

User's guide BILAN

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1 Introduction

The BILAN model (version 1.7) has been developed to simulate components of the water balance for a catchment. The model is based upon a set of relationships, which describe basic principles of the water balance both for the unsaturated and saturated zone. The time step is one month.

Input data used for water balance computation are monthly series of basin precipitation and air temperature. Furthermore, relative air humidity (option 1) or potential evapotranspiration series (option 2) need to be specified. To calibrate the eight model parameters (applying an optimisation algorithm), simulated and observed monthly runoff series at the outlet from the basin are compared.

The model simulates time series of monthly potential evapotranspiration (option 1), actual evapotranspiration, infiltration into the soil and recharge from the soil into the aquifer. The amount of water that is stored in the snow pack, the soil and aquifer is also simulated for each month. All these hydrological variables apply to the whole catchment (lumped physically-based model). The total runoff consists of three components, i.e. direct runoff, through flow (interflow) and base flow.

The calculation method for the monthly potential evapotranspiration (option 1) uses the temperature and relative humidity series. The temperature is also used for the distinction between winter and summer conditions (regime type). If a snow pack occurs, snow storage and melting algorithms are applied. Melting snow and rainfall infiltrate into the soil. In the soil the infiltrated water is stored that can be extracted by vegetation in following time steps. The vegetation extracts soil moisture at potential rate (potential evapotranspiration) as long as there is sufficient water in the soil. If there is insufficient water in the soil the actual evapotranspiration will drop below the potential rate. During wet months, when the precipitation exceeds the potential evapotranspiration, the surplus is used to replenish soil water storage. Subsequently, if soil moisture storage reaches maximum soil capacity, percolation from the soil occurs. The percolation from the soil can follow a quick path towards the stream through interflow or a slow path through the aquifer. A third streamflow component, i.e. direct runoff, may also occur if the rainfall amount is high.

The BILAN model computer code was written by using the DELPHI STUDIO programming system. The reader finds the executable file ('Bilan.exe') on the CD. For its execution, the 'qtintf70.dll' library has to be located in the same directory.

2 Input data

The input data are read from a file in ASCII code. Each row (or record) gives data for a particular month, whereas columns are used for individual variables. The data must be arranged in water years (hydrological years); the first month of the water year is November.

Table 1 gives the format of the input file. An example input file ('METU.dat') is stored on the CD.

Table 1 Description of input file for BILAN

Example of data	Description
120	first row: total number of months of the input data series, e.g. 120 if the length of the input series is 10 years.
4	second row: number of columns in the data file minus 1.
1971	third row: initial water year of the data series, e.g. 1971 if simulation starts on November 1970.
106.55 87.53 2.55 89 64.78	fourth and following rows contain monthly data: Column 1 – Precipitation P (mm) Column 2 – Runoff (observed) R (mm) Column 3 – Air temperature T (°C) Column 4 – Alternatively air humidity H (%) or potential evapotranspiration PE (mm) Column 5 – Optional series; this column can contain any time series. This series is not used in the computation and it is only a component of the output files and could be used in the graphic output of the model. For example, the user can use base flow series (B) estimated by using groundwater measurements (if available) to be compared with base flow calculated by BILAN model.
83.3 	data for last month of the simulation period.

2.1 Alternatives for input variables

The potential evapotranspiration series can be either calculated from the series of the air temperature and relative air humidity (option 1) or it can directly be read from the input file instead of the relative humidity series (option 2). The option need to be specified by the user by making the relevant choice in the *input file* window, which is in the first window that appears (*BILAN WATER BALANCE MODEL 1.7* window). The *BILAN WATER BALANCE MODEL 1.7* window is shown in Figure 1.

2.2 Validation of input data

After reading the input data, the program calculates mean values of all input series, which are subsequently displayed (together with other information). This allows the user to check if the correct input file was used and whether the data were correctly read.

