European Water 5/6: 3-11, 2004.

Medbasin: a Mediterranean rainfall-runoff software package

D. Tigkas and G. Tsakiris
Lab. of Reclamation Works & Water Resources Management
National Technical University of Athens
9, Iroon Polytechniou, 15780 Athens – Greece
water@survey.ntua.gr

Abstract: A deterministic conceptual rainfall-runoff simulation model is proposed for the Mediterranean basins. The model is based on the equations describing the processes of the hydrological cycle used by MERO, a model proposed by FAO. The new software package called Medbasin is using an accounting technique in which the inputs are the daily values of precipitation and potential evapotranspiration and the outputs are the daily runoff and water storage in the soil. The paper describes the background of the model and proposes methods for its calibration and verification. The model's performance is considered satisfactory based on a number of applications in hydrological basins in the Mediterranean region.

Key words: rainfall-runoff model, conceptual model, Mediterranean region, water resources management

1. INTRODUCTION

Since streamflow data are not easily available for planning, designing or management of river flows, it is common practice to use rainfall-runoff models to acquire such data. Therefore using this type of models and rainfall data, which can be found virtually everywhere, can be transformed to streamflow data.

Since the development of the Stanford Watershed Model in 1966 by Crawford and Linsley, there has been a proliferation of such models. Although models have been developed to serve different purposes they exhibit structural similarities. They can be classified according to different criteria that may encompass the process description, the scale and the technique of solution. Comprehensive presentations of rainfall-runoff models may be found in various publications (Singh, 1995).

According to Abbott and Refsgaard (1996) rainfall-runoff models may be either deterministic or stochastic. Further a deterministic model may be empirical, lumped, conceptual or distributed / physically based.

From the various categories of rainfall-runoff models the most popular ones are the lumped conceptual deterministic models. A huge variety of these models have been used in the past with varying degree of success.

A well known conceptual model used for applications in the Mediterranean river basins is the MERO, proposed by FAO in the sixties.

In this paper an up-to-date modified version of MERO is presented which is user-friendly and has enhanced facilities for calibration and verification. The created package is called Medbasin.

2. THEORETICAL BACKGROUND

2.1 The rainfall-runoff model

Medbasin is a comprehensive deterministic conceptual daily rainfall-runoff simulation model which is based on the basic principles of MERO, suitable for applications in the Mediterranean basins. The hydrological cycle processes and the interactions between them are described within the model by empirical relationships. Examples of such relationships are the overland flow function, the interflow function and the soil water storage – recharge relationship (Giakoumakis et al., 1991). Daily values of average precipitation and potential evapotranspiration at a basin scale are used as input data, while daily and monthly runoff is the output of the model. An accounting procedure is followed in which the precipitation (input) passes through several storage zones, from each of which some outflow is removed until the whole input has been accounted for (Underhill et al., 1970).

