Hydrologic modelation performance assessment to estimate runoff series

Joana MATIAS, Rodrigo PROENÇA DE OLIVEIRA

Instituto Superior Técnico, Lisboa, Portugal

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Abstract

The aim of this study is to evaluate the performance of the hydrological model of Thornthwaite-Mather to simulate the flow of a given watershed. This study is divided into two parts: (1) to evaluate the model's simulation capability for monthly and daily calculation steps, (2) to verify the relation of the model parameters with the characteristics of the watershed. To carry out this analysis, the model was applied to 25 watersheds in continental Portugal with scares human intervention, using the *add-in XLWAT 4.0* to *MS-Excel*. The parameters used in the model calibration are the usable water capacity of the soil, $H^{máx}$, and the coefficient of distribution of flow, α. The results show that Thornthwaite-Mather model can run on a daily or monthly time step. The values for $H^{máx}$ and α parameters are the following: for $H^{máx}$ values are the same for both simulations; values of α_{day} , in a daily simulation, are relate to α_{month}, in a monthly simulation, through a function. It is also possible to verify the possibility of parameter regionalization. In the North and Center regions, the values of $H^{máx}$ parameter are between 200mm and 300mm and the parameter α_{month} is constant between 0.5 and 0.7. In the Alentejo and Algarve regions, the values of $H^{máx}$ parameter are between 100mm and 250mm and the parameter α_{month} is around 0.7 and 0.9. The α_{day} values can be obtained from the monthly simulation.

Key-words: Hydrologic modelation performance, Thornthwaite-Mather model, XLWAT 4.0, Parameter calibration and validation, Parameter regionalization

1. Introduction

According to authors Krause, Boyle and Base (2005), there are several reasons why it is necessary to evaluate the performance of hydrological models: (1) to provide a quantitative estimation of model's ability to reproduce the behavior of a watershed; (2) to provide means to assess improvements to the models (adjusting the parameters, structural changes, including additional watershed information and its representation of spatial or temporal characteristics); (3) to compare current modeling efforts with previous results.

The precipitation-runoff transformation models can be formulated in many time scales such as day or month. The main difference between these models is the degree of detail with which each processes involved in the hydrological cycle is represented (Star, 1992). However, models with smaller time intervals (hours or days) require larger amounts of data compared with monthly or yearly models (Xu & Singh, 1998).

According to Estrela (1992), models with few parameters are widely used for three main reasons: (1) Not always the purpose of the study justifies time scales simulations lower than the month; (2) Lack of availability of data for more complex models application; (3) Convenience to simulate and compare data at a higher temporal scale before proceeding to the evaluation of water resources at a lower scale.

It will be possible that the same aggregate model, with few parameters, can be used in simulations with different time scales and still produce good results?

1.1. Thornthwaite-Mather Model

The Thornthwaite-Mather water balance of soil was developed by Thornthwaite (1948) and formally introduced in Thornthwaite and Mather (1955, 1957). This model is mainly used on a monthly scale The advantage of using a smaller interval of time (day) is to obtain better resolution of the flow series, i.e., some effects are attenuated when using higher time intervals (months or years). Model extension to smaller time scales proposed in this study can be quite important in watershed management. For example, if the first part of the month is moist and the second part is dried, taking into account the evaporation and the precipitation potential during the month, can be foreseen water shortage (Steenhuis & Van der Molen, 1986).

To calculate Thornthwaite-Mather water balance it is used the MS-Excel add-in XLWAT 4.0. In this way, it is possible to make modeling process fastest and most effective. The formulation of the model is available in Oliveira & Simões (2016).

To calculate the potential evapotranspiration, ETP, is used the Thornthwaite formula. The fact that this formula depends only on temperature can be a disadvantage. Other variables such as wind speed, humidity or solar radiation can be decisive in determining the magnitude of potential evapotranspiration, depending on the region and season (Chen, Gao, Xu, Guo, & Ren, 2005). Camargo and Camargo (2000) conclude that under arid conditions, the Thornthwaite model underestimates the value of ETP_t, because it does not consider the advective energy received from distant dry areas. However, due to its ease of use and the good results obtained by Portela & Santos (2007), the use of this formula is justified.

