Put the text for the new variable in the right

- place in the BASTXT-vector;
 - Put the name of the new variable in BASNAM;
 - Define the limits for the allowed values in BASMIN and BASMAX;
 - Note that introducing or removing a BAS-variable leads to a new order in the remaining BAS-data;
- 3 Compile all program elements that include BAS.INC or BASFIL.INC;
 - 4 Link the program;
 - 5 Put the value of the new variable in BAS.DAT. Be sure this is conform the formerly mentioned points!

* Changes in PAR.DAT:

- 1 If necessary change BAS.INC:
 - If necessary change IPAR (=number of elements in PAR-matrix);
- 2 Change PAR.INC:
 - Declare the new variable as 'real';
 - Put the new variable in the right place in common block '/pardat/';
- 3 Change PARFIL.INC:
 - Change in vector PARAVD (this is the number of parameters in each part of PAR.DAT);
 - Put the name of the new parameter on the right place in PARTXT;
 - Define the limits of the allowed values in PARMIN and PARMAX;
 - Change if necessary the numbers of FC (IFCNR) and MAXBAS (IMBNR) conform the new order;
 - Note that introducing or removing a parameter leads to a new order of the remaining parameters;
- 4 Compile the whole program;
- 5 Link the program;
- 6 Change PAR.DAT conform the formerly mentioned points.

* Change of the number of variables or the order of the output list:

- 1 Change BAS.INC:
 - Put MAXHYD or MAXKEM (maximum number of hydrological or chemical variables) to the desired value;
- 2 Change IODATA.INC:
 - Rewrite the variable list into the new form (which means change the common block '/hyddat/' or '/kemdat/');

- 3 Change IOLIM.INC:
 - Define the limits which shall be assumed to be valid for allowed values;
- 4 Change BASFIL.INC:
 - Define data-lines for the vectors HYD*** and KEM***; be sure to put them in the right place;
- 5 Compile the program;
- 6 Link the program.

Appendix D

Variable list.

AAR1KE	first year in KEMSUI-vector	
AAR1PH	first year in PHMSUI-vector	
ACCDIF	fault in volume between calculated and observed discharge	(mm)
ADSENS	value of ACCDIFF for a series in sensitivity-analysis	
AEQCLZ	alkalinity in CLZ	
AEQCOM	calculated alkalinity in discharge	
AEQCOR	correction of calculated alkalinity	
AEQGEN	alkalinity in groundwaterflow	
AEQLAA	alkalinity in lake, active part	
AEQLAP	alkalinity in lake, passive part	
AEQLZ	starting value for PH in response function (N.B. has no importance if ALK is a function of LZ)	
AEQOBS	observed alkalinity in discharge	
AEQP	observed alkalinity in precipitation	
AEQS	alkalinity in response function pulse, remnant from residence time calculation	
AINLAK	alkalinity contents in lake from rain and snow	
ALAKEA	amount of alkalinity in lake, active part	
ALAKEP	amount of alkalinity in lake, passive part	
ALKDAT	alkalinity, 100*mg/l, input from KEMxxxx	
ALKMIN	the lowest permitted alkalinity in the response function	
ANTDT	number of days with correct values for both observed and calculated values	
ANTOMR	number of subbasins, stated in BAS-file	
ANTUD	number of updatings in the run-period	
AQBAS	amount of alkalinity in transformation function	
AQCOM	amount of alkalinity in calculated discharge	
AQGEN	amount of alkalinity in discharge from response function	
AQLAKE	amount of alkalinity in discharge from lake	
AQLDEL	amount of alkalinity in discharge from lake part per day	
AREA	area of one subbasin	(km ²)
AREAFO	summed forest area of all subbasins	(km ²)
AREASM	summed area without lakes in all subbasins	(km ²)
AREATO	area total for all subbasins	(km ²)
AVROMR	name of discharge area, stated in BAS-file	
BASDAG	used to weighing MAXBAS of discharge	
BASDAT	vector to be read in from BAS-file	
BASMAX	vector which is containing the highest approved values of all BAS-variables	
BASMIN	vector which is containing the lowest approved values of all BAS-variables	
BASTXT	vector which is containing the names of all BAS-variables	
BDAT	starting date of simulation, stated in BAS-file	
BETA	soil moisture routine parameter	(1)
BLAKE	Characterization of the form of the lake (0=superlobate, 100=round)	(1)
BYTDAT	states dates for changes of parameters	
BYTNR	number of parameters that will be changed, according to BYTTXT	

BYTOMR states for which subbasins parameters must be changed (0 = no change, 1 = change)
 BYTSKR states if parameter changes must be written out during simulation
 BYTTXT vector which is containing the names of the parameters whose values have to be changed

 CADATA calcium, 100*mg/l, input from KEMxxxx
 CAEQPH parameter in pH/alkalinity equation
 CFLCAP maximum capacity for capillary rise (mm/d)
 CFLUX calculated capillary rise (mm/d)
 CFR refreezing factor, part of the degree-day factor (1)
 CLAKE monthly values for the exchange coefficient in lakes (%)
 CLDATA chloride, 100*mg/l, input from KEMxxxx
 CLZ contribution of soil routine to response function (mm/d)
 CMELT degree-day factor (mm/C*d)
 CONDDA conductivity, ms/m, input from KEMxxxx
 CPHMLT states degree of washing-out of hydrogen-ions from snow
 CPHSM states how fast PHEQSM can be approached
 CSF correctioning factor for snow precipitation
 CWH watercontaining capacity of snow, part of snow storage (1)

 DAGANT calculator of the days included in the calculation period
 DAGDEL is used to weigh discharge
 DATUM date of the day
 DAY daynumber in month
 DELOMR current subbasin
 DIFF31 difference in condition variables for a whole month

 E monthly values for potential evaporation (mm/d)
 ELAKE exponent of discharge curve of the lakes (1)
 EMNE material to be simulated (integer value, stated in BAS-file)
 1 => conductivity
 2 => alkalinity (and pH)
 3 => sulfate
 4 => chloride
 5 => nitrate
 6 => calcium
 7 => magnesium
 8 => kalium
 9 => natrium
 that means the same order as in the KEM-files(80 and 85)
 The programm is calculating constantly with alkalinity, irrespective of which material is mentioned in the BAS-file.
 The only difference between the different materials is that the simulated concentration is compared to the measured concentration of the choosen material.
 If EMNE has a minus-sign in the BAS-file then the measured concentration is recalculated into meq/l
 (ex: EMNE = -6 => Ca²⁺ in meq/l)

 ENDPHP end of file sign of the PHP-file
 ENDPHQ end of file sign of the PHQ-file
 ENDUD end of file sign of the updating file
 ENHET unity of output and plotting
 EVP calculated current evaporation (mm/d)
 EVPLAK evaporation from lake (mm/d)
 F02 variance of the observed series
 F2 sum of the square residuals

F2SENS keeps F2 in case of sensitivity analysis
FACT reduction factor (%) for plotting (100 = normal) (%)
F field capacity (mm)
FCBYT keeps a check in case FC has ~~changed~~ (=) res (> 0)
FILDAT reads a date from the PTQ-file
FOREST forested part of subbasin (1)
FORM1 string that is used as format-set on days with rain
FORM2 " " " " " " " " without rain

HI hydrogen ion-content in interception rain/melted snow
HICSP hydrogen ion-content in snow interception
HINLZ hydrogen ion-content in contribution to LZ
HINSM hydrogen ion-content in contribution to soil moisture routine
HP hydrogen ion-content in rain
HRAIN hydrogen ion-content in the amount of rain bigger than WC
HSP hydrogen ion-content in snowstorage
HUVUD contents info about the criterion, version mm is written on plot
HYDCHK vector with info whether a certain variable per subbasin can be plotted (j or n)
HYDDAT very central vector containing all 'hydrological' variables available for output or plotting.
 N.B.1: in subroutine DELUT HYDDAT is only valid for the actual subbasin, otherwise it is the weighed mean for the whole basin.
 N.B.2: HYDDAT(1) = P, HYDDAT(2) = T, and so on.
HYDDEC vector with info about the number of decimals in the output (read from BAS.DAT)
HYDDEL vector with info whether a certain variable should be plotted subbasin-wise (read from BAS.DAT)
HYDENH vector with unities of all 'hydrological' variables.
HYDLNG vector with info about how long the Y-ax should be while plotting (read from BAS.DAT)
HYDMAX vector with info about the highest value of the Y-ax while plotting (read from BAS.DAT)
HYDMIN vector with info about the lowest value of the Y-ax while plotting (read from BAS.DAT)
HYDPEN vector with info about the thickness of the pen while plotting (read from BAS.DAT)
HYDPLT vector with info whether the variable should be plotted or not (read from BAS.DAT)
HYDPRT vector with info whether the variable should be written or not (read from BAS.DAT)
 P and T are always put out.
HYDTSK vector with info whether a time-scale should be plotted or not (read from BAS.DAT)
HYDTXT vector with the names of the variables
HYDTYP vector with info about which type of plot should be made (read from BAS.DAT)
HYDYAX vector with info whether the text should be plotted to the left of to the right of the scale (read from BAS.DAT)
HYDYOR vector with info about Y-origo (read from BAS.DAT)
HYPS altitude for subbasin
I common counter
IANT number of days for plotting

IBAS maximum number of BAS-variables, set as
a parameter in BAS.INC
I storage of interception (rain/melted snow) (mm)
ICMAX maximum interception storage (mm)
ICMELT calculated melting from the snow interception storage (mm/d)
ICSP snow interception storage (mm)
IDAYM number of days in each month (in the plot)
IN31 summed wateramount in the model when the next month
starts (mm)
INFORM states format of the PTQ-file, 0 = free, 1 = machine
INLAKE contribution of rain/melted snow to lake (mm/d)
INSOIL contribution of rain/melted snow to the soil routine (mm/d)
INUNIT file to read in the subroutine PARLES
IPAR maximum number of lines in PAR-vector,
set as a parameter in BAS.INC
IPLNR serial number of the plotting, standing in PAR-file
ISANT number of series, used in the plotting program
ITT help variable for formats
ITF1,2 help variables
IUTANT holds a check of how many variables should be written out

J common counter

K(1) recession coefficient; stating k0 in PAR-file (1/1000*d)
K(2) recession coefficient; stating k1 in PAR-file (1/1000*d)
K(3) recession coefficient; stating k2 in PAR-file (1/1000*d)
K(4) recession coefficient; stating k3 in PAR-file (1/1000*d)
KALK lowest value of alkalinity as a consequence of 'chalking'
KDATA kalium, 100*mg/l, input from KEMxxxx
KEMCHK vector with info whether a certain variable can be
plotted subbasin-wise (j or n)
KEMDAT very central vector containing all 'CHEMICAL' variables
available for output or plotting.
N.B.1: in subroutine DELUT KEMDAT is only valid for the
actual subbasin, otherwise it is the weighed mean for the
whole basin.
N.B.2: KEMDAT(1) = PHP, KEMDAT(2) = PHSP, and so on.
KEMDEC vector with info about the number of decimals in the output
(read from BAS.DAT)
KEMDEL vector with info if a certain variable should be
plotted subbasin-wise (read from BAS.DAT)
KEMENH vector with unities of all 'chemical' variables.
KEMISU monthly values for chemical values of the precipitation
read from separate files
KEMLNG vector with info about how long the Y-ax should be while
plotting (read from BAS.DAT)
KEMMAX vector with info about the highest value on the Y-ax while
plotting (read from BAS.DAT)
KEMMIN vector with info about the lowest value on the Y-ax while
plotting (read from BAS.DAT)
KEMPEN vector with info about the thickness of the pen while
plotting (read from BAS.DAT)
KEMPLT vector with info whether the variable should be plotted
(read from BAS.DAT)
KEMPRT vector with info whether the variable should be written
(read from BAS.DAT)
KEMTSK vector with info whether a time-scale should be plotted
(read from BAS.DAT)