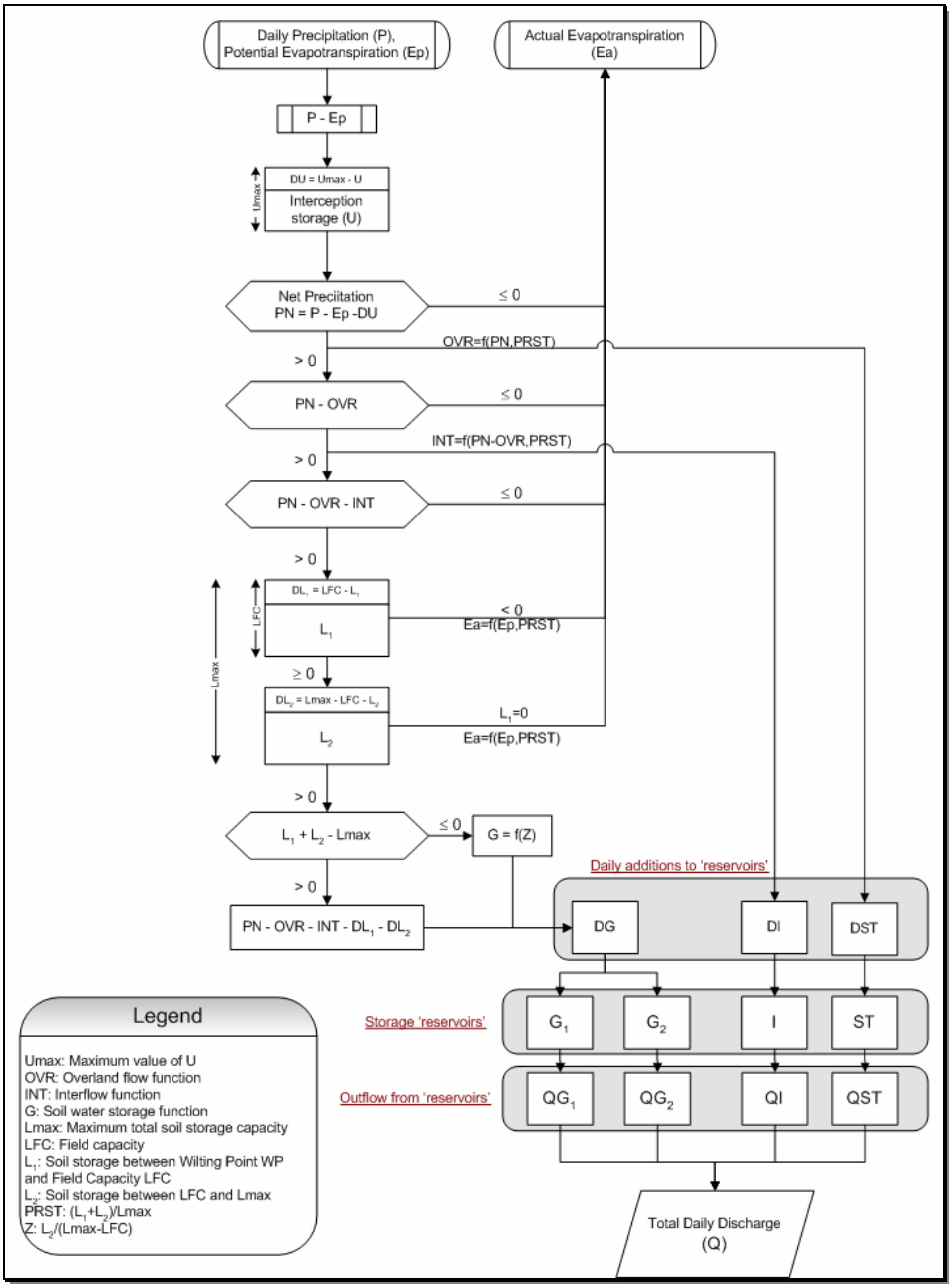


Figure 1. The flow chart of the model.

The soil is divided into two different interconnected storage reservoirs: the interception storage (U) and the total groundwater storage (L). The groundwater storage L is further divided in the upper soil zone (L_1) which may be considered as the root zone and in which soil moisture can reach a maximum value up to field capacity (L_{FC}), and the lower zone (L_2) which receives moisture from L_1 when field capacity is exceeded (Giakoumakis et al, 1991).

The river flow is the sum of outflows from four reservoirs: the overland flow reservoir ST, the interflow reservoir I, the temporary spring reservoir G_1 and the permanent spring reservoir G_2.

The distribution of the moisture over the various storage zones is described by the following rules. Precipitation (P) is added to interception storage (U). If U is not less than the potential evapotranspiration (Ep), evaporation takes place from U, otherwise evaporation occurs from the soil moisture L. If the interception storage has a value greater than its maximum U_{max} the additions STPR to the storm runoff reservoir ST_{mm} and GPR to the interflow reservoir IN_{mm} are calculated, accordingly. If I is less than I_{max}, there is an addition to the interflow reservoir only if the soil moisture L is greater than its maximum L_{max}. The addition GWPR to the shallow and deep spring reservoirs occurs when the soil moisture L is greater than the field capacity (L_{FC}).

The maximum value of interception storage (U_{max}) as well as the maximum total soil moisture capacity of both zones (L_{max}) and the field capacity (L_{FC}), are not usually based on actual field measurements, but they are determined during the model calibration stage to give the best possible fit with the measured runoff volumes.