The Thornthwaite-Mather model parameters are: H_{max} (mm), available water capacity in the soil and α, flow partition coefficient between time t and future time intervals. There are some variations in parameter values when it is changed the simulation calculation interval from monthly to daily. In the case of H_{max}, there is no change in the parameter value. H_{max} is the capacity of the reservoir that represents the unsaturated zone of the soil, in mm, so the value to be assigned to this parameter in a monthly or daily simulation should be equal (Oliveira & Simões, 2016).The same is not true for α. This parameter has no units and represents the portion of surplus that contributes to the surface runoff in the next time interval, depending on the time interval (Oliveira & Simões, 2016). Several experiments performed by the authors Oliveira & Simões (2016) indicate the approximate relationship between the values of the parameter α_{day}, for daily simulations and α_{month}, for monthly simulations, presented in Figure 1 .

The evaluation of the degree of adjustment achieved between the observed and simulated flow series can only be made based on the results obtained through the calibration and validation processes (Vaz, 2010).

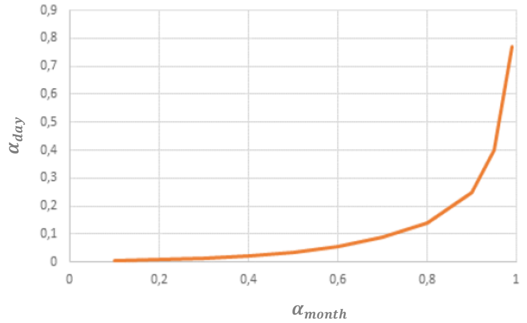

Figure 1 - Relation between the values of α parameter for simulations with daily (α_{day}) and monthly (α_{month}) calculation interval (Oliveira & Simões, XLWAT - hydrological modeling add-in for MS-Excel, 2016).

2. Methodology

For this study watersheds that meet the following criteria are selected: (a) watersheds in natural system located entirely in mainland Portugal; (b) watersheds with monthly flow/average daily flow data over 18 years; (c) watersheds with meteorological data available for the study period; (d) watersheds that are mostly inside Portugal. There are 26 watersheds that follow this criteria. For this selection, the hydrological and climatological data available for each watershed was analyzed, using (SNIRH, 2015).

In order to simplify the analysis of results, continental Portugal map is divided into 5 regions: Norte, Centro, Tejo, Alentejo and Algarve. This division is made according to the APA Regional Department (Water). Thus, the Norte region encompasses RH1, RH2 and RH3; the Cento region includes RH4; RH5 is included in the Tejo region; the Alentejo region encompasses RH6 and part of RH7; finally, the Algarve region includes the other part of RH7 and RH8.

The characterization of watersheds is based on climatic factors: precipitation and temperature, and physiographic factors: perimeter, area, height, soil type and land use. In addition, the Soil Conservation Service Curve Number (CN) is also used to complete this characterization. Its also made a characterization of hydrometric data: runoff, precipitation and average air temperature, for monthly and daily time step, for each watershed.

With the intention of reduce the errors arising from the discrepancies between the monthly and daily input values some principles are adopted. In first place the gaps in the daily values are filled, substituting the values in lack for the daily average of the variable in cause. Later the following topics are followed:

▪ Precipitation and runoff: (1) Failures in the monthly data are replaced by the sum of the daily values corresponding to the same time interval; (2) When the monthly data does not correspond to the sum of the daily values, this value is replaced by the sum of the daily values in the same time interval.

▪ Temperature: (1) Failures in the monthly data are replaced by the average of the daily values corresponding to the same time interval; (2) When the monthly data does not correspond to the average daily values, this value is replaced by the average of the daily values in the same time interval.

Only when there are no daily or monthly data, XLWAT 4.0 replaces the monthly missing values with the monthly average of the variable in question (Oliveira & Simões, 2016).

The hydrometric and meteorological records used for each watershed are divided into 2 periods. The first period, characterized by $N_{cal} = 2/3$ of the data, is used for parameters calibration. The second period, characterized by $N_{val} = 1/3$ of the data, is related to the validation of the model.