KEMTXT matrix with the names of variables depending of the choice of material
KEMTYP vector with info about the type of plotting that should be made (read from BAS.DAT)
KEMYAX vector with info whether the text should be plotted to the left or to the right of the scale (read from BAS.DAT)
KEMYOR vector with info about Y-origo (read from BAS.DAT)
KLAKE recession coefficient of the lake (1/d)
KNAMN various names of variables, corresponding to the choice of material
KOLLM2 calculator of maximum number of pulses in response function

L common counter
LENGTH length of Y-ax while plotting (cm)
LAKE percentage lake in every subbasin (%)
LAST31 keeping condition variables of the last day of the former month
LEDIG* empty place in BAS-file
LISTA string which is used for the plotting of the PAR-file
LPTOFC lower limit for the soil moisture content if evaporation is potential (1)
LZ storage in response function (mm)
LZL() threshold level in response function (mm)
LZLSUM actual LZL-level for which calculation is made (mm)
LZMIN lower limit of LZ, CFLUX is taking off linearly between LZ = 0 (CFLUX = CFLUX) and LZ = LZMIN (CFLUX = 0) (mm)
This function is disconnected if LZMIN is chosen < -9999.
(N.B. LZMIN = 0 is allowed)
LZMAX level in response function above which alkalinity is not increasing (mm)

MAIN steering degree checkings in BASLES and PARLES (means in principal to call the subroutines from the main program or not)
MAX Number of pulses in the response function
MAXBAS distribution of discharge in time
MAXBYT maximum number of parameter changes, set as a parameter in BAS.INC
MAXDAG maximum number of days in the simulation, set as a parameter in BAS.INC
MAXDEL maximum number of subbasins, set as a parameter in BAS.INC
MAXHYD number of 'hydrological' variables that can be used for output and plotting, set as a parameter in BAS.INC
MAXKEM number of 'chemical' variables that can be used for output and plotting, set as a parameter in BAS.INC
MAXPLS maximum number of pulses in response function, set as a parameter in BAS.INC
MAXPST maximum number of precipitation stations, set as a parameter in BAS.INC
MAXQST maximum number of discharge stations, set as a parameter in BAS.INC
MAXTST maximum number of temperature stations, set as a parameter in BAS.INC
MEAN31 mean value for the condition and variables in one month
MELT melted snow (mm/d)
MGDATA magnesium, 100*mg/l, input from KEMxxxx

MODVAL choice of subroutine, stated in BAS-file
MONTH month number

NADATA natrium,100*mg/l, input from KEMxxxx
NO3DAT nitrate,100*mg/l, input from KEMxxxx

OPEN contribution of bare soil in every subbasin (%)
OUT31 sum of water amount in model at the end of the month (mm)

P corrected precipitation (mm/d)
PALT altitude of precipitation station (m)
PANT number of precipitation stations in PTQ-file
PAR vector with parameters for the subbasin that is being calculated

PARAVD number of parameters in the resp. part of the PAR-file
PARAST matrix filled with '*' for every change of parameters after the last plotting

PARBYT number of changes of parameters, stated in BAS-file
PARMAX vector with the highest allowed value for every par.
PARMIN vector with the lowest allowed value for every par.
PARNEW help variable for the reading of the input
PARNOW = PARTOT for the actual plotting
PAROLD = PARTOT for the former plotting
PARORI = PARTOT for reading in from PAR-file before eventual change of parameters

PARTOT matrix with all parameters of all subbasins
PARTXT vector with names of parameters
PCALT height dependency of precipitation (%/100 m)
PCO2 factor that states (actual co2-press.)/(co2-press. at 1 atm)

PCORR correction of measured precipitation
PFEJK updating of P (mm/d)
PHDATA pH,*100, input from KEMxxxx
PHEQSM equilibrium pH-value for soil routine
PHINSM pH-value of INSOIL
PHMISU monthly values of pH of prec., separate file
PHP pH-value of precipitation
PHPTID states validity in time for PHP-measurements (0= daily value, 1 = summed after the last measurement, 2 = only monthly values available) if PHPTID is 0 or 1 and values are missing then monthly values are used

PHQCOM calculated pH-value in discharge
PHQGEN calculated pH in discharge from response function
PHQOBS observed pH of discharge
PHSP pH-value in snow storage
PIN reads precipitation value from PTQ-file (10*mm/d)
PLAKE threshold value for passive zone in lake (mm) calculations (input)

PLDEL matrix with values for subbasin-wise plotting
PLOBS as PLDEL but corresponding to observed values (N.B. To this FN is not used)

PLRES vector with values for plotting
 N.B. dimension of MAX consists of MAXHYD and MAXKEM

PRAIN precipitation weighed and corrected for height but not for snow (mm/d)

PRINT decides the range of the output, stated in BAS-file
PSTAT weighing of precipitation station

PULS ordinal for the pulses in the response function
QANT number of discharge stations
QBAS contribution of discharge in time
QCOM calculated discharge (m3/s, l/s, mm/d)
QGEN discharge generated of the response function (mm/d)
QIN reads Q from the PTQ-file (100*l/s)
QLDEL discharge of the lake divided into WSTEG steps
QMAX31 amount of water in the transformation function
at the end of the month
QOBS observed discharge (m3/s, l/s, mm/d)
QOPL0T states whether QOBS should be plotted
(special treating of missing values)
QRIKTN vector describing the way the water moves between the
subbasins
QSORT unity of discharge (m3/s=1, l/s=2, mm/d=3)
QSTAT number of the Q-station in the PTQ-file
QSTN discharge station, stated in BAS-file
QTXT unity for Q
QVIKT weighing of contribution of discharge in time

R2() R2-value 1=q, 2=pH, 3=alk, 4=transport
R2SENS R2-value for a series in sensitivity-analysis
RAIN part of rain precipitation exceeding SP*CWH
RESKOL control variable for residual

S amount of water in every pulse in the resp.function (mm)
SALK** saving vector for the next calculation of
R2 mm for alkalinity
SDAT last date for calculation
SERIE serie calculator in sensitivity-analysis
SH** saving vector for the next calculation of
R2 mm for H+
SM calculated soil moisture (mm)
SMMEDV mean value of SM of day plus former day (mm)
SNSPLT text about sensitivity-analysis for plotting
SNSTXT text about sensitivity-analysis for plotting
SO4DAT sulfat, 100*mg/l, input from KEMxxxx
SP calculated snow storage (mm)
SP1,2 mean value for SP in forest and bare soil resp. (mm)
SPACE ordinal for blank line between parameter compartments
SPANT saving vector for PANT
SPAR1-5 matrices to keep several model conditions if necessary,
see below
SPEVP parameter that is steering evaporation where there is
snow (mm)
SPH** saving vector for later calculation
of R2 mm for pH
SPIN saving matrix for precipitation (until the
sensitivity-analysis)
SPMEM remembering precipitation of the day before (mm)
SQ** saving vector for later calculation
of R2 mm for Q
SQANT saving vector for QANT (until the sens.an.)
SQIN saving matrix for discharge (until the sens.an.)
STANT saving vector for TANT (until the sens.an.)
STIN saving matrix for temperature (until the
sens.an.)

STN station of different kinds
STNNR reads a Q station number from the PTQ-file
STRECK underlines output for a new month
SUM31 sum of variables over one month,
SVAL choice of run type, stated in the BAS-file
0 => normal run
1 => sensitivity-analysis for QCOM/QOBS
2 => sensitivity-analysis for PHQCOM/PHQOBS
3 => sensitivity-analysis for HQCOM/HQOBS
4 => sensitivity-analysis for AEQQCOM/AEQOBS

T corrected temperature (C)
TALT altitude of temperature station (m)
TANT number of temperature stations
TCALT change of temperature with height (C/100m)
TEXT* several strings with text.
TFEJK updating of T (C)
TIDSK time-scale for the plotting (mm/month)
TILL matrix with the starting situation, if necessary
in a separate file, see below
TIME date and hour of the run
TIN temperature statement of the respective station (10*C)
TITEL string with the name of the variables that have been
chosen to be written out
TMDO corrects TMEAN for the height for every subbasin
TMEAN mean value for the temperature value of the last
20 days
TQUEUE temperature values of the last 20 days
TSTAT weighing of the temperature stations
TTMELT threshold temperature for snow melt (C)
TTPREC threshold temperature for rainfall (C)
TYP exactly 80, 8 means chemical sampling and 0 sampling place
TXT* various strings

UPPDAT states whether updating should be made, 0=no, 1=yes, in
BAS-file
UTDATA help vector for output
UTUNIT file for writing in the subroutine PARLES

V(PULS) generated discharge from a pulse in the response
function (mm/d)
VALPLT plotting or not (0=no plot, 1=plot),
stated in BAS-file
VARMAX upper border for the scale while plotting
VARMIN lower border for the scale while plotting
VEGZON states forest (=1) or bare soil (=2)
VERSION version of the program, ought to be updated
continuously, written on the plot

W content of melt water in snow storage (mm)
WC1,2 mean value for WC in forest or bare soil respectively (mm)
WCMEM remembering WC of yesterday (mm)
WLAKE waterlevel in lake (mm)
WSTEG number of steps the lake calculation is divided into

XA vector with the X-value in cm on the plotting per day
XADEL see YADEL
XADIFF see YADIFF

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XAXEL total length of X-axes in the plotting (cm)
XDELOM see YDELOM
XDIFF see YDIFF
XPAR see YPAR
XPARNR see YPARNR
XSENS see YSENS
XSTART see YSTART
XTXT see YTXT

YADEL number of subbasins of which Y shall be used for sens.an.
YADIFF number of differences for Y in sensitivity-analysis
YDELOM number of the subbasin for which Y shall be used for sens.an.
YDIFF difference value for Y in sensitivity-analysis
YEAR year, 2 figures
YPAR calculated Y-parameter value in sensitivity-analysis
YPARNR parameter number for Y in sensitivity-analysis
YSENS calculator in sensitivity-analysis
YSM SM of yesterday (mm)
YSTART starting value for Y in sensitivity-analysis
YTXT name of the variable for the sensitivity-analysis

ZADEL see YADEL
ZADIFF see YADIFF
ZDELOM see YDELOM
ZDIFF see YDIFF
ZLAKE threshold value for discharge from the lake (mm)
ZPAR see YPAR
ZPARNR see YPARNR
ZSENS see YSENS
ZSTART see YSTART
ZTXT see YTXT

TABLES

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- Table 2a** Example of BAS.DAT.
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FIGURES

- Figure 1** Results of 1983/1984.
- Figure 2** Results of 1984/1985.
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- Figure 7** Results of the dependency test.
a Period 1983/1984.
b Period 1984/1985.
c Period 1985/1986.

Table 1 Example of PTQ.DAT

st.nr.	date		P1	P2	T1	T2	Q1
10000	830101	2	11	-9999	2	10 -9999	1 607
10000	830102	2	2	-9999	2	29 -9999	1 761
10000	830103	2	86	-9999	2	68 -9999	1 3906
10000	830104	2	125	-9999	2	90 -9999	1 4829
10000	830105	2	44	-9999	2	87 -9999	1 2963
10000	830106	2	9	-9999	2	109 -9999	1 2271
10000	830107	2	31	-9999	2	52 -9999	1 1996
10000	830108	2	20	-9999	2	49 -9999	1 1703
10000	830109	2	23	-9999	2	49 -9999	1 1478
10000	830110	2	8	-9999	2	62 -9999	1 1462
10000	830111	2	0	-9999	2	85 -9999	1 1269
10000	830112	2	0	-9999	2	57 -9999	1 1060
10000	830113	2	59	-9999	2	43 -9999	1 1051
10000	830114	2	113	-9999	2	19 -9999	1 2315
10000	830115	2	187	-9999	2	57 -9999	1 6168
10000	830116	2	6	-9999	2	82 -9999	1 5254
10000	830117	2	0	-9999	2	75 -9999	1 2489
10000	830118	2	20	-9999	2	54 -9999	1 1857
10000	830119	2	49	-9999	2	16 -9999	1 1696
10000	830120	2	2	-9999	2	22 -9999	1 1680
10000	830121	2	4	-9999	2	53 -9999	1 1418
10000	830122	2	0	-9999	2	54 -9999	1 1183
10000	830123	2	0	-9999	2	27 -9999	1 1002
10000	830124	2	0	-9999	2	17 -9999	1 856
10000	830125	2	40	-9999	2	53 -9999	1 1150
10000	830126	2	5	-9999	2	83 -9999	1 1280
10000	830127	2	4	-9999	2	106 -9999	1 1209
10000	830128	2	48	-9999	2	87 -9999	1 1383
10000	830129	2	21	-9999	2	78 -9999	1 2040
10000	830130	2	34	-9999	2	39 -9999	1 1669
10000	830131	2	129	-9999	2	24 -9999	1 3096
10000	830201	2	232	-9999	2	67 -9999	1 11320

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Table 2a Example of BAS.DAT.