The reservoirs release water to the river according to a delay function:

$$F = (1\text{-}\exp(-1/T_0)) \qquad (1)$$

where T_0 is a characteristic value for each reservoir.

Within the model certain intake areas are defined for each one of the reservoirs. The total area of the basin is allocated to the storm runoff reservoir. To the remaining reservoirs, portions of the basin are assigned which normally make up the total area. If there are losses from the basin via underground flow, the total area should not be allocated to the remaining reservoirs. The volume of underground flow (deep percolation) is equal to the total moisture flow to the spring reservoir multiplied by the area which is not allocated. On the other hand, if there is underground inflow the sum of the allocated areas should be greater than the area of the basin.

2.2 Equations

The precipitation is added to the interception storage, after which the potential evapotranspiration is subtracted. If the resulting net precipitation (P_N) is negative, evaporation occurs from the soil moisture according to the following equation:

$$DL = P_N \cdot L_1 / L_{FC} \qquad (2)$$

where DL is the depletion of soil moisture by evaporation, L_1 is the soil moisture in the upper soil zone and L_{FC} is the field capacity.

The addition to the storm runoff reservoir (STPR) is calculated according to certain infiltration formulae (Schenkenveld, 1971):

$$STPR = (-0.32 + 0.071 \cdot P_N + 0.05 \cdot (PRST - 0.5) - Q_0) \cdot CT \qquad \text{if } PN \leq 10\text{ mm} \qquad (3)$$

$$STPR = (-0.45 + 0.06 \cdot P_N + 0.0025 \cdot P_N^2 - 0.00001 \cdot P_N^3 + 0.25 \cdot (P_N - 8) \cdot (PRST - 0.5) - Q_0) \cdot CT$$

$$\text{if } PN > 10\text{ mm} \qquad (4)$$

A third equation may also be utilised (Phanartzis, 1972):

$$STPR = (1.43 - 0.039 \cdot P_N + 0.0032 \cdot P_N^2 - 0.000003 \cdot P_N^3 + 0.25 \cdot (P_N - 8) \cdot (PRST - 0.5) - Q_0) \cdot CT$$

$$\text{if } PN > 40\text{ mm} \qquad (5)$$

where PRST is the ratio of soil moisture to the soil moisture storage capacity (L_{max}), Q_0 and CT are constants.

The addition to the interflow reservoir (GPR) is calculated in two steps, the first according to the ratio of the soil moisture:

$$GPR = P_N \cdot L / L_{max} \cdot CO_3 \tag{6}$$

where CO_3 takes into account the area concept of the model and ensures consistency in the volumes. In the second step, any soil moisture GW in excess of L_{max} is added:

$$GPR = GPR + GW \cdot CO_3 \tag{7}$$

The addition to the spring reservoirs is (Schenkenveld, 1971):

$$GWPR = CL_2 \cdot L_2^2 \ / (L_{max} - LFC) \tag{8}$$

where CL_2 is a constant in the range 0.001 to 0.1 and L_2 is the soil moisture in storage in the lower soil zone.

The remainder of the excess over L_{max} is added to GWPR according to:

$$GWPR' = GW + GWPR \cdot CO_{12} \tag{9}$$

where CO_{12} is a factor related to the area and ensures consistency in flow volume.

Any remainder from the total area is assigned to deep percolation, which represents water that escapes underground from the basin. If there is any underground inflow into the basin the value of this remainder is negative (Underhill et al., 1970). If a part of the total runoff is contributed by spring flow (Q_{sp}) which is considered as an inflow to the basin, it is taken as input to the model (Schenkenveld, 1971).

Finally, the daily runoff (Q) is:

$$Q = ST + IN + S_1 + S_2 + (Q_{sp}) \tag{10}$$

where Q is the runoff of the river, ST the flow from storm runoff reservoir, IN the flow from inflow reservoir, S_1 the flow from temporary spring reservoir, S_2 the flow from permanent spring reservoir and Q_{sp} the spring flow. All the above values are in daily basis.