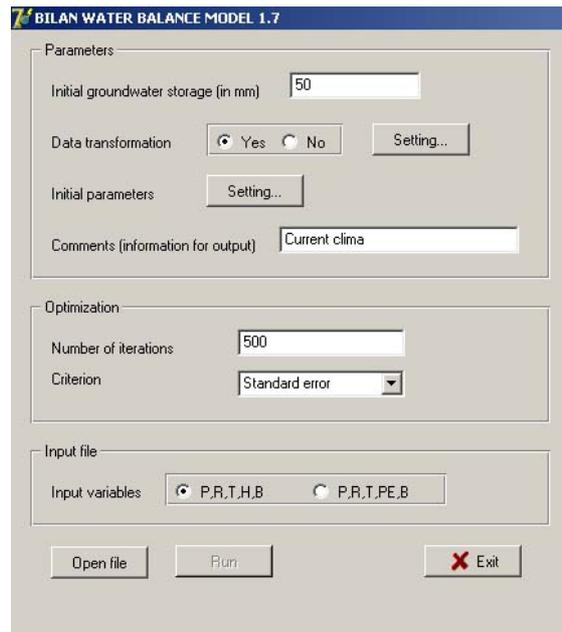


Figure 1 BILAN WATER BALANCE MODEL 1.7 window.

2.3 Input data transformation

The user of the model may wish to make transformation of some of the input data series before they are used in the computation. The tools of the program include linear transformation of the input data series, i.e. the user can set a constant to be added (addend) to all members of the selected series and/or all members of the series can be multiplied by a constant (factor). For allowed combinations (the addend, the factor or both) for individual variables see *Transformation setting* window that can be selected in the *BILAN WATER BALANCE MODEL 1.7* window.

3 Calculation of potential evapotranspiration (option 1)

The potential evapotranspiration is estimated from the saturation deficit by using functions (in form of tables) that have been derived for individual months and for different bioclimatic zones from empirical graphs given in Rekomendatsii (1976). The user should be aware of the fact that the graphs represent conditions of the Northern Hemisphere. The saturation deficit (in mbar) is calculated from data on the air temperature and relative air humidity.

The following bioclimatic zones are distinguished:

- a) tundra;
- b) coniferous forest;
- c) mixed forest;
- d) deciduous forest, and
- e) steppe.

Each bioclimatic zone is characterised by a characteristic mean air temperature. The model includes an interpolation algorithm, which uses catchment long-term average air temperature for

interpolating between the bioclimatic zones that is between particular tables. Information on the two bioclimatic zones that were used for the calculation of potential evapotranspiration in a particular catchment is given in the output of the model.

4 Initial groundwater storage

The initial conditions in the catchment can significantly affect the results of the water balance simulation, particularly during the first year. These conditions can be specified by setting the initial groundwater storage (*BILAN WATER BALANCE MODEL 1.7* window). Default value of initial groundwater storage is 50 mm. It can be changed either on the basis of knowledge of actual state of the catchment in the first month or knowledge derived from preliminary simulations.

5 Comments

The comment window in the *BILAN WATER BALANCE MODEL 1.7* window, facilitates identification of the results. The information (to be given by the user) from this window (e.g. name of the catchment, gauging station, river) is shown in the in the output of the model.

6 Model parameters

Eight free model parameters have to be identified to simulate the streamflow generation by the model (Table 2).

Table 2 Description of the model parameters of the BILAN model

Parameter	Description
<i>Spa</i>	capacity of soil moisture storage (mm)
<i>Dgm</i>	snow melting factor
<i>Dgw</i>	factor for calculating the quantity of liquid water available on the land surface under winter conditions
<i>Alf</i>	parameter for rainfall- surface runoff equation (direct runoff)
<i>Soc</i>	parameter controlling distribution of percolation into through flow (interflow) and groundwater - recharge under summer conditions
<i>Mec</i>	parameter controlling distribution of percolation into through flow (interflow) and groundwater - recharge under conditions of snow melting
<i>Wic</i>	parameter controlling distribution of percolation into through flow (interflow) and groundwater - recharge under winter conditions
<i>Grd</i>	parameter controlling outflow from groundwater storage (base flow)

6.1 Calibration of the parameters

The eight parameters of the model (Table 2) are identified (calibrated) by using an optimisation algorithm. The optimisation aims at attaining the best fit between the observed and simulated runoff series.

The calibration of the parameters is executed in two steps. In the first step, the *standard error* of estimate (standard deviation between the observed and simulated runoff series) or *mean absolute error* (mean calculated from absolute deviations between the observed and simulated runoff series, where ‘absolute’ means that negative deviations are converted to positive values) is used as the optimisation criterion to calibrate *Spa*, *Dgm*, *Dgw* and *Alf* parameters that affect significantly the mean runoff. Selection of standard error or mean absolute error can be done in the *optimization* window in the *BILAN WATER BALANCE MODEL 1.7* window.