Basdata for the PULS-model

```

=====
Runoff area                HUPSEL
Start date (act.the day before) 830331
Last date                  840331
Number of basins (max 12)    1
Reduction factor (50=normal) 50
Station number for Q-station 10000
Output 0,1 little,daily     0
Time scale on plot (mm/month) 15
Choice of Q-station in PTQ-file 1
Run 0-4 R2,Q,PH,ALK,TR      0
Updating 0,1 no,yes         0
Choice of model 1,2 QMOD,PHMOD 2
Format PTQ-file 0,1 free,machine 0
QSORT, plot 1,2,3 m3/s,1/s,mm/d 3
Number of days not in R2-calc. 20
pH in prec 0,1,2 daily, sum.MISU 2
Number of par. changes (max 10) 0
Plotting 0,1 no,yes        1
WSTEG (step/day in lake calc) 15
Choice of EMNE -9 to 9, not 0 2
Output per par.ch. 0,1 n,y 1
Y-origin of plot 0,1 def., BAS 0
Standard dev. at MonteCarlo (%) 0
Transport-unit 0,1,2,3 1,k,M,G 0
                                0
                                0
    
```

Sensitivity analysis according to below

```

=====

```

	parameter	startvalue	difference	diffnumb	subbasinnr	subbasin
x-led	cflcap	0.30	0.10	3	1	1
y-led	uzl	4.00	2.00	3	1	1
z-led	beta	2.00	0.20	2	1	1

Information about output and plotting

```

=====

```

	prt	dec	plt	lng	yax	yor	min	max	pen	tsc	typ	sub	
	sp	y	2	n	10	l	100.0	0.00	100.00	1	n	c	n
	melt	n	2	n	10	l	0.0	0.00	10.00	1	n	s	n
	sm	n	1	n	10	l	60.0	0.00	200.00	1	y	c	n
	evp	y	2	n	10	l	60.0	0.00	8.00	1	n	c	n
	cflux	n	2	n	10	l	0.0	0.00	4.00	1	n	c	n
c	clz	y	2	n	10	r	0.0	0.00	20.00	1	n	s	n
	lz	y	2	n	25	l	20.0	0.00	50.00	1	y	c	n
c	lz	y	2	n	10	l	20.0	0.00	20.00	1	y	c	n
	qgen	y	2	n	10	l	0.0	0.00	20.00	1	n	c	n
	acdif	n	2	y	10	l	0.0	-50.00	50.00	1	n	c	n
	qcom	y	2	y	40	l	20.0	0.00	20.00	1	y	c	n
	qobs	y	1	y	40	r	20.0	0.00	20.00	2	y	c	n

end

	php	n	2	n	40	l	150.0	4.00	8.00	1	y	3	n
	phsp	n	2	n	20	l	0.0	4.00	8.00	1	n	c	n
	aeqgen	n	3	n	40	l	80.0	-0.40	0.40	1	n	c	n
	aeqcom	n	3	n	20	l	20.0	-0.10	0.30	1	n	c	n
	aeqobs	n	3	n	40	r	20.0	-0.10	0.30	1	n	l	n
c	phqgen	n	2	n	20	l	0.0	4.00	8.00	1	n	c	n
	phqcom	n	2	n	40	l	25.0	4.00	8.00	1	y	c	n
	phqobs	n	2	n	40	r	25.0	4.00	8.00	1	n	l	n
	aeqtco	n	1	n	40	l	25.0	0.00	100.00	1	y	h	n
	aeqtob	n	1	n	40	r	25.0	0.00	100.00	3	n	h	n
	SO4tco	n	1	n	40	l	25.0	0.00	800.00	1	y	c	n
	SO4tob	n	1	n	40	r	25.0	0.00	800.00	1	n	l	n

end

Parameter change

=====

datum	parameter	new value	subbasin
840601	lp/fc	0.75	110000000000
841001	lp/fc	0.85	110000000000
840301	fc	200.00	110000000000
840301	beta	2.75	110000000000
850301	beta	3.00	110000000000

Table 2b Description of BAS.DAT

First part:

Var. name	Description.
BDAT	Start date: actually the day before the simulation starts;
SDAT	Last date: date of the last day of the simulation period;
ANTOMR	Number of basins (max.12): number of subbasins;
FACT	Reduction factor (50=normal): not used anymore;
QSTN	Station number for Q-station: if unknown choose 10000;
PRINT	Output 0,1 little,daily: output to screen during run, only mean values (=0) or daily values (=1);
TIDSK	Time scale on plot mm per month: choice of length in mm of one month on time-ax in plot;
QSTN	Choice of Q-station in PTQ-file: in case of more than one Q-station choice of which data should be used as observed discharge;
SVAL	Run 0,4 usually R2(Q,PH,ALK,TR): 0 = normal run; 1 = sensitivity analysis for discharge; 2 = sensitivity analysis for pH; 3 = sensitivity analysis for chosen material; 4 = sensitivity analysis for transport of chosen material;
UPPDAT	Updating 0,1 no,yes: states whether updating is needed, if so UD.DAT is needed (see section A3d);
MODVAL	Choice of model 1,2 QMOD,PHMOD: if QMOD is chosen only simulation of discharge possible;
INFORM	Format PTQ-file 0,1 free, machine: if 1 is chosen a run will take less time; usually 0 is used;
QSORT	QSORT, plot 1,2,3 m ³ /s, l/s, mm/d: choice of unit of computed discharge (usualy in mm/d);
R2INSV	Number of days excl.from R2-calc.: number of days skippen before R2-calculation is starting;
PHPTID	pH in prec. 0,1,2 daily, sum, MISU: in the program only MISU is used: monthly mean values; if 2 is chosen KEM85.DAT is not needed;
PARBYT	Number of par.changes (max.10): number of parameter changes, stated in the last part of BAS.DAT;
VALPLT	Plotting 0,1 no,yes: if plotting is chosen PULS_52.TMP is created (see section A4);
WSTEG	WSTEG (step/day in lake calc.): number of steps in which the lake calculation is divided;
EMNE	Choice of EMNE -9 to 9, not 0: choice of the material to be simulated: 1 = conductivity; 2 = alkalinity and pH; 3 = sulphate; 4 = chloride; 5 = nitrate; 6 = calcium; 7 = magnesium; 8 = potassium; 9 = sodium; If a minus-sign is used, the measured concentration is recalculated into meq/l (not used!);

Var. name	Description.
BYTSKR	Output per par.ch. 0,1 no,yes: if 1 is chosen parameter changes within the simulation period are written to the screen;
DEFORI	Y-origin of plot 0,1 def, BAS: if 0 is chosen the Y-origin is calculated within the plot program, otherwise they are read from the third part of BAS.DAT;
MONTE	Standard deviation at Monte Carlo (%): is not used in the program, should be chosen 0;
TRSORT	Transport unit 0,1,2,3 1,k,M,G: prefix for transport unit: 0 = no prefix (eq/day); 1 = k (kilo) (keq/day); 2 = M (mega) (Meq/day); 3 = G (giga) (Geq/day);

Third part:

Var. name	Choice	Description
PRT	y/n	States whether the results of a variable should be written to the screen;
DEC	0-3	Number of decimals in the result-list;
PLT	y/n	States whether a variable should be plotted;
LNG	(in mm)	Length of Y-ax on plot;
YAX	l/r/0	l = Y-ax to the left; r = Y-ax to the right; 0 = no Y-ax;
YOR	(in mm)	Place of Y-origin, if DEFORI=0. (see former table in this section) this is not used;
MIN	(in unit var.)	Minimum value on Y-ax;
MAX	(in unit var.)	Maximum value on Y-ax;
PEN	(in 10 mm)	Thickness of pen for plot;
TSK	y/n	States whether month-output should be plotted on scale;
TYP	h,c,s,1-9	Type of plot: h = histogram, monthly mean values; c = continuous curve; s = histogram, daily values; 1-9 = different types of spots (non-continuous curve);
SUB	y/n	States whether a variable should be plotted subbasinwise;

Table 3a Example of PAR.DAT.

Param.file for HUPSEL

=====

pot evp	0.13	0.31	1.00	1.63	2.03	3.53
pot evp	3.55	2.42	1.53	0.81	0.20	0.06
clake	100.00	100.00	100.00	100.00	100.00	100.00
clake	100.00	100.00	100.00	100.00	100.00	100.00
hyps	30.00	110.00	0.00			
area	6.50	0.43	0.00			
forest%	9.00	80.00	0.00			
open%	91.00	20.00	0.00			
lake%	0.00	00.00	0.00			
palt	10.00	100.00	150.00			
p 1	1.00	0.00	0.00			
p 2	0.00	1.00	0.00			
p 3	0.00	0.00	0.00			
p 4	0.00	0.00	0.00			
p 5	0.00	0.00	0.00			
p 6	0.00	0.00	0.00			
p 7	0.00	0.00	0.00			
p 8	0.00	0.00	0.00			
p 9	0.00	0.00	0.00			
p 10	0.00	0.00	0.00			
pcalt	0.10	0.10	0.10			
pcorr	1.00	1.02	1.00			
talt	10.00	30.00	155.00			
t 1	1.00	1.00	1.00			
t 2	0.00	0.00	0.00			
t 3	0.00	0.00	0.00			
t 4	0.00	0.00	0.00			
t 5	0.00	0.00	0.00			
t 6	0.00	0.00	0.00			
tcalt	0.60	0.60	0.60			
csf 1	0.70	0.70	0.78			
csf 2	0.80	0.80	0.85			
ttprec	-3.00	0.50	0.00			
ttmelt	-1.00	2.00	0.00			
cmelt 1	2.50	2.50	1.65			
cmelt 2	4.00	4.00	3.10			
cfr	0.05	0.05	0.05			
cwh	0.10	0.10	0.10			
spevp	25.00	25.00	25.00			
cphmelt	1.00	1.00	1.00			
icmax 1	0.00	0.00	0.00			
icmax 2	0.00	0.00	0.00			
pevpic	1.00	1.00	1.00			
fc	150.00	100.00	250.00			
lp/fc	0.60	0.85	0.72			
beta	2.00	3.00	3.00			
pheqsm	4.00	4.00	4.00			
cphsm	1.00	1.00	1.00			

cflcap	0.30	1.50	0.30
lzmin	-9999.99	-9999.99	0.00
k0	140.00	100.00	0.00
k1	40.00	40.00	160.00
k2	0.00	40.00	15.00
k3	0.00	10.00	0.00
uzl	7.00	10.00	0.00
lzl	0.00	33.00	30.00
dzl	0.00	2.00	0.00
maxbas	1.00	1.00	1.00
aeqz	0.05	0.25	0.06
alkmin	0.20	0.25	-0.03
ctz	0.00	0.00	0.13
lzmax	20.00	20.00	20.00

zlake	0300.00	300.00	3000.00
klake	0.17	1.50	2.00
elake	1.00	2.20	2.20
blake	2.00	2.00	004.00
plake	0.00	0.00	0.00
kalk	-0.99	-0.99	-0.99

pco2 8.00
aeqkorr 0.00

Q flows in direction

from subbasin	1	2	3	4	5	6	7	8	9	10	11	12
to subbasin	0	0	0	0	0	0	0	0	0	0	0	0
plot nr	282											

Table 3b List of parameters in PAR.DAT

The first two lines of PAR.DAT (see table 3a) should not be changed except for the name of the catchment. If this name is incompatible with the name stated in the BAS-file (section A3b) the program run will be interrupted.