2.3 Calibration

The model has fourteen calibration parameters which represent the physical characteristics of the basin:

- U_{max}, L_{max} and L_{FC} limit the size of the basin
- A_1, A_2, A_3 and A_4 represent the intake areas for the reservoirs determining their respective outflow
- T_{01}, T_{02}, T_{03} and T_{04} are the delay constants for the outflow of the reservoirs
- Constants that used for the size of the storm runoff: CT as a multiplier and Q_0 as the amount that should be added or subtracted initially
- CL_2 controls the flow to the spring reservoirs

Calibration process is usually applied to a portion of the available dataset and may follow a manual (trial-and-error) or automatic (based on objective functions) procedure by comparing the model estimated runoff values with the measured ones. The Route Mean Square Error (RMSE) is the objective function used in Medbasin:

$$RMSE = \left(\sum [q_{sim} - q_{obs}]^2 / n\right)^{-1/2} \tag{11}$$

where q_{sim} is the simulated discharge, q_{obs} is the observed discharge and n is the total number of observations. This function is the unbiased, minimum variance estimator, and it is the Maximum Likelihood Estimator under the assumption that measurement errors ($e = q_{sim} - q_{obs}$) are normally distributed with zero mean and constant variance σ^2 (Yapo et al., 1998).

2.4 Verification

For the verification of the results five criteria are used (WMO, 1975, 1986, 1992, Cavadias and Morin, 1986):

- The coefficient of variation of the residual of errors for the discharge variables

$$Y = \frac{\left(\sum [q_{sim} - q_{obs}]^2 / n\right)^{-1/2}}{\overline{q}_{obs}} \tag{12}$$

- The ratio of relative error to the mean of the discharge variables

$$R = \frac{\sum (q_{sim} - q_{obs})}{n\overline{q}_{obs}} \tag{13}$$

- The ratio of absolute error to the mean of the discharge variables

$$A = \frac{\sum | q_{sim} - q_{obs} |}{n\overline{q}_{obs}} \tag{14}$$

- The arithmetic mean of the discharge variables

$$D = \frac{\sum q_{sim,obs}}{n} \tag{15}$$

- One minus the ratio of the sum of squares of the daily residuals to the sum of squares of the deviations of the observed flows from their mean

$$NTD = 1 - \frac{\sum (q_{sim} - q_{obs})^2}{\sum (q_{obs} - \overline{q}_{obs})^2} \tag{16}$$

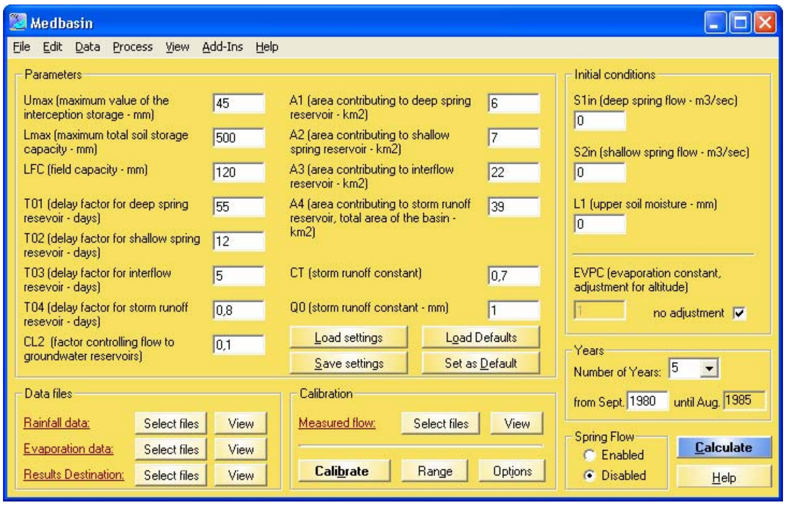
where $q_{obs,sim}$ is the observed and the simulated discharges and $\overline{q}_{obs}$ is the mean of the observed values.

3. SOFTWARE INTERFACE

3.1 General description

The software interface of Medbasin has been developed mainly with the Visual Basic 6 programming language. The recommended system requirements are a personal computer with Pentium 4 processor, 256MB of RAM and a Windows operating system.