The remaining four parameters (*Mec*, *Wic*, *Soc*, *Grd*) affecting the runoff distribution into its individual components are then calibrated by using the mean of absolute values of relative deviations (relative means that each deviation is divided by observed value). It has been demonstrated by experimental calculations that this calibration procedure ensures mostly an acceptable fit in terms of both mean runoff and low flow runoff, which is generated predominantly by base flow. The resulting mean of absolute values of relative deviations is shown (under ‘optimisation criterion’) in the output of the model.

6.2 Setting of initial values

The optimisation procedure requires initial values of the parameters and their lower and upper limits to be set by the user. The program uses default values, which normally do not have to be changed. However, the *Setting of initial parameters* window in the *BILAN WATER BALANCE MODEL 1.7* window can be used for setting alternative initial values.

6.3 Number of iterations

The values of the model parameters resulting from the optimisation algorithm can also be affected by setting the maximum number of iterations to be performed by this algorithm. The default value, which was derived from practical experience, is 500. Normally, this value does not have to be changed. The maximum number of iterations can be changed in the *optimization* window in the *BILAN WATER BALANCE MODEL 1.7* window

The program can also be run without optimisation of parameters by using the values set in *Setting of initial parameters* window. This option can be achieved by setting number of iterations of the optimization procedure as zero. This is important for scenario studies when parameter values from reference conditions need to be used.

7 Output

The output from the model consists of two types of series (Figure 2), namely monthly series and monthly averages (‘monthly characteristics’). The *monthly series* are time series of variables

(both input and output) that have been pre-processed or simulated by the model. The *monthly characteristics* include monthly mean values, mean monthly minima and mean monthly maxima that have been derived from the monthly series for each month of a year and each variable. The output of the series can be either in a form of numerical data, which can be saved in a file, or in a form of a graph of selected data series, which can be displayed and subsequently also printed. The format of the numerical data files allows these files to be directly imported into selected spreadsheet program for post-processing.

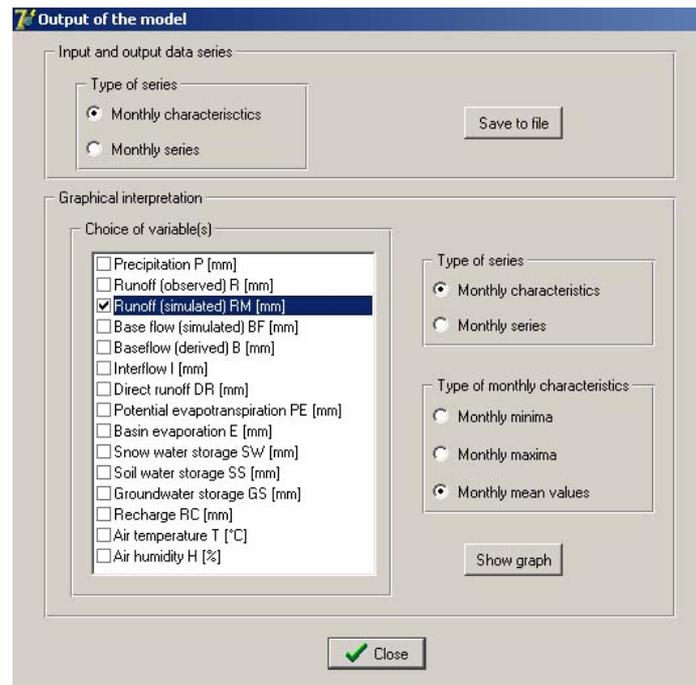


Figure 2 Output window of the BILAN model.

In addition to the monthly series or monthly characteristics, identification information and summary characteristics are given in the output. An example of the type and format of this part of the output (identical for both the monthly time series and the monthly characteristics) is shown below.

```
"BILAN model simulation - monthly series"

"Input file name", "E:\bilan\Modell11\METU.DAT"
"Initial year", 1991
"Number of months", 120
"Initial groundwater storage", 150
"Comments", "Current clima"

"Climate zone", "Coniferous forest - mixed forest"

"Mean annual values of input and output series"
```

```
"P [mm] ", "R [mm] ", "PE [mm] ", "RM [mm] ", "E [mm] ", "BF [mm] ", "DR [mm] ", "I
[mm] ", "H [%] ", "SS [mm] ", "T [°C] ", "GS [mm] "
765.2, 362.6, 479.7, 341.3, 424.9, 219.9, 34.01, 87.41, 81.19, 34.08, 5.
699, 169.9
```

```
"Resulting parameters of the model"
```

```
"Spa", "Dgm", "Dgw", "Alf", "Soc", "Mec", "Wic", "Grd"
42.9, 33.98, 9.697, 0.0009203, 0.1468, 0.5576, 0.2592, 0.1076
```

```
"Optimization criterion"
```

```
0.2426
```

Water balance components (*P*, *R*, *RM*, *BF*, *B*, *I*, *DR*, *PE*, *E*, *RC*) are expressed as monthly and annual totals in mm (mm year⁻¹, mm month⁻¹).