Var.name	Description	Order	Unit
POT EVP	potential evapotranspiration, daily values (recalculated from monthly values);		[mm]
CLAKE	monthly values for the exchange coefficient for the lakes;		[%]
hyps	altitude of catchment;	*1	[m]
area	area of catchment;	*1	[km ²]
forest%	percentage forested land in catchment;	*1	[%]
open%	percentage open land in catchment;	*1	[%]
lake%	percentage lake in catchment;	*1	[%]
palt	altitude of precipitation station;	*1	[m]
p1/p10	weight of each precipitation station;	0.0-1.0	[-]
pcalt	precipitation-altitude gradient;	10-20	[%/100 m]
pcorr	correctioning factor for precipitation;	0.9-1.1	[-]
talt	altitude of temperature station;	*1	[m]
t1/t6	weight of each temperature station;	0.0-1.0	[-]
tcalt	temperature-altitude gradient;	0.6	[°C/100m]
csf1	correctioning factor for snow precipitation, 1 = forest;	0.6-0.9	[-]
csf2	" 2 = open,lake;	0.8-1.1	[-]
ttprec	threshold for precipitation snow or rain;	-1 - +1	[°C]
ttmelt	threshold for snow melt or refreezing;	-1 - +1	[°C]
cmelt1	degree-day factor, 1 = forest;	2.0	[mm/°C*d]
cmelt2	" , 2 = open,lake;	3.0-5.0	[mm/°C*d]
cfr	refreezing factor;	0.05*2	[-]
cwh	waterholding capacity of snow;	0.1 *2	[-]
spevp	parameter for evaporation from snow;	0 *2	[mm]
cphmelt	-- (is not used anymore);	-	-
icmax 1	maximum interception storage, 1 = forest;	0.0 *2	[mm]
icmax 2	" 2 = open,lake;	0.0 *2	[mm]
pevpic	parameter for evaporation from interception storage;	1.0 *2	[-]
fc	field capacity;	100-300	[mm]

Var.name	Description	Order	Unit
lp/fc	lower limit for potential evaporation;	0.6-1.0	[-]
beta	empirical parameter in soil routine;	2.0-3.0	[-]
pheqsm	-- (is not used anymore);	-	-
cphsm	-- (is not used anymore);	-	-
cflcap	maximum capacity for capillary rise;	0.5-1.0	[mm/d]
lzmin	lower limit of lz;	20-50	[mm]
k0	recession coefficient above uzl;	100-400	[1/1000*d]
k1	" " above lz1;	50-200	[1/1000*d]
k2	" " above dz1;	20-100	[1/1000*d]
k3	" " above 0;	10- 50	[1/1000*d]
uzl	upper zone limit;	5-20	[mm]
lz1	lower zone limit;	5-20	[mm]
dz1	deep zone limit;	2-10	[mm]
maxbas	time base for distribution of discharge in time;	1-10	[d]
aeqz	mean value for alkalinity;	0.05* ²	[meq/l]
alkmin	lowest allowed value for alkalinity in response function;	0.20* ²	[meq/l]
ctz	seasonal dependency for relation between depth in aquifer and alkalinity;	0 * ²	[-]
lzmax	limit for storage in response function above which alkalinity is not increasing;	0-100	[mm]
zlake	threshold depth for discharge from lake;	* ³	[mm]
klake	recession coefficient for lake;	2.0 * ²	[m ² /s]
elake	exponent in lake discharge equation;	2.2 * ²	[-]
blake	states the amount of exchange between active and passive zone;	100 * ²	[%]
plake	threshold value for passive zone in lake routine;	* ³	[mm]
kalk	lowest alkalinity value following from chalking;	0 * ²	[meq/l]
pCO2	factor stating quotient pCO ₂ actual/pCO ₂ at 1 atm.;	3-30	[-]
aeqkorr	correctioning factor for calculated alkalinity;	0 * ²	[meq/l]

Direction of discharge

Plot nr (is changed every time the program is run);

*¹ Should be estimated by using a map.

*² No change allowed.

*³ zlake = mean depth of lake;

blake = 0.5 * zlake.

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Table 4 Example of TILL.DAT.

Start situation for date 830331 for HUPSEL

```
=====
```

sp 1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
sp 2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
wc 1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
wc 2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
phsp 1	4.60	4.60	4.60	4.60	4.60	4.60	4.60
phsp 2	4.60	4.60	4.60	4.60	4.60	4.60	4.60
smdef 1	0.00	0.00	100.00	100.00	100.00	100.00	100.00
smdef 2	0.00	0.00	100.00	100.00	100.00	100.00	100.00
lz	10.10	10.00	0.00	0.00	0.00	0.00	0.00
phlz	4.50	4.50	4.50	4.50	4.50	4.50	4.50
wlake	2100.00	2000.00	2000.00	2100.00	2000.00	2000.00	2100.00
aeqlake	0.02	0.02	0.02	0.02	0.02	0.02	0.00

Description:

1 = forest, 2 = open/lake;
 sp = snow pack;
 wc = water content;
 phsp = pH in snow pack;
 smdef = soil moisture deficit;
 lz = storage in response function;
 phlz = pH in storage in response function;
 wlake = water level in lake;
 aeqlake = alkalinity in lake;

Table 5 Example of UD.DAT.

Datum	P	T
860404	1.2	0.0
860405	1.2	0.0
860406	1.2	0.0
861011	0.0	0.1
861012	0.0	0.1
861013	0.0	0.1
861014	0.0	0.1
861015	0.0	0.1
861016	0.0	0.1

73

Table 7 Example of **MISU.DAT (PHMISU.DAT)

pH in precipitation, for Nolsjön, from MISU

Yr	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
66	4.40	4.40	4.40	4.40	4.40	4.40	4.40	4.40	4.40	4.40	4.40	4.40
67	4.40	4.40	4.40	4.40	4.40	4.40	4.40	4.40	4.40	4.40	4.40	4.40
68	4.60	4.60	4.60	4.60	4.60	4.60	5.20	4.90	5.50	4.50	5.60	4.50
69	4.40	4.40	4.70	4.70	4.70	6.10	4.10	6.10	5.90	5.60	5.90	4.70
70	5.10	4.50	4.50	4.40	4.50	4.60	5.00	5.50	4.40	4.90	5.00	4.50
71	4.30	4.20	4.40	4.20	4.70	4.20	4.70	4.60	4.40	4.80	4.90	4.40
72	4.10	4.20	4.10	4.20	4.30	4.30	5.60	5.80	4.50	4.50	4.30	4.20
73	4.10	4.10	4.00	4.20	4.30	4.20	4.40	4.20	4.40	4.40	4.40	4.30
74	4.20	4.10	4.40	4.60	5.70	4.70	4.30	4.20	4.20	4.50	4.20	4.30
75	4.20	3.80	4.00	4.10	4.70	5.00	4.20	4.00	4.40	4.00	4.00	4.20
76	4.60	4.00	4.40	4.50	3.90	4.30	4.60	4.20	6.00	4.30	4.20	4.60
77	5.30	4.00	4.00	4.60	4.00	4.30	4.40	4.40	4.50	4.50	4.80	4.30
78	4.30	3.90	4.10	3.80	5.00	4.80	4.40	4.00	4.60	4.20	5.20	6.20
79	3.60	4.50	3.80	5.80	4.10	4.10	4.30	4.40	4.00	4.30	4.40	4.20
80	5.10	4.40	3.70	5.30	5.00	4.80	4.30	4.40	4.10	4.30	4.30	4.50
81	4.60	4.20	4.20	4.30	4.10	4.50	4.30	4.70	4.30	4.30	4.60	4.20
82	4.30	4.20	4.30	4.30	4.10	4.20	4.70	4.50	4.40	4.10	4.30	4.30
83	4.40	4.70	4.20	4.10	4.30	4.00	4.40	4.40	4.40	4.40	4.40	4.40
84	4.40	4.40	4.40	4.40	4.40	4.40	4.40	4.40	4.40	4.40	4.40	4.40
85	4.40	4.40	4.40	4.40	4.40	4.40	4.40	4.40	4.40	4.40	4.40	4.40
86	4.40	4.40	4.40	4.40	4.40	4.40	4.40	4.40	4.40	4.40	4.40	4.40
87	4.40	4.40	4.40	4.40	4.40	4.40	4.40	4.40	4.40	4.40	4.40	4.40
88	4.40	4.40	4.40	4.40	4.40	4.40	4.40	4.40	4.40	4.40	4.40	4.40
89	4.40	4.40	4.40	4.40	4.40	4.40	4.40	4.40	4.40	4.40	4.40	4.40
Yr	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec

Table 8 Output vectors

Ordinal	Hydrological variables	Unit
1	Precipitation;	[mm/d]
2	Temperature;	[° C]
3	Increase of precipitation;	[mm/d]
4	Increase of temperature;	[° C]
5	Snow pack;	[mm]
6	Melt water in snow storage;	[mm]
7	Rain interception storage;	[mm]
8	Snow interception storage;	[mm]
9	Amount of melt water;	[mm/d]
10	Contribution to soil routine;	[mm/d]
11	Soil moisture;	[mm]
12	Evaporation;	[mm/d]
13	Capillary rise;	[mm/d]
14	Contribution to response function;	[mm/d]
15	Storage in response function;	[mm]
16	Generated discharge;	[mm/d]
17	Waterlevel of lake;	[mm]
18	Accumulated difference between computed and observed discharge;	[mm]
19	Calculated discharge;	[mm]
20	Observed discharge;	[mm]

Ordinal	Chemical variables	Unit
1	Observed pH in precipitation;	[-]
2	pH in snow storage;	[-]
3	Observed alkalinity in precipitation;	[meq/l]
4	pH in soil moisture;	[-]
5	pH in contribution to soil routine;	[-]
6	pH in contribution to response function;	[-]
7	Alkalinity in lake, active part;	[meq/l]
8	Alkalinity in lake, passive part;	[meq/l]
9	Alkalinity in groundwater;	[meq/l]
10	Calculated alkalinity in discharge;	[meq/l]
11	Observed alkalinity in discharge;	[meq/l]
12	Generated pH in discharge;	[-]
13	Computed pH in discharge;	[-]
14	Observed pH in discharge;	[-]
15	Computed transport of alkalinity in discharge;	[eq/l]
16	Observed transport of alkalinity in discharge.	[eq/l]

Table 9 Declaration files and subroutines.

Main program:

	BAS	BASFIL	COMP	IODATA	IOLIM	PAR	PARFIL	HPPH9 ¹	SENSMM
AVBRYT	-	-	-	-	-	-	-	-	-
BASLES	*	*	-	*	-	-	-	-	*
CALC	*	-	*	*	*	*	-	*	*
DATADD	*	-	-	-	-	-	-	-	-
DELUT	*	-	*	*	-	*	-	-	-
FILES	*	-	-	-	-	-	-	-	-
JOMAIN	*	-	*	*	*	*	-	*	*
NYDAG	-	-	-	-	-	-	-	-	-
PARLES	*	-	-	*	-	*	*	-	*
PHMOD9	*	-	*	*	-	*	-	-	-
PHQLES	-	-	-	-	-	-	-	-	-
PTQLES	*	-	*	*	-	-	-	-	-
PLSADD	*	-	*	-	-	*	-	-	-
QMOD9	*	-	*	*	-	*	-	-	-
R2COMP	*	-	-	-	-	-	-	-	-
SOIL	-	-	-	-	-	-	-	-	-
TILLES	*	-	*	-	-	*	-	-	-
UTKOLL	*	-	*	*	*	*	-	-	-

Plot program:

	BAS	BASFIL	COMP	IODATA	IOLIM	PAR	PARFIL	PLOT ²	SENSMM
AXES	-	-	-	-	-	-	-	-	-
JOPLLOT	*	-	-	*	-	*	-	*	*
JOTIDSER	*	-	-	-	*	-	-	*	-

Note 1: HPPH9.INC only used in main program (subroutine CALC is part of JOMAIN);

Note 2: PLOT.INC only used in plot program.