When designing the Medbasin interface the focus was on structural simplicity, usability and giving the user direct access to each function of the programme. The parameters of the model, the values of the initial conditions for the deep and shallow spring flow ($S1_{in}$, $S2_{in}$) and the upper soil moisture (L_1), as well as the EVPC evaporation constant, can be assigned directly from the main window of the programme. The number and the period of water years which are used for the calculation of the leap years are also defined in this window.



Umax (maximum value of the interception storage - mm) 45
Lmax (maximum total soil storage capacity - mm) 500
LFC (field capacity - mm) 120
T01 (delay factor for deep spring resevoir - days) 55
T02 (delay factor for shallow spring resevoir - days) 12
T03 (delay factor for interflow resevoir - days) 5
T04 (delay factor for storm runoff resevoir - days) 0,8
CL2 (factor controlling flow to groundwater reservoirs) 0,1
A1 (area contributing to deep spring reservoir - km2) 6
A2 (area contributing to shallow spring reservoir - km2) 7
A3 (area contributing to interflow reservoir - km2) 22
A4 (area contributing to storm runoff reservoir, total area of the basin - km2) 39
CT (storm runoff constant) 0,7
Q0 (storm runoff constant - mm) 1
S1in (deep spring flow - m3/sec) 0
S2in (shallow spring flow - m3/sec) 0
L1 (upper soil moisture - mm) 0
EVPC (evaporation constant, adjustment for altitude) 1 no adjustment ☑
Number of Years: 5
from Sept. 1980 until Aug. 1985
○ Enabled
● Disabled

Figure 2. Main Window.

All the basic commands, options and other settings can be accessed or executed from the menu list of the programme. The structure of the menu appears in Fig. 3.

3.2 Data input

Data used by the programme are on daily basis. Surface average precipitation and potential evapotranspiration are required. If there is a spring which contributes to the river runoff and its water supply is located in an area outside the basin, average monthly spring flow data is accounted as input to the model. Measured river flow is also required for the calibration process.

Datasets can be imported in the programme from Excel worksheet archives. The appropriate input files can be selected and loaded from the data selection windows for precipitation, evaporation, spring flow and measured streamflow data, respectively.

Regarding the evaporation data, there is the option to use directly potential evapotranspiration (Ep) values or to calculate Ep from pan evaporation data (E). For the latter option E is multiplied with a standard annual constant or monthly constants, if the correlation between E and Ep is known for the region under study (e.g. Vardavas et al., 1997).

The software also includes a subroutine to handle data gaps in the datasets. In such cases the gaps are either replaced by zeros or by using an interpolation algorithm in the case of evaporation data.