Components of water storage (*SW*, *SS*, *GS*) are expressed as columns of water (mm).

The output for the *monthly series* has a matrix form. Each row of the matrix gives data for one particular month (e.g. November 1991), whereas individual variables form the columns of the matrix. The first two columns are used to specify (rank) the month and year. Rank of months and years is identical to that in the input file. Below an example is presented for the monthly series.

```
"Monthly time series of output variables"
```

```
"Rank
```

```
number", "Year", "P [mm] ", "R [mm] ", "RM [mm] ", "BF [mm] ", "B [mm] ", "I [mm
] ", "DR [mm] ", "PE [mm] ", "E [mm] ", "SW [mm] ", "SS [mm] ", "GS [mm] ", "RC [mm
] ", "T [°C] ", "H [%] "
```

```
1, 1991, 80, 21.71, 31.1, 16.13, 11.45, 9.074, 5.89, 12.29, 12.29, 0, 42.9
, 186.6, 52.75, 2.27, 75.7
```

```
2, 1991, 72, 28.42, 33.2, 20.07, 11.89, 13.13, 0, 6.763, 6.763, 14.59, 42.
9, 204.1, 37.52, -2.777, 72.71
```

```
...
```

In the output of *monthly characteristics*, a matrix is given for each variable. Rows of the matrixes contain data for individual months of a year (e.g. November), whereas the columns of the matrixes contain month, minimum value, mean value and maximum value. An example for the monthly characteristics is presented below.

```
"Monthly characteristics of input and output variables"
```

```
"Precipitation P [mm] "
```

```

"Month", "Min", "Mean", "Max"
"XI", 24.1, 52.98, 80
"XII", 25.8, 67.93, 152.9
"I", 1.2, 52.3, 137.2
"II", 18.9, 39.84, 73.4
"III", 22.5, 72.84, 200.8
"IV", 5.2, 37.94, 72.6
"V", 21.2, 65.07, 102.5
"VI", 21.3, 83.58, 146.9
"VII", 20.8, 110, 306.6
"VIII", 26.8, 60.99, 102.2
"IX", 24.3, 72.8, 122.9
"X", 0, 48.99, 176.2

```

```
"Runoff (observed) R [mm]"
```

```

"Month", "Min", "Mean", "Max"
"XI", 12.98, 23.35, 65.61

```

...

8 Error messages

The model BILAN comes with different type of error messages, for example, if the model is fed with inappropriate input data or specification of output is incorrect. An overview of the error messages is given in this section.

8.1 Opening and reading of input file

Possible error messages associated with opening and reading of the input file is presented below.

Error in opening input file

Error in reading input file

Invalid format of input data

Input file must not contain less than four data columns

8.2 Input data transformation

The tools of the program include linear transformation of the input data series (Figure 3), i.e. the user can set a constant to be added to each member of some of the series (addend) and/or individual members of some of the series can be multiplied by the specified constant (factor). The error message below is shown if invalid character(s) in this specification are notified.

Invalid value of P/R/T/H factor/addend

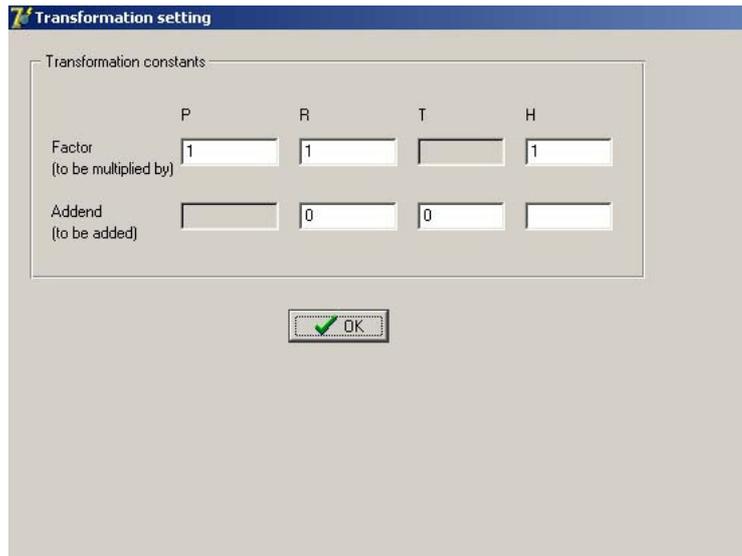


Figure 3 Transformation setting window; option to change input time series.