Table 10 Command-files for compilation, linking and running of the simulation program and the plot program.

CMAIN.COM:

```
! Compilation of PULSE-model on VAX (without debug)
! =====
!
$ for/check/list/cont=99 jomain,phmod9,qmod9,r2comp,ptqles,-
    files,parles,basles,tilles,soil,datadd,-
    nydag,nydat,avbryt,utkoll,phples,phqles,-
    delut,plsadd
$ exit
```

LMAIN.COM:

```
! Linking of the PULSE model on the VAX (without debug)
! =====
!
$ link jomain+phmod9+qmod9+parles+r2comp+basles+tilles+-
    ptqles+soil+datadd+files+nydag+nydat+avbryt+-
    utkoll+phples+phqles+delut+plsadd
$ exit
```

START.COM:

```
! Startsequence for PULSE-model
! -----
!
$ def for011 phmisu.dat
$ def for012 par.dat
$ def for013 par.las
$ def for014 ptq.dat
$ def for017 till.dat
$ def for019 bas.dat
$ def for020 plintq.dat
$ def for021 plintq.dat
$ def for024 kem80.dat
$ def for026 ud.dat
$ def for032 alkmisu.dat
$ run/nodeb jomain
```

CPLOT.COM:

```
! Compilation of the plot program belonging to the
! PULSE model on VAX
! =====
!
$ for/check/cont=99 joplot,axes,jotidser,basles,parles
$ exit
```


LPLOT.COM:

```
! Linking of the plot program belonging to the  
! PULSE model on the VAX  
! =====  
!  
$ link joplot+basles+axes+parles+jotidser+-  
      nydag+avbryt+files,unilib/lib  
$ pu  
$ exit
```

Table 11 Optimization criteria.

n = number of situations with both observed and calculated values.

$$\text{medcom} = \frac{1}{n} \sum_{i=1}^n \text{com}(i)$$

$$\text{medobs} = \frac{1}{n} \sum_{i=1}^n \text{obs}(i)$$

$$\text{meddif} = \frac{1}{n} \sum_{i=1}^n (\text{com}(i) - \text{obs}(i))$$

$$\text{medfel} = \frac{1}{n} \sum_{i=1}^n |\text{com}(i) - \text{obs}(i)|$$

$$\text{com/obs} = \text{medcom}/\text{medobs}$$

$$\text{mkvfel} = \frac{1}{n} \sum_{i=1}^n (\text{com}(i) - \text{obs}(i))^2$$

$$\text{varobs} = \frac{1}{n} \sum_{i=1}^n \text{obs}(i)^2 - \text{medobs}^2$$

variancy of observed series.

$$\text{varcom} = \frac{1}{n} \sum_{i=1}^n \text{com}(i)^2 - \text{medcom}^2$$

variancy of computed series.

$$\text{r2} = 1 - \frac{\frac{1}{n} \sum_{i=1}^n (\text{com}(i) - \text{obs}(i))^2}{\frac{1}{n} \sum_{i=1}^n (\text{obs}(i) - \text{medobs})^2} = 1 - \text{mkvfel}/\text{varobs}$$

r2 corresponds to Nash, sometimes called explained variancy, however this is not similar to what is called explained variancy in statistics.

$$\text{corrc} = \frac{\frac{1}{n} \sum_{i=1}^n \text{obs}(i) * \text{com}(i) - \text{medobs} * \text{medcom}}{(\text{varobs} * \text{varcom})^{1/2}}$$

Correlation coefficient (-1 < corrc < 1)

$$\text{rl} = 1 - \frac{\frac{1}{n} \sum_{i=1}^n |\text{obs}(i) - \text{com}(i)|}{\frac{1}{n} \sum_{i=1}^n |\text{obs}(i) - \text{medobs}|}$$

rl estimates the linear deviation (- rl 1)

FIGURES.

Fig.1 Results of 1983/1984.

Fig.2 Results of 1984/1985.

Fig.3 Results of 1985/1986.

Fig.4 Results of 1983/1986 with parameter set 1983/1984.

Fig.5 Results of 1983/1986 with parameter set 1984/1985.

Fig.6 Results of 1983/1986 with parameter set 1985/1986.

Fig.7 Results of the dependency test.

a Period 1983/1984.

b Period 1984/1985.

c Period 1985/1986.

The order of graphs of fig.1 to 6 is described below:

P = Precipitation;
T = Temperature;
SM = Soil moisture storage;
EVP = Evaporation;
ACDIF = Accumulated difference between observed and
computed discharge;
QCOM = Computed discharge, in combination with observed
discharge.

Fig.7 is subdivided into three pages: the first page is
containing the results for the period 83/84, the second
page for 84/85 and the last page for 85/86.

On each page several results are represented. The
parameters tested are:

K0 = recession coefficient layer 0;
K1 = recession coefficient layer 1;
UZL = limit between layer 0 and 1;
LP/FC = limit above which evaporation is potential;
BETA = empirical parameter.

Fig.1 Results of 1983/1984.

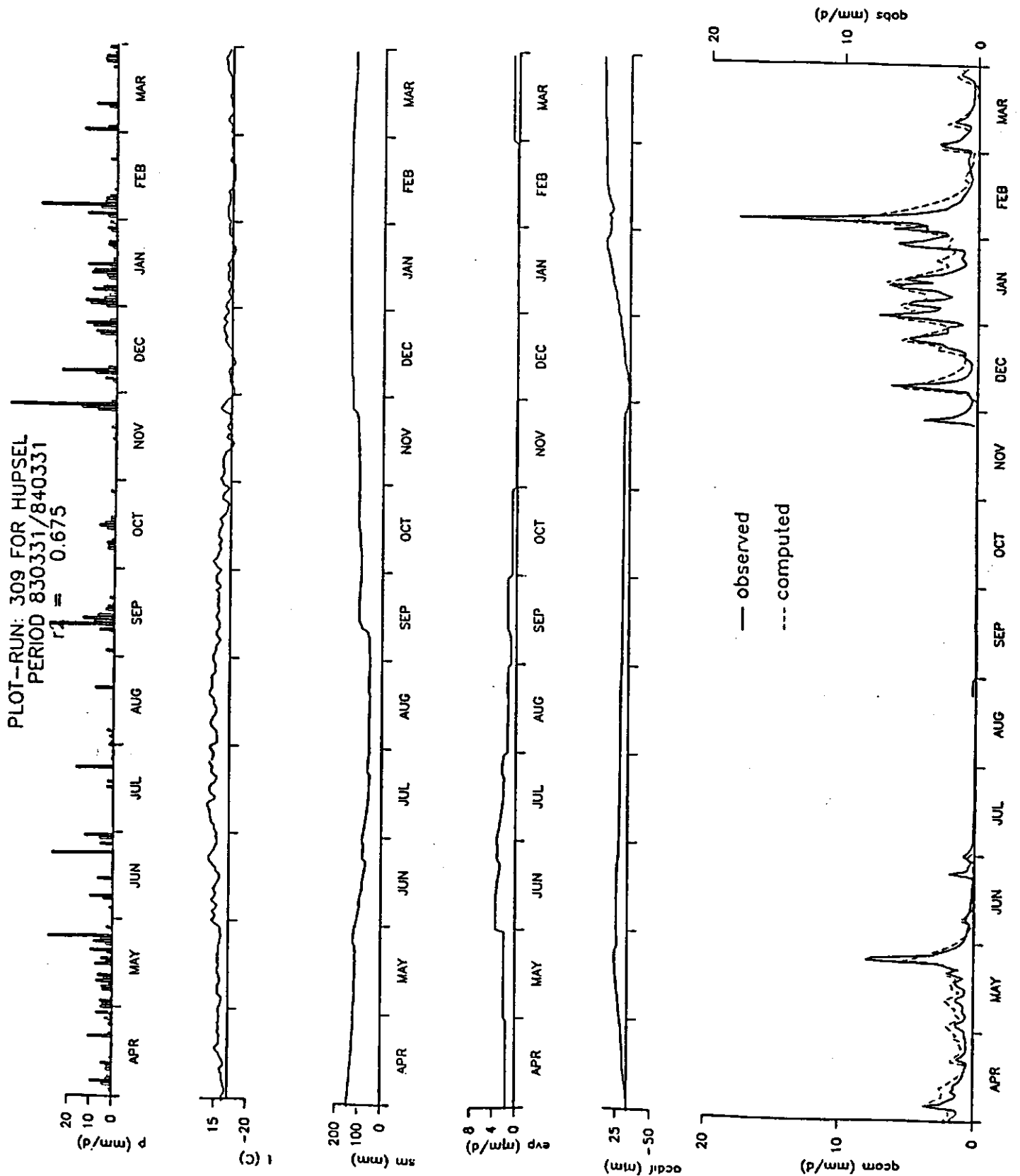


Fig.2 Results of 1984/1985.

PLOT-RUN: 284 FOR HUPSEL
 PERIOD 840331/850331
 $r^2 = 0.645$

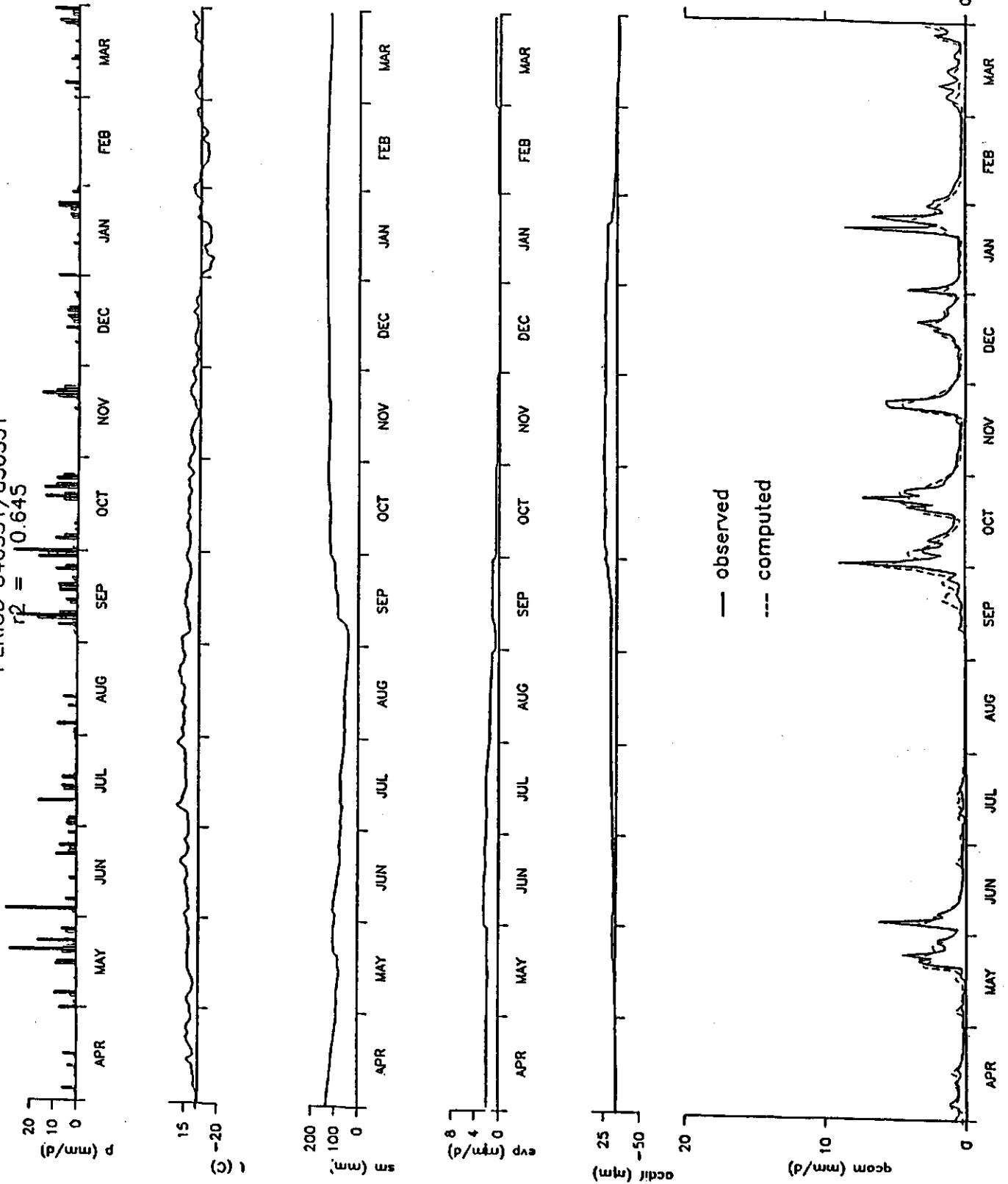


Fig.3 Results of 1985/1986.