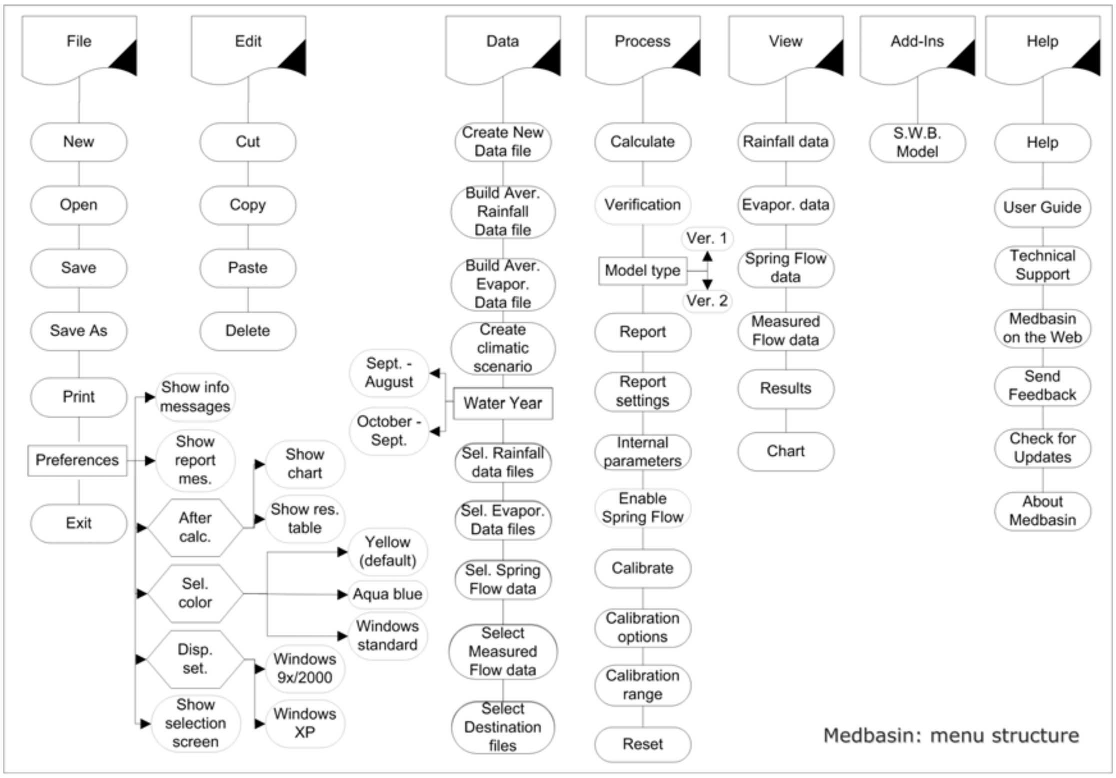


Figure 3. The structure of Medbasin menu.

3.3 Calibration procedure

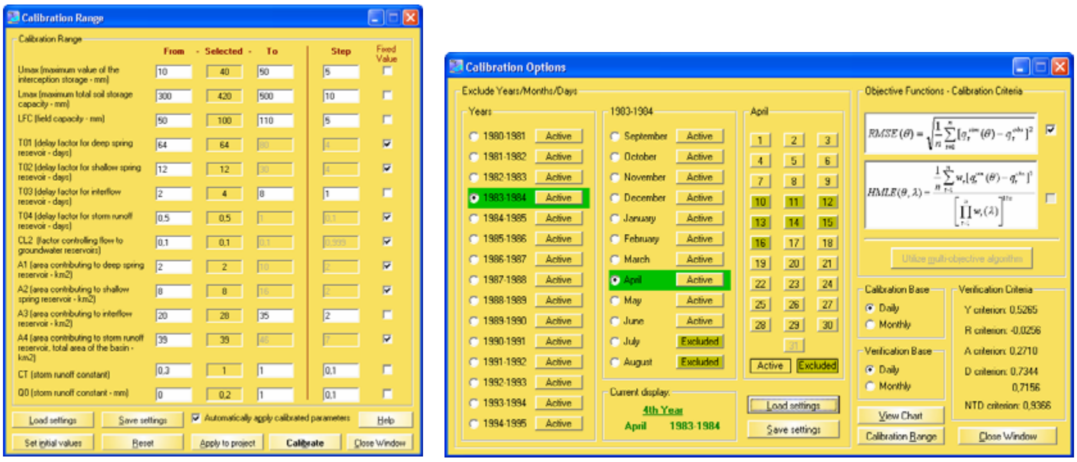
As it has already been mentioned, the calibration of the model can be performed either manually or automatically. Medbasin includes a semi-automatic calibration procedure which is based on an iterative routine. The range of values for each parameter has to be defined. The selection of these limits depends on the characteristics of the watershed.

The optimisation process intents to specify the set of parameters which minimizes the selected objective function. The procedure may be repeated several times, by changing the range and the ‘fixed value’ option of the parameters, until a satisfying value of the objective function is being achieved.

In the ‘Calibration Options’ window it is possible to exclude data from the calibration procedure. Data exclusion is the way for avoiding problems caused by incorrect or incomplete data. However, it can also be used as a technique to focus the optimisation on specific parts of the hydrograph (e.g. peaks).

3.4 Results - Reports

Loaded data and the runoff simulation results are displayed in data grids and can also be projected graphically in the Chart window, as single series or combination charts. There are several 2D and 3D projection options, of daily or monthly basis for the specified period of years. The charts can be printed, saved as bitmaps or exported to compatible grid-based programmes (MS Excel, Surfer etc.).