The Chart 1 show parameters upper and lower bound considered in this study.

Chart 1 - Parameters of Thornthwaite-Mather model, upper and lower bound.

Parameter	Upper limit	Lower limit
$\boldsymbol{H_{máx}}$ (mm)	10	300
$\boldsymbol{\alpha}$ (-)	0,01	1

Since calibration is a complex process, it is divided into two phases. The first phase follows the sequence: (1) calibration with monthly values; (2) calibration with daily values; (3) calibration with daily values, setting H_{max} to the value obtained from the monthly calibration; (4) calibration with monthly values, setting H_{max} to the value obtained from daily calibration; (5) calibration with daily values, setting α_{day} to value obtained from monthly calibration (after conversion by Figure 1); (6) calibration with monthly values, setting α_{month} to value obtained from daily calibration (after conversion by Figure 1). Thus, it is possible to restrict the parameter values to a range of values for which a good simulation of the model is obtained. In the second phase, is selected the parameter value that reveals the best performance of the model, for each watershed. Finally, the hydrological model is validated using the calibrated parameters values.

With the aim of evaluate the adjustment and to inquire about the performance of the Thonthwaite-Mather model, on a monthly and daily scale, two efficiency indicators are used: MSE (Mean Square Error) and NSE (Nash-Sutcliffe Efficiency).

$$MSE = \frac{1}{M}\sum_{t=1}^{M}(Q_t^{obs} - Q_t^{calc})^2$$

$$NSE = 1 - \frac{\sum_{t=1}^{M}(Q_t^{obs} - Q_t^{calc})^2}{\sum_{t=1}^{M}\left(Q_t^{obs} - \overline{Q^{obs}}\right)^2}$$

Where $\overline{Q^{obs}}$ is the average total surface runoff observed, Q_t^{obs} is the total surface runoff observed in the time interval t, Q_t^{calc} is the total simulated surface runoff in time interval t and M is the number of simulated time intervals.

In order to be able to compare the results obtained for the daily time step and monthly time step the monthly time interval, $mm^2/mês$, is used as the basis.

With the purpose of relate the values obtained with parameters calibration and validation with the characteristics of the watershed, are selected the watersheds for which the performance of Thornthwaite-Mather model show better results. Since two values of NSE are obtained for the same basin, for monthly simulations and daily simulations, basins are selected when at least one of the NSE values is equals or greater than 0.7.This study is divided into 2 situations: Case A, relation of the soil types with the values of H_{max} and α (monthly); Case B, relationship of NE with the values of H_{max} and α (monthly).

3. Case study

The watersheds selected for the present study and some of their general characteristics are indicated in Chart 2.

In the master's thesis a more complete characterization of the watersheds is made, presenting also the percentages of soil type and land use. In addition, a description of the hydrometric and meteorological data used is also provided.

4. Results

4.1. Calibration and validation of hydrologic model

In this subchapter it is presented the results obtained for the parameters through the calibration and validation of the hydrological model under study, for monthly (Chart 3) and daily (Chart 4) simulation Values of $H^{máx}$ parameter that lead to a better performance of Thornthwaite-Mather model are equal, both in monthly simulation and in daily simulation For parameter α, the relationship between the parameter values for simulations with daily and monthly calculation intervals is shown in Figure 1. Regarding the NSE efficiency indicator, for 25 watersheds studied, it is verified that most watersheds present values above 0.5, for monthly and daily simulation, which indicates a reasonably good performance of Thornthwaite-Mather model. The only watersheds that have an unacceptable NSE value in both simulations for calibration and validation are Manteigas, Ponte Coruche, São Domingos (Algalé) and Vidigal. On the other hand, there are watersheds that present significant differences between monthly and daily simulation or between calibration and validation processes

Chart 2 – Selected watersheds and their general characteristics.