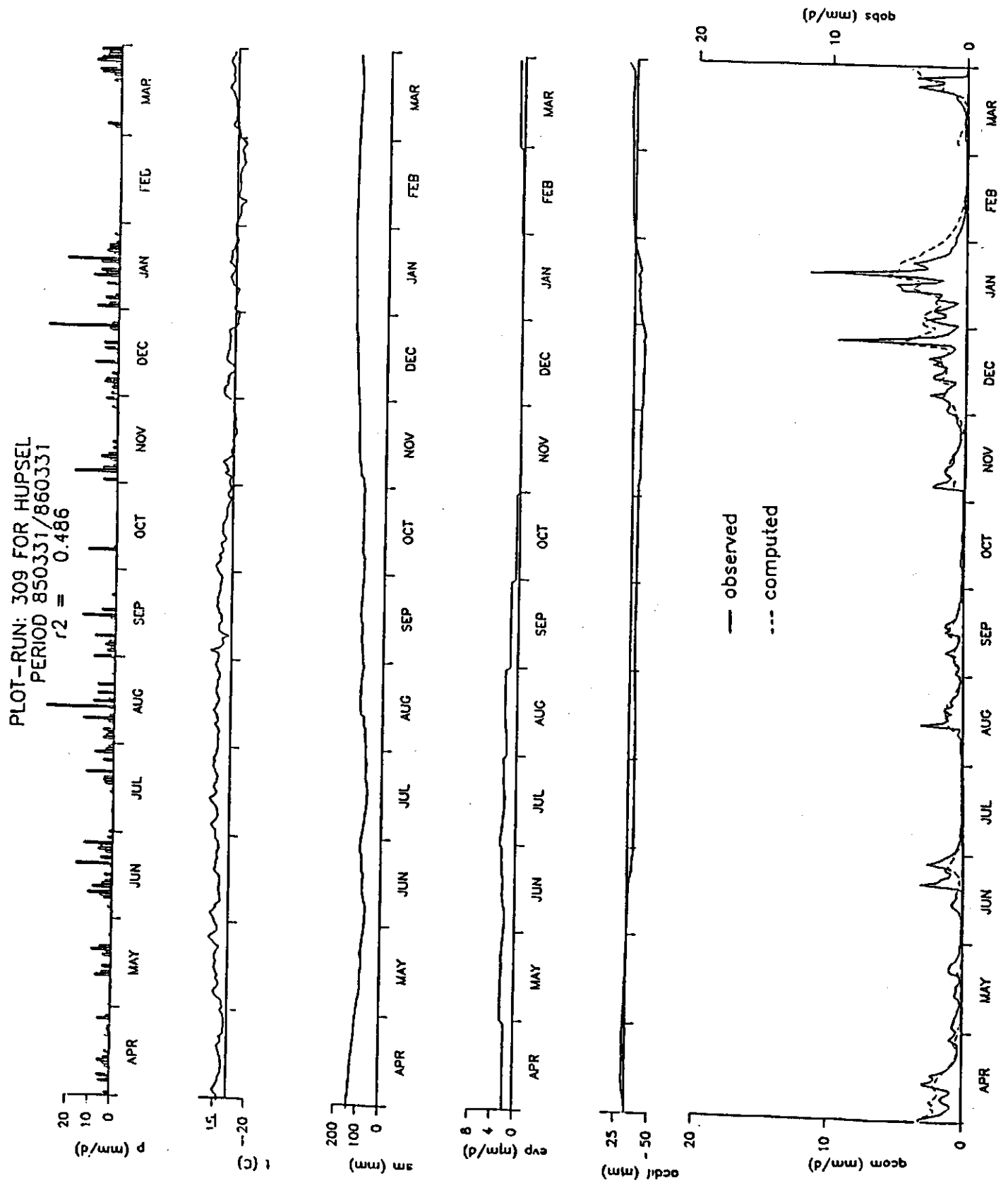
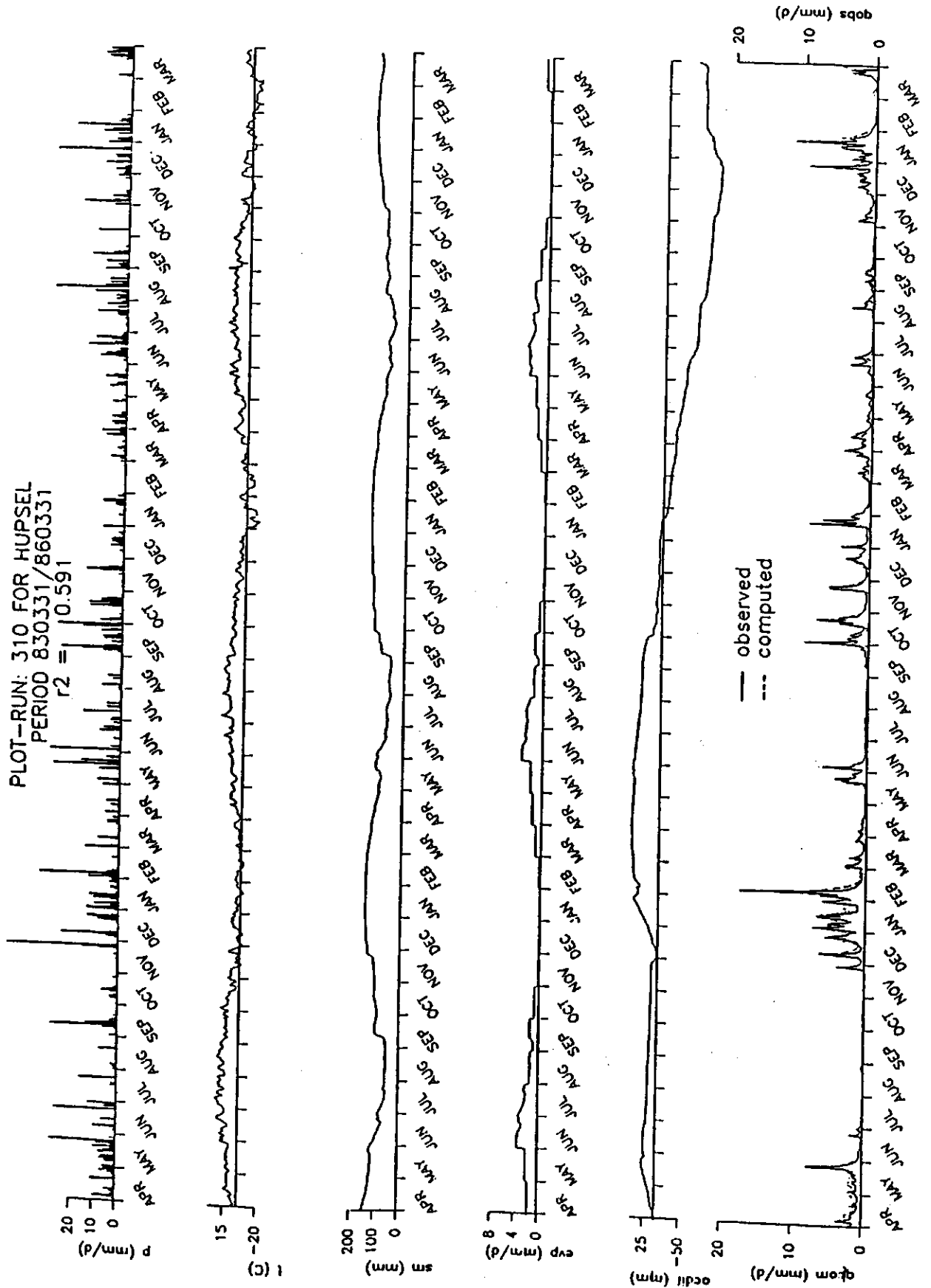


Fig. 4 Results of 1983/1986 with parameter set 1983/1984.



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Fig.5 Results of 1983/1986 with parameter set 1984/1985.

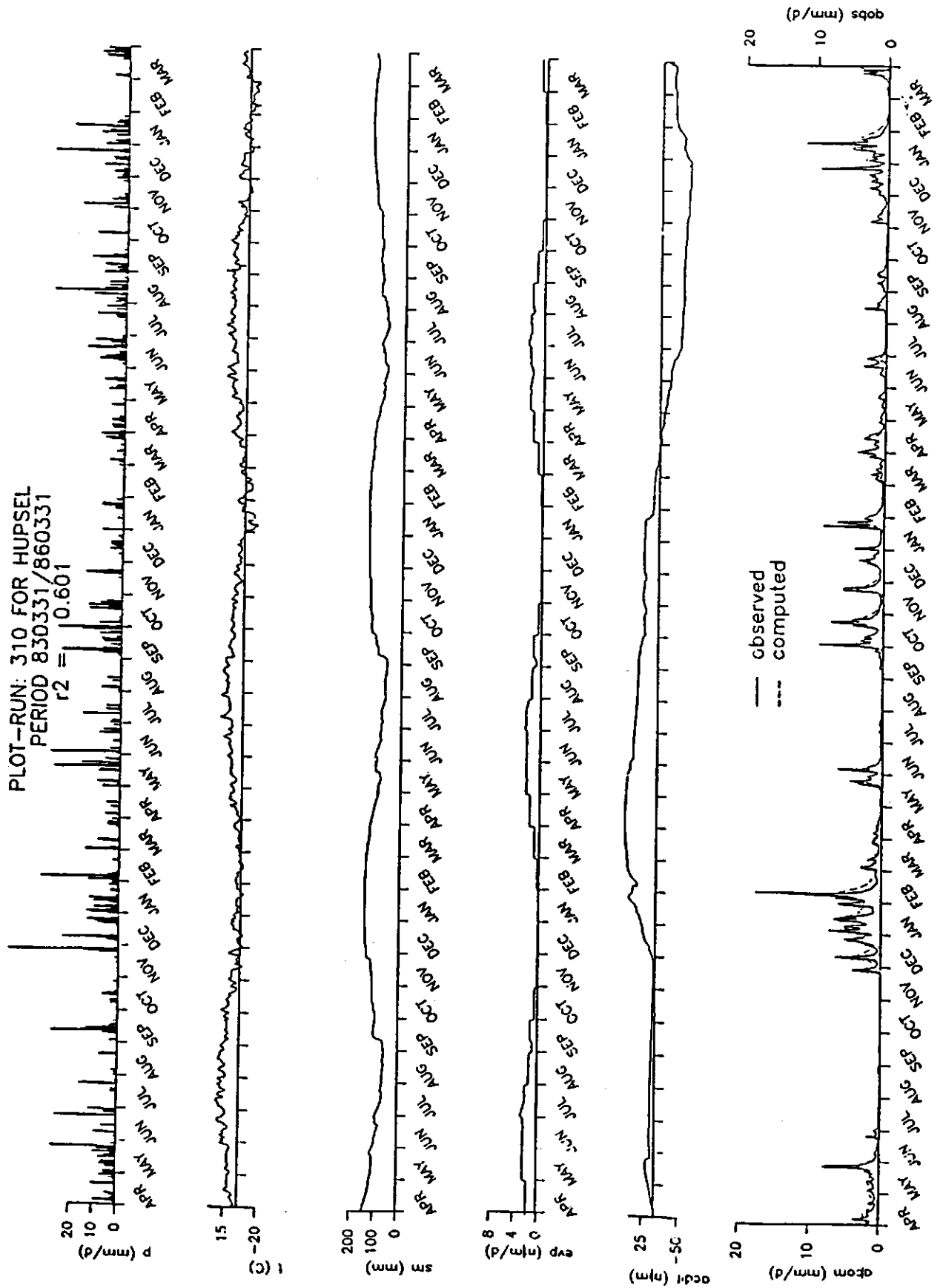


Fig.6 Results of 1983/1986 with parameter set 1985/1986.