Calibration Range

Calibration Range	From	Selected	To	Step	Fixed Value
Umax (maximum value of the interception storage - mm)	10	40	50	5	☐
Lmax (maximum total soil storage capacity - mm)	300	420	500	10	☐
LFC (field capacity - mm)	50	100	110	5	☐
T01 (delay factor for deep spring reservoir - days)	64	64	80	4	☑
T02 (delay factor for shallow spring reservoir - days)	12	12	30	4	☑
T03 (delay factor for interflow reservoir - days)	2	4	8	1	☐
T04 (delay factor for storm runoff reservoir - days)	0.5	0.5	1	0.1	☑
CL2 (factor controlling flow to groundwater reservoirs)	0.1	0.1	0.1	0.999	☑
A1 (area contributing to deep spring reservoir - km2)	2	2	10	2	☑
A2 (area contributing to shallow spring reservoir - km2)	8	8	16	2	☑
A3 (area contributing to interflow reservoir - km2)	20	28	35	2	☐
A4 (area contributing to storm runoff reservoir, total area of the basin - km2)	39	39	46	7	☑
CT (storm runoff constant)	0.3	1	1	0.1	☐
Q0 (storm runoff constant - mm)	0	0.2	1	0.1	☐

☑ Automatically apply calibrated parameters

Calibration Options

Exclude Years/Months/Days

Years: ○ 1980-1981 Active; ○ 1981-1982 Active; ○ 1982-1983 Active; ● 1983-1984 Active; ○ 1984-1985 Active; ○ 1985-1986 Active; ○ 1986-1987 Active; ○ 1987-1988 Active; ○ 1988-1989 Active; ○ 1989-1990 Active; ○ 1990-1991 Active; ○ 1991-1992 Active; ○ 1992-1993 Active; ○ 1993-1994 Active; ○ 1994-1995 Active

1983-1984: ○ September Active; ○ October Active; ○ November Active; ○ December Active; ○ January Active; ○ February Active; ○ March Active; ● April Active; ○ May Active; ○ June Active; ○ July Excluded; ○ August Excluded

April: 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31

Active Excluded

Current display: 4th Year, April 1983-1984

Objective Functions - Calibration Criteria

☑ $RMSE(\theta) = \sqrt{\frac{1}{n}\sum_{t=1}^{n}[q_t^{sim}(\theta) - q_t^{obs}]^2}$

☐ $HMLE(\theta,\lambda) = \frac{\frac{1}{n}\sum_{t=1}^{n} w_t[q_t^{sim}(\theta) - q_t^{obs}]^2}{\left[\prod_{t=1}^{n} w_t(\lambda)\right]^{1/n}}$

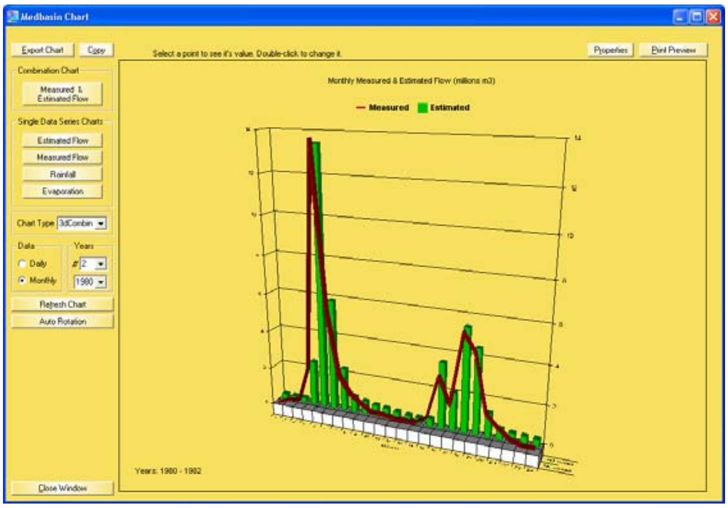
Calibration Base: ● Daily ○ Monthly

Verification Base: ● Daily ○ Monthly

Verification Criteria:
Y criterion: 0,5265
R criterion: -0,0256
A criterion: 0,2710
D criterion: 0,7344
0,7156
NTD criterion: 0,9366

Figure 4. The windows of calibration settings.