Watershed - Hydrometric station code	Region (-)	Main watershed (-)	Drained area (km^2)	CN II (-)
Pontilhão de Celeiros - 02G/01H	Norte	Lima	171	69.4
Boticas - 03L/01H	Norte	Douro	100	66.1
Vinhais (Quinta da Ranca) - 03P/01H	Norte	Douro	479 (271*)	76.3
Quinta das Laranjeiras - 06O/03H	Norte	Douro	3487 (2937*)	79.9
Santa Marta do Alvão - 05K/01H	Norte	Douro	49	75.0
Cabriz - 07I/04H	Norte	Douro	11	75.6
Fragas da Torre - 08H/02H	Norte	Douro	647	71.2
Vale Giestoso - 03K/01H	Norte	Douro	78	76.2
Vale Trevo - 08O/01H	Norte	Douro	405	74.5
Lustosa da Ribafeita - 09J/01H	Centro	Vouga/Ribeiras Costeiras	273	75.7
Ponte Águeda - 10G/02H	Centro	Vouga/Ribeiras Costeiras	404	70.4
Almaça - 11H/01H	Centro	Mondego	204	72.6
Caldas de São Gemil - 10J/01H	Centro	Mondego	619	77.2
Louçainha (Rio) - 13H/03H	Centro	Mondego	6	77.5
Manteigas - 11L/01H	Tejo	Tejo	27	86.1
Ponte Coruche - 20F/02H	Tejo	Tejo	5847	73.7
Odivelas (Rio) - 24I/01H	Alentejo	Sado	441	81.5
São Domingos (Algalé) - 24H/01H	Alentejo	Sado	16	77.8
Flôr da Rosa - 23I/01H	Alentejo	Sado	328	80.9
Vale da Ursa - 24H/02H	Alentejo	Sado	76	82.9
Amieira - 24L/01H	Alentejo	Guadiana	1477	80.9
Monte da Ponte - 27J/01H	Alentejo	Guadiana	719	82.0
Vascão - 28L/02H	Alentejo	Guadiana	410	73.7
Monte dos Fortes - 29L/01H	Alentejo	Guadiana	284	73.0
Vidigal - 30F/02H	Algarve	Ribeiras do Algarve	19	81.4

4.2. Relation of model parameters with watershed characteristics

In this chapter it is evaluated the relation of the parameters of Thornthwaite Mather model with the characteristics of watersheds.

The watersheds considered in this study are: Vinhais (Quinta da Ranca), Santa Marta do Alvão, Cabriz, Fragas da Torre and Vale Giestoso, in Norte region; Ponte Águeda, Almaça, Caldas de São Gemil and Louçainha (Rio), in Centro region; Flôr da Rosa, Vale da Ursa and Monte da Ponte, in Alentejo region; Vascão and Monte dos Fortes, in Algarve region. It is considered the overall performance of the watershed in 4 simulations (monthly and daily, calibration and validation) and, sometimes, is neglected a less good value.

Two case studies, A and B, were then analyzed to verify the relation of model parameters, $H^{máx}$ and α_{month}, with watershed characteristics.

In case A, the relationship between the soil types that characterize the selected watersheds and the values resulting from the calibration of the model parameters are evaluated. For the present study it is considered only the α_{month}, since daily simulations present few watersheds with The green dashed circle includes the points that represent, predominantly, Litosols and Luvisols predominant in the regions of Alentejo and Algarve.

In case B, the relationship between watersheds CN and the values resulting from the calibration of the parameters are evaluated. Analyzing Figure 4, there is a good performance and therefore would not be a conclusive study.

Analyzing Figure 2 it is verified that there are some types of soil that present a tendency. Rankers are related to higher $H^{máx}$ values, between 250mm and 300mm. Also the humic cambisols (eruptive rocks) are represented for values of the parameter between 200mm and 300mm. Humic Cambisols (shale) have $H^{máx}$values between 200 and 300 mm, so a trend can also be deduced. Relative to the eutric lithosols, they are distributed in reduced values of $H^{máx}$, between 100mm and 150mm. Gleyic albic Luvisols also appear to have a tendency for parameter values between 100mm and 200mm, however, the number of points on the graph is not sufficient to draw a conclusion. In general, we can distinguish two clusters in the graph of Figure 2: red dashed circle and blue dashed circle. In the red dashed circle are mainly Cambisols and Rankers, predominant in the Norte and Centro regions. The blue dashed circle encompasses the points corresponding to Luvisols and Litosols, characteristic of the Alentejo and Algarve regions.