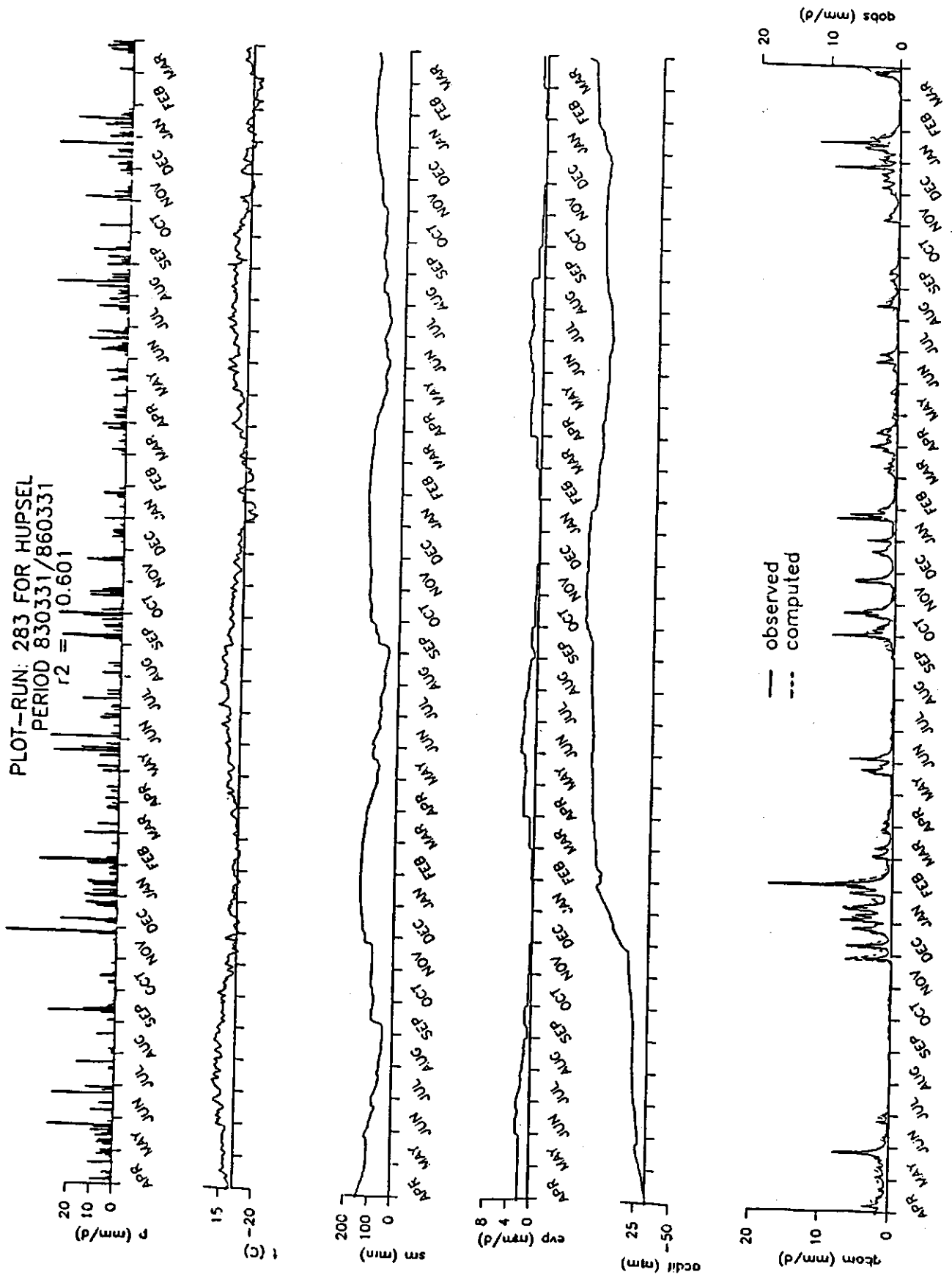
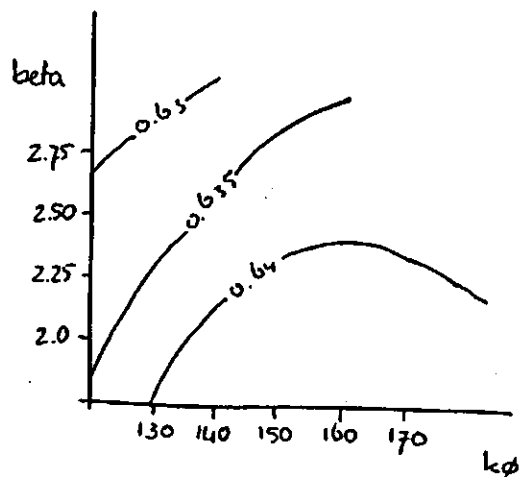
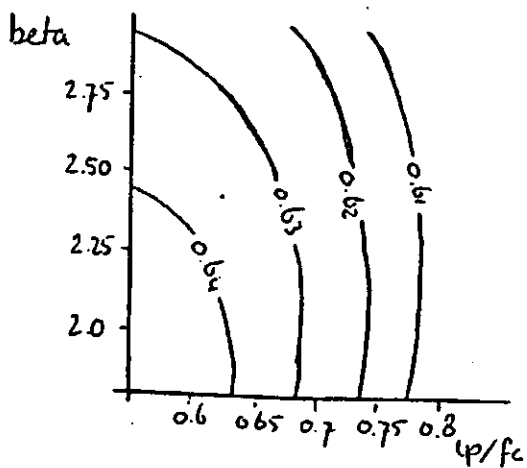
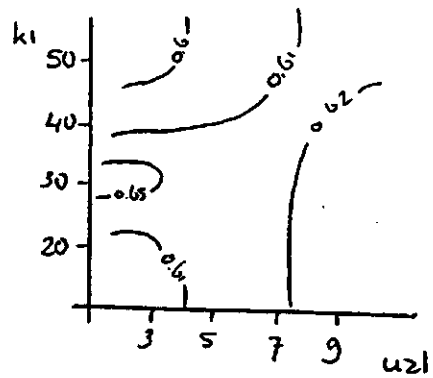
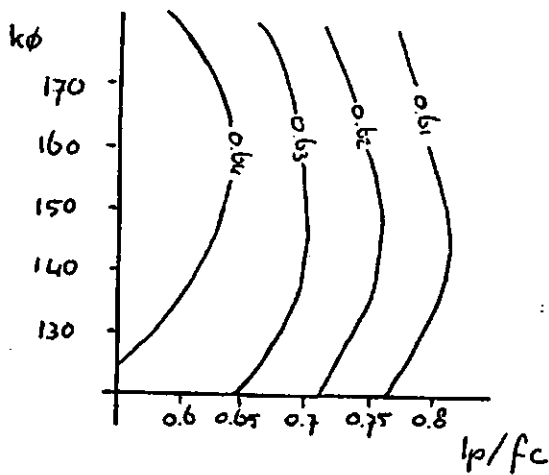
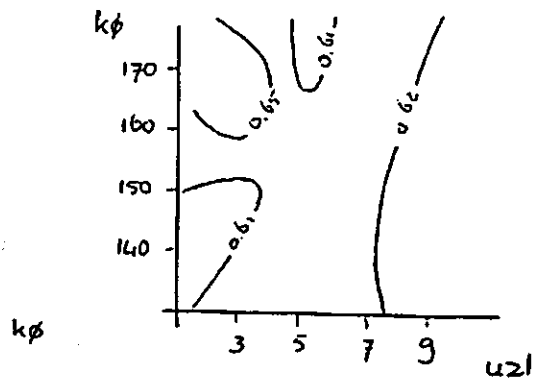
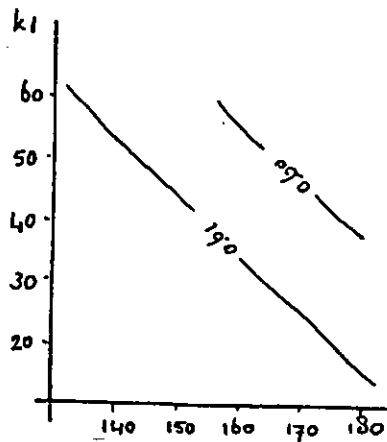
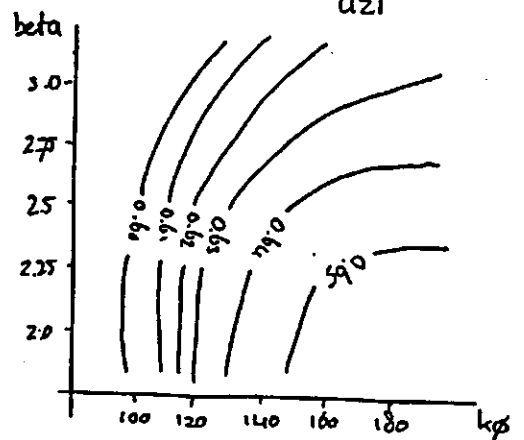
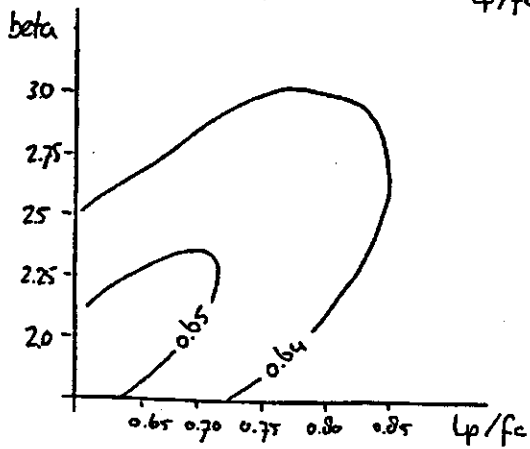
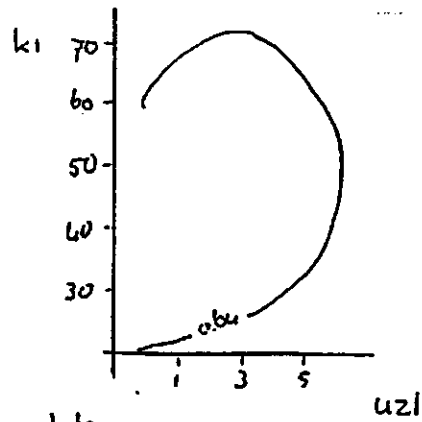
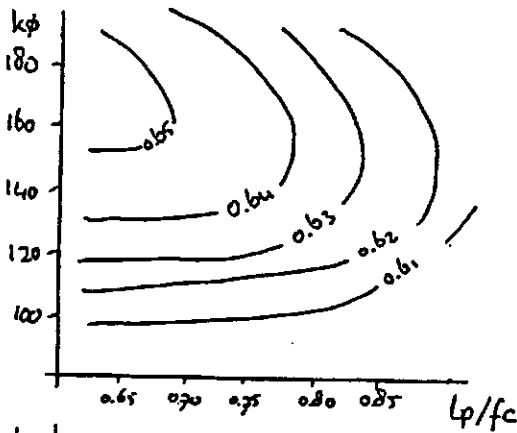
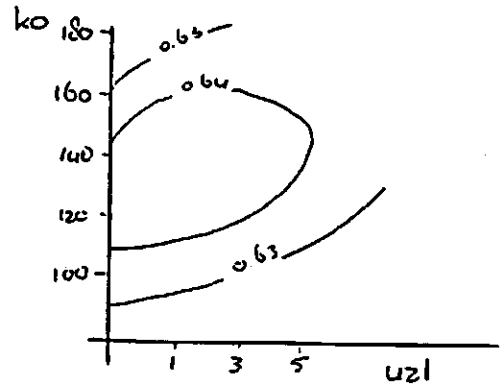
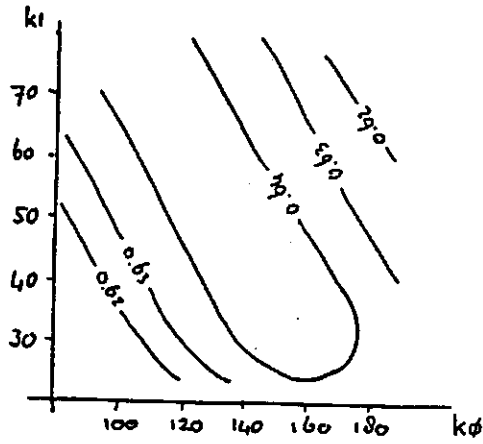


Fig.7 Results of the dependency test.