A list of the values of the internal parameters of the model and a report of the calibration and verification criteria is being created, after the end of the calibration or the runoff simulation procedures.



Medbasin Chart

Select a point to see it's value. Double-click to change it.

Chart Type: 3dCombin

Data: ○ Daily ● Monthly

Years: #2, 1980

Years: 1980 - 1982

Figure 5. Chart projections of the observed and simulated hydrographs.

A detailed calibration report file may also be created, containing the optimum parameters' sets (depending on the value of the objective function), as well as the calibration and verification criteria, respectively.

4. CONCLUDING REMARKS

A software package called Medbasin was presented. The package is based on the deterministic, lumped, conceptual model of F.A.O., MERO, which has been used extensively in many hydrological basins of the Mediterranean region for the simulation of rainfall-runoff relationship.

The software package is easy to use following the calibration and verification procedures which are incorporated in the package. Graphical representations help the user to understand the data and the results and identify possible mistakes.

Although the trend in watershed modelling is to devise distributed physically based models, these models cannot be used in a scientifically sound basis in Mediterranean region due to the lack of detailed spatial data and the ambiguous calibration and verification procedures adopted by this type of models.

On the contrary, Medbasin offers a powerful friendly package, working on a daily time basis which exploits the facilities of the modern personal computers, giving flexibility for possible human involvement in a number of stages during the execution of calculations.

ACKNOWLEDGEMENTS

Parts of Medbasin software package were developed within the framework of EU-MEDA 'MEDROPLAN' project. The financial support from MEDROPLAN is acknowledged.

REFERENCES

Abbott, M., Refsgaard, J., 1996, Distributed Hydrological Modelling. Kluwer Academic Publisers.

Cavadias, G., Morin, G., 1986, The combination of simulated discharges of hydrological models. Application to the WMO intercomparison of conceptual models of snowmelt runoff. Nordic Hydrology; 17: 21-32.

Giakoumakis, S., Tsakiris, G., Efremides, D., 1991, On the rainfall-runoff modelling in a Mediterranean region environment. In Advances in water resources technology. Tsakiris G., ed. A. A. Balkema Publishers, Rotterdam.

Phanartzis, C. A., 1972. Morphou – Tylliria feasibility studies. Simulation of watershed runoff in Morphou – Tylliria area. AGL:SF/CYP.513, Technical Report.

Schenkeveld, M. M., 1971. Study of water resources and their exploitation for irrigation in eastern Crete. Watershed of Messara basins. Food and Agriculture Organization of the U.N. - Working document No. 24. Iraklio, Greece.

Singh, V. P. (ed.), 1995. Computer models of Watershed Hydrology. Water Resources Publications. Colorado, USA.

Underhill, H. W., Schenkeveld, M. M., Goodwill, I. M., 1970. Study of water resources and their exploitation for irrigation in eastern Crete. Trials of mathematical watershed model for runoff simulation. Food and Agriculture Organization of the U.N. - Provisional document, Iraklio, Greece.

Vardavas, I. M., Papamastorakis, G., Fountoulakis, A., Manousakis, M., 1997. Water resources in the desertification-threatened Messara Valley of Crete: estimation of potential lake evaporation. Ecological Modelling; 102: 363-374.

World Meteorological Organization (WMO), 1975. Intercomparison of conceptual models used in operational hydrological forecasting. Operational Hydrology Report No. 7. WMO – No 429. Secretariat of the WMO, Geneva, Switzerland.

World Meteorological Organization (WMO), 1986. Intercomparison of models of snowmelt runoff. Operational Hydrology Report No. 23. WMO – No 646. Secretariat of the WMO, Geneva, Switzerland.

World Meteorological Organization (WMO), 1992. Simulated real-time intercomparison of hydrological models. Operational Hydrology Report No. 38. WMO – No. 779. Secretariat of the WMO, Geneva, Switzerland.

Yapo, P. O., Gupta, H. V., Sorooshian, S., 1998. Multi – objective global optimisation for hydrologic models. J. Hydrol.; 204: 83-97.