From Figure 3 analysis it is verified that the Humic cambisols (shale) are represented for α_{month} between 0.6 and 0.7, so there is a very probable tendency. Also the Humic cambisols (eruptive rocks) and Rankers are among these values. The Lithosols have higher values of α_{month}, ranging from 0.7 to 0.9. The Ferric luvisols are between 0.8 and 0.9, however the number of points on the graph is not enough to draw a conclusion The general analysis of the graph of Figure 3 reveals that are two groups of points: gray dashed circle and green dashed circle. In the gray dashed circle are points with a lower α_{month}, corresponding, for the most part, to Cambisols and Rankers.

Analyzing Figure 4, there is a regionalization of the $H^{máx}$ parameter according to CN value. Thus, the basins located in the Norte and Centro regions have values of the parameter between 200mm and 300mm, and a trend can also occur: the higher the value of CN, the greater the value of $H^{máx}$. The watersheds in Alentejo region have higher CN values, however, $H^{máx}$ values that do not exceed 200 mm, there may also be a trend that needs to be proven with a larger number of watersheds in this region. Finally, in the Algarve region, values of CN are found in order of 73 and values of the parameter between 100 and 150 mm.

Chart 3 - Values obtained for parameters, $H^{máx}$ and α, in calibration and validation processes of the Thornthwaite-Mather model and values of efficiency indicators used for monthly simulation.

Watershed	Parameter value		Efficiency indicators							
			Calibration				Validation			
	$H^{máx}$ (mm)	α $(-)$	N_{cal} (month)	MSE $(mm^2/month)$	NSE $(-)$	Hydrograph observation	N_{val} (month)	MSE $(mm^2/month)$	NSE $(-)$	Hydrograph observation
Pontilhão de Celeiros	150	0.8	252	23241	0.53	Good	120	8102	0.67	Good
Boticas	300	0.5	168	919	0.59	Acceptable	72	4084	0.74	Acceptable
Vinhais (Quinta da Ranca)	220	0.6	264	812	0.86	Good	156	729	0.86	Good
Quinta das Laranjeiras	70	0.8	384	589	0.56	Bad	192	568	0.52	Bad
Santa Marta do Alvão	250	0.7	276	1154	0.90	Good	144	1293	0.87	Good
Cabriz	300	0.6	192	2673	0.86	Good	96	3342	0.73	Good
Fragas da Torre	220	0.7	360	1691	0.90	Good	180	2497	0.79	Good
Vale Giestoso	300	0.6	264	954	0.88	Good	132	722	0.74	Good
Vale Trevo	95	0.5	264	400	0.57	Good	132	85	0.85	Good
Lustosa da Ribafeita	240	0.4	216	1228	0.63	Acceptable	96	2997	-0.08	Bad
Ponte Águeda	300	0.6	444	1782	0.67	Good	216	1393	0.75	Good
Almaça	200	0.7	180	2960	0.71	Good	84	6383	0.41	Acceptable
Caldas de São Gemil	220	0.5	312	577	0.78	Good	144	369	0.80	Good
Louçainha (Rio)	270	0.6	252	697	0.84	Good	120	578	0.80	Good
Manteigas	10	1.0	372	30392	0.03	Bad	180	21591	0.29	Bad
Ponte Coruche	300	0.1	372	179	0.03	Bad	180	207	-0.13	Bad
Odivelas (Rio)	130	0.7	288	568	0.28	Acceptable	144	381	0.65	Good
São Domingos (Algalé)	300	0.5	204	787	0.20	Bad	96	328	0.04	Bad
Flôr da Rosa	100	0.9	264	279	0.79	Good	132	321	0.82	Good
Vale da Ursa	200	0.8	276	438	0.65	Good	144	495	0.79	Good
Amieira	200	0.8	372	349	0.68	Acceptable	180	347	0.59	Acceptable
Monte da Ponte	125	0.9	252	150	0.84	Acceptable	132	147	0.77	Good
Vascão	110	0.8	240	541	0.81	Good	120	638	0.47	Acceptable
Monte dos Fortes	150	0.7	240	404	0.76	Good	120	451	0.84	Good
Vidigal	230	0.5	456	728	0.32	Bad	228	946	0.22	Bad

Chart 4 - Values obtained for parameters, $H^{máx}$ and α, in calibration and validation processes of the Thornthwaite-Mather model and values of efficiency indicators used for daily simulation.