8.3 Initial groundwater storage

The user of the model can set the initial groundwater storage (default value is 50 mm). Invalid character(s) in this specification are notified by displaying an error message as given below.

Invalid value of initial groundwater storage

8.4 Setting of initial parameters

For successful completion of the optimization procedure, the initial values of the parameters (to be set by the user) should not be close to the lower or upper limits. If such situation occurs, the user is notified by an error message as displayed below. The rank number refers to the following sequence of the parameters: Spa, Dgm, Dgw, Alf, Soc, Mec, Wic and Grd.

Initial value of parameter Spa/Dgm/Dgw/Alf/Soc/Mec/Wic/Grd is too close to its lower or upper limit. Check and reset its value in Setting of initial parameters dialog box.

Invalid character(s) in specification of the initial parameters or the limits are notified by displaying the following error message.

Invalid value of Spa/Dgm/Dgw/Alf/Soc/Mec/Wic/Grd initial value/lower limit/upper limit

8.5 Setting of number of iterations

The user of the model can set number of iterations to be performed by the optimisation algorithm. Invalid character(s) in this specification are notified by displaying an error message as shown below.

Invalid value of number of iterations

8.6 Calculation of potential evapotranspiration

The method that is applied for simulation of potential evapotranspiration (option 1) uses saturation deficit, which is calculated from air temperature and relative air humidity. For extreme, improbable or erroneous combinations of these variables, the resulting saturation deficit can either be less than zero or it can exceed calculation limits of the method (values outside the range of given tables) that is used for derivation of the potential evapotranspiration.

If the saturation deficit is less than zero, the execution of the program is terminated and correction of the data is required. The user is notified by displaying an error message as given below.

Saturation deficit that was derived from the air temperature and relative air humidity for x-th month is less than zero. Correction of the data is required.

If the saturation deficit exceeds the calculation limits, the execution of the program is not terminated but the user is notified by displaying an error message as presented below.

Saturation deficit that was derived from the air temperature and relative air humidity for x-th month exceeds calculation limit of the method used for derivation of potential evapotranspiration. Maximum possible value was substituted.

8.7 Graphical interpretation

The input and output data series can be displayed in a graph. Associated error messages are given. In the *Graph* window in the *Output of the model* window, the user is assumed to specify variables to be displayed in the graph. If no variable is selected or if the number of the variables exceeds 8, the following error message is given.

Nothing selected to be displayed
Maximum number of variables to be displayed is 8

The user can also set some scale parameters for the graph. Invalid character(s) in this specification lead to error message as shown below.

Invalid value of X min
Invalid value of X max
Invalid value of Y min
Invalid value of Y max
Invalid value of X grid
Invalid value of Y grid

List of symbols

<i>P</i>	Precipitation (mm month ⁻¹)
<i>R</i>	Runoff (observed) (mm month ⁻¹)
<i>RM</i>	Runoff (simulated) (mm month ⁻¹)
<i>BF</i>	Base flow (simulated) (mm month ⁻¹)
<i>B</i>	Base flow (derived) (mm month ⁻¹)
<i>I</i>	Through flow (interflow) (mm month ⁻¹)
<i>DR</i>	Direct runoff (mm month ⁻¹)
<i>PE</i>	Potential evapotranspiration (mm month ⁻¹)
<i>E</i>	Catchment evapotranspiration (mm month ⁻¹)
<i>SW</i>	Snow water storage (mm)
<i>SS</i>	Soil water storage (mm)
<i>GS</i>	Groundwater storage (mm)
<i>RC</i>	Recharge (mm month ⁻¹)
<i>T</i>	Air temperature (°C)
<i>H</i>	Air humidity (%)

References

Rekomendatsii (1976) Rekomendatsii po roschotu ispareniiia s poverhnosti suchi (Guidelines for calculation of evaporation from land surface). *Gidrometeoizdat*, St. Peterburg, Russia.