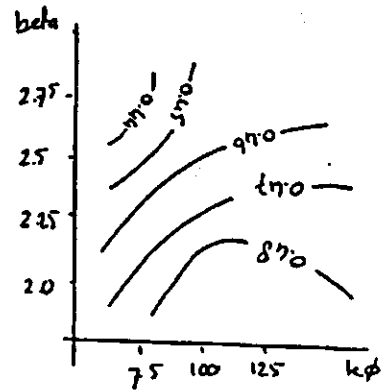
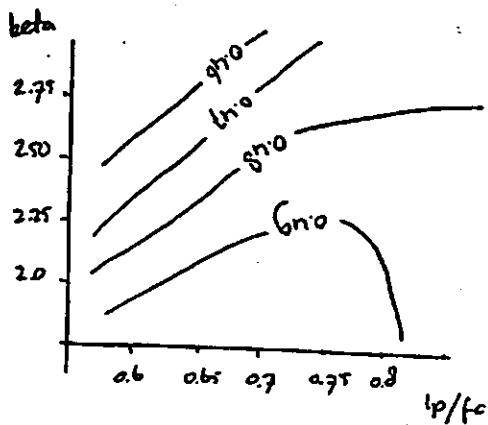
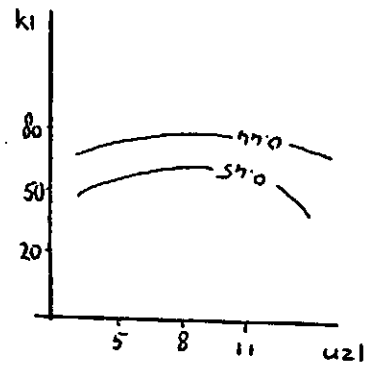
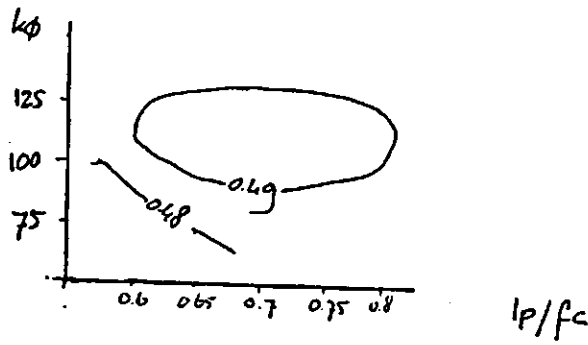
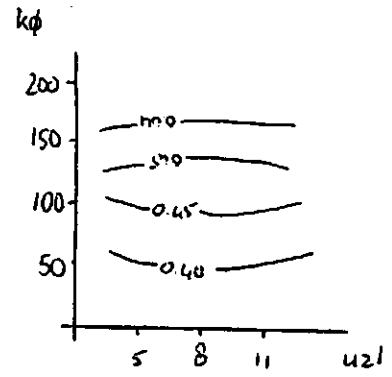
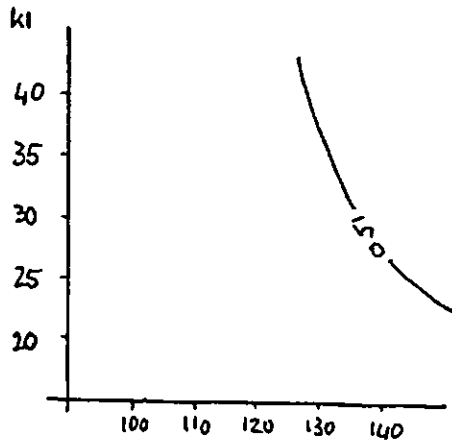
a Period 1983/1984.



b Period 1984/1985.



c Period 1985/1986.



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Appendix D

Variable list.

AAR1KE first year in KEMSUI-vector
AAR1PH first year in PHMSUI-vector
ACCDIF fault in volume between calculated and observed discharge (mm)
ADSENS value of ACCDIFF for a series in sensitivity-analysis
AEQCLZ alkalinity in CLZ
AEQCOM calculated alkalinity in discharge
AEQCOR correction of calculated alkalinity
AEQGEN alkalinity in groundwaterflow
AEQLAA alkalinity in lake, active part
AEQLAP alkalinity in lake, passive part
AEQLZ starting value for PH in response function (N.B. has no importance if ALK is a function of LZ)
AEQOBS observed alkalinity in discharge
AEQP observed alkalinity in precipitation
AEQS alkalinity in response function pulse, remnant from residence time calculation
AINLAK alkalinity contents in lake from rain and snow
ALAKEA amount of alkalinity in lake, active part
ALAKEP amount of alkalinity in lake, passive part
ALKDAT alkalinity, 100*mg/l, input from KEMxxxx
ALKMIN the lowest permitted alkalinity in the response function
ANTDT number of days with correct values for both observed and calculated values
ANTOMR number of subbasins, stated in BAS-file
ANTUD number of updatings in the run-period
AQBAS amount of alkalinity in transformation function
AQCOM amount of alkalinity in calculated discharge
AQGEN amount of alkalinity in discharge from response function
AQLAKE amount of alkalinity in discharge from lake
AQLDEL amount of alkalinity in discharge from lake part per day
AREA area of one subbasin (km²)
AREAFO summed forest area of all subbasins (km²)
AREASM summed area without lakes in all subbasins (km²)
AREATO area total for all subbasins (km²)
AVROMR name of discharge area, stated in BAS-file
BASDAG used to weighing MAXBAS of discharge
BASDAT vector to be read in from BAS-file
BASMAX vector which is containing the highest approved values of all BAS-variables
BASMIN vector which is containing the lowest approved values of all BAS-variables
BASTXT vector which is containing the names of all BAS-variables
BDAT starting date of simulation, stated in BAS-file
BETA soil moisture routine parameter (1)
BLAKE Characterization of the form of the lake (1) (0=superlobate, 100=round)
BYTDAT states dates for changes of parameters
BYTNR number of parameters that will be changed, according to BYTTXT

F2SENS keeps F2 in case of sensitivity analysis
FACT reduction factor (%) for plotting (100 = normal) (%)
F field capacity (mm)
FCBYT keeps a check in case FC has changed (=> res <> 0)
FILDAT reads a date from the PTQ-file
FOREST forested part of subbasin (1)
FORM1 string that is used as format-set on days with rain
FORM2 " " " " " " " " without rain

HI hydrogen ion-content in interception rain/melted snow
HICSP hydrogen ion-content in snow interception
HINLZ hydrogen ion-content in contribution to LZ
HINSM hydrogen ion-content in contribution to soil moisture routine
HP hydrogen ion-content in rain
HRAIN hydrogen ion-content in the amount of rain bigger than WC
HSP hydrogen ion-content in snowstorage
HUVUD contents info about the criterion, version mm is written on plot
HYDCHK vector with info whether a certain variable per subbasin can be plotted (j or n)
HYDDAT very central vector containing all 'hydrological' variables available for output or plotting.
 N.B.1: in subroutine DELUT HYDDAT is only valid for the actual subbasin, otherwise it is the weighed mean for the whole basin.
 N.B.2: HYDDAT(1) = P, HYDDAT(2) = T, and so on.
HYDDEC vector with info about the number of decimals in the output (read from BAS.DAT)
HYDDEL vector with info whether a certain variable should be plotted subbasin-wise (read from BAS.DAT)
HYDENH vector with unities of all 'hydrological' variables.
HYDLNG vector with info about how long the Y-ax should be while plotting (read from BAS.DAT)
HYDMAX vector with info about the highest value of the Y-ax while plotting (read from BAS.DAT)
HYDMIN vector with info about the lowest value of the Y-ax while plotting (read from BAS.DAT)
HYDPEN vector with info about the thickness of the pen while plotting (read from BAS.DAT)
HYDPLT vector with info whether the variable should be plotted or not (read from BAS.DAT)
HYDPRT vector with info whether the variable should be written or not (read from BAS.DAT)
 P and T are always put out.
HYDTSK vector with info whether a time-scale should be plotted or not (read from BAS.DAT)
HYDTXT vector with the names of the variables
HYDTYP vector with info about which type of plot should be made (read from BAS.DAT)
HYDYAX vector with info whether the text should be plotted to the left of to the right of the scale (read from BAS.DAT)
HYDYOR vector with info about Y-origo (read from BAS.DAT)
HYPS altitude for subbasin
I common counter
IANT number of days for plotting

KEMTXT matrix with the names of variables
 depending of the choice of material
KEMTYP vector with info about the type of plotting that should be
 made (read from BAS.DAT)
KEMYAX vector with info whether the text should be plotted to the
 left or to the right of the scale (read from BAS.DAT)
KEMYOR vector with info about Y-origo
 (read from BAS.DAT)
KLAKE recession coefficient of the lake (1/d)
KNAMN various names of variables, corresponding to the choice
 of material
KOLLM2 calculator of maximum number of pulses in response function

L common counter
LENGTH length of Y-ax while plotting (cm)
LAKE percentage lake in every subbasin (%)
LAST31 keeping condition variables of the last day of the former
 month
LEDIG* empty place in BAS-file
LISTA string which is used for the plotting of the PAR-file
LPTOFC lower limit for the soil moisture content if evaporation is
 potential (1)
LZ storage in response function (mm)
LZL() threshold level in response function (mm)
LZLSUM actual LZL-level for which calculation is made (mm)
LZMIN lower limit of LZ, CFLUX is taking off linearly between (mm)
 LZ = 0 (CFLUX = CFLUX) and LZ = LZMIN (CFLUX = 0)
 This function is disconnected if LZMIN is chosen < -9999.
 (N.B. LZMIN = 0 is allowed)
LZMAX level in response function above which alkalinity is not
 increasing (mm)

MAIN steering degree checkings in BASLES and PARLES (means in
 principal to call the subroutines from the main program
 or not)
MAX Number of pulses in the response function
MAXBAS distribution of discharge in time
MAXBYT maximum number of parameter changes, set as a parameter in
 BAS.INC
MAXDAG maximum number of days in the simulation, set as a parameter
 in BAS.INC
MAXDEL maximum number of subbasins, set as a parameter in
 BAS.INC
MAXHYD number of 'hydrological' variables that can be used for
 output and plotting, set as a parameter in BAS.INC
MAXKEM number of 'chemical' variables that can be used for output
 and plotting, set as a parameter in BAS.INC
MAXPLS maximum number of pulses in response function, set as a
 parameter in BAS.INC
MAXPST maximum number of precipitation stations,
 set as a parameter in BAS.INC
MAXQST maximum number of discharge stations,
 set as a parameter in BAS.INC
MAXTST maximum number of temperature stations,
 set as a parameter in BAS.INC
MEAN31 mean value for the condition and variables in one month
MELT melted snow (mm/d)
MGDATA magnesium, 100*mg/l, input from KEMxxxx

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