Watershed	Parameter value		Efficiency indicators							
			Calibration				Validation			
	$H^{máx}$ (mm)	α $(-)$	N_{cal} (day)	MSE $(mm^2/month)$	NSE $(-)$	Hydrograph observation	N_{cal} (day)	MSE $(mm^2/month)$	NSE $(-)$	Hydrograph observation
Pontilhão de Celeiros	150	0.15	7671	22519	0.54	Good	3652	7471	0.70	Good
Boticas	300	0.04	5114	2012	0.09	Acceptable	2191	1005	0.47	Acceptable
Vinhais (Quinta da Ranca)	220	0.06	8401	870	0.85	Good	4383	695	0.86	Good
Quinta das Laranjeiras	70	0.13	11688	785	0.48	Acceptable	5844	776	0.19	Acceptable
Santa Marta do Alvão	250	0.10	8401	1751	0.86	Good	4383	2187	0.78	Good
Cabriz	300	0.06	5844	5299	0.72	Good	2922	5313	0.37	Acceptable
Fragas da Torre	220	0.10	10957	1991	0.91	Good	5479	3527	0.68	Good
Vale Giestoso	300	0.06	8035	1648	0.79	Good	4018	1113	0.60	Good
Vale Trevo	95	0.04	8035	562	0.29	Good	4018	172	0.56	Good
Lustosa da Ribafeita	240	0.02	6209	2113	0.27	Acceptable	3287	2242	-0.55	Bad
Ponte Águeda	300	0.06	13880	3224	0.30	Acceptable	6209	1987	0.62	Good
Almaça	200	0.10	5844	2254	0.77	Good	2192	5290	0.56	Acceptable
Caldas de São Gemil	220	0.04	9496	1146	0.53	Good	4383	501	0.69	Good
Louçainha (Rio)	270	0.06	7671	1180	0.75	Good	3652	784	0.80	Good
Manteigas	10	0.40	11322	27701	0.10	Bad	5479	18898	0.39	Bad
Ponte Coruche	300	0.01	11323	476	-1.75	Bad	5479	432	-1.71	Bad
Odivelas (Rio)	130	0.10	8766	749	0.01	Bad	4383	304	0.62	Acceptable
São Domingos (Algalé)	300	0.04	6209	750	-0.83	Bad	2922	343	-0.07	Bad
Flôr da Rosa	100	0.25	8035	376	0.77	Acceptable	4018	494	0.69	Good
Vale da Ursa	200	0.15	8401	597	0.59	Good	4383	741	0.66	Good
Amieira	200	0.15	11322	623	0.32	Bad	5479	267	0.58	Acceptable
Monte da Ponte	125	0.25	7670	331	0.64	Acceptable	4018	264	0.50	Acceptable
Vascão	110	0.15	7305	884	0.76	Good	3652	1365	-0.16	Acceptable
Monte dos Fortes	150	0.10	7305	930	0.53	Good	3652	1267	0.52	Good
Vidigal	230	0.04	13879	1056	0.07	Bad	6940	1374	-0.20	Bad

Analyzing Figure 5, it is verified that also the parameter α_{month} seems to present a regionalization. In the Northern region a concentration of the values of this parameter between 0.6 and 0.7 is observed, whereas the NE varies between 70 and 80, there may also be a trend: the higher the NE value, the lower the value of α_{month}. Also, the watersheds in the Alentejo region seem to show a tendency: show high values of NE (higher than 80) and values of α_{month} between 0.8 and 0.9. Centro region presents greater variability in α_{month} values, between 0.5 and 0.7. In Algarve region, although the points appear to focus on specific values, more points would be needed to prove this assumption.

From the evaluation of the relation between parameters of the model with the two watersheds characteristics: soil type and NE, it is possible to draw the following conclusions: Norte and Centro regions are characterized by Rankers, Humic cambisols (eruptive rocks) and Humic cambisols (shales), which in turn are associated with high values of $H^{máx}$ (between 200mm and 300mm) and α_{month} which range from 0.5 to 0.7; Alentejo and Algarve regions are characterized by Litosols and Luvisols, which are associated with values of $H^{máx}$ between 100mm and 200mm and values of α_{month} that vary between 0.7 and 0.9; Norte and Centro regions are characterized by NE values between 70 and 80, corresponding to values of $H^{máx}$ ranging from 200mm to 300mm and α_{month} values between 0.6 and 0.7; In Alentejo region the values of NE vary between 80 and 85 and the values of $H^{máx}$ between 100mm and 200mm, α_{month} varies between 0,8 and 0,9; Nothing can be concluded regarding the relationship between land use and model parameters.

5. Conclusions

The Thornthwaite-Mather model can be run with a daily or monthly calculation interval, and the value to be assigned to the parameters $H^{máx}$ and α are as follows: $H^{máx}$ values are the same for the monthly simulation and daily simulation; Values to be assigned to α_{day}, in the daily simulation, is related to α_{month}, for the monthly simulation through a function represented in Figure 1.

Thus, it is found that the results for a daily or monthly calculation step are equal if the value of monthly precipitation and temperature are evenly distributed in the month. However, in the real world daily precipitation and temperature do not distribute evenly in the month, so the results may be different. It is concluded that the main conditioning factors of a good performance in the monthly and daily simulations of the model are: the daily and monthly input data available on the national monitoring network are concentrated in very short periods of time; the high distance and high altitude differences between the watershed and hydrometric and meteorological stations used; inexperience of the operator in the calibration process; simplicity of the Thornthwaite-Mather model. Thus, 14 of the 26 watersheds included in this study show a good performance when using the NSE efficiency indicator:

Vinhais (Quinta da Ranca), Santa Marta do Alvão, Cabriz, Fragas da Torre, Vale Giestoso, Ponte Águeda, Almaça, Caldas de São Gemil, Louçainha (Rio), Flôr da Rosa, Vale Ursa, Monte da Ponte, Vascão and Monte dos Fortes

The relationship between parameters value and the soil and NE types that characterize the watersheds with the best performance in the model simulation, suggest a parameters regionalization: (a) North and Central regions presents values for $H^{máx}$ parameter generally high, around 200mm and 300mm. For the same regions, α_{month} is also constant between 0.5 and 0.7. (b) For Alentejo and Algarve regions there is also a consistency of α_{month} values between 0.7 and 0.9. $H^{máx}$ parameter values range from 100mm to 250mm in this regions.

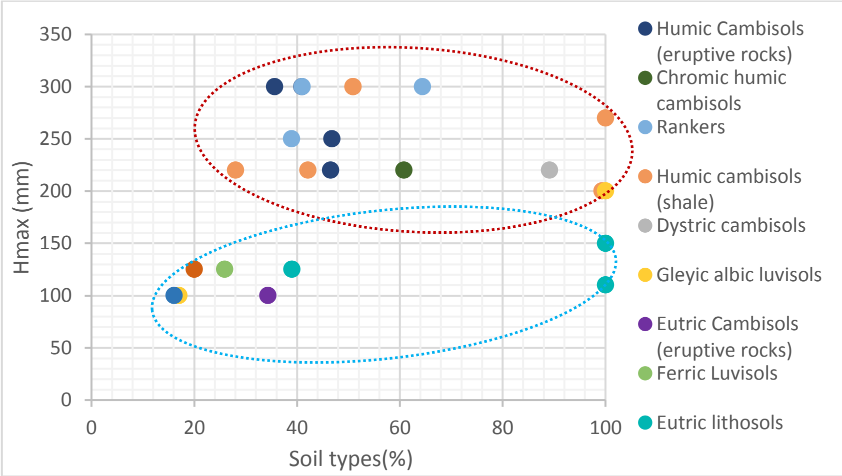

Figure 2 - Relationship between soil type (%) and $H^{máx}$, for the best performing watersheds.

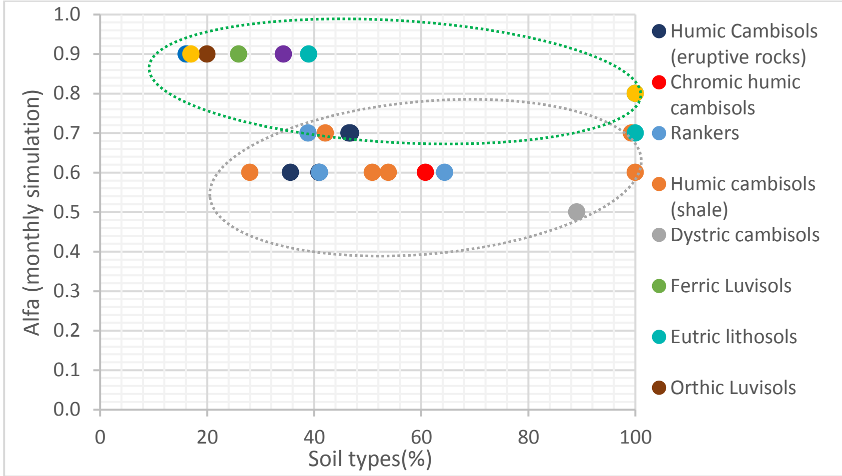

Figure 3 - Relationship between soil type (%) and α_{month} , for the best performing watersheds

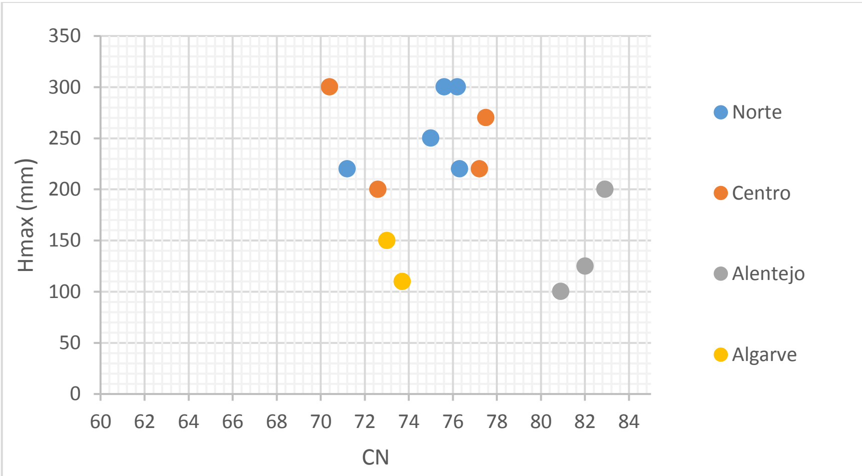

Figure 4 - Relationship between CN and $H^{máx}$, for the best performing watersheds

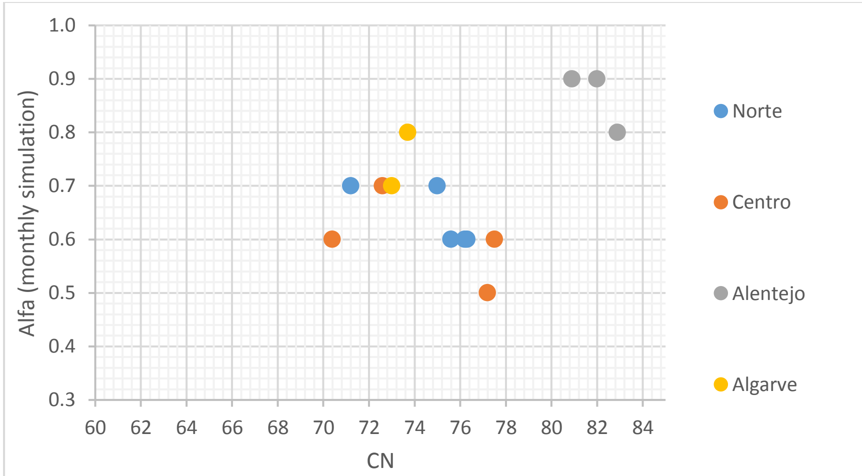

Figure 5 - Relationship between CN and α_{month}, for the best performing watersheds.

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