QUERENÇA-SILVES RECHARGE ESTIMATION
Suitability of SWAT Model to Karst Watersheds

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Abstract *– The Querença-Silves aquifer is the largest in the Algarve region and the most important. Over the years has served to provide water, whether for public supply or agriculture. Due to its enormous importance, there are several studies that have focused on this important water reservoir.*
This study aims to increase the knowledge about this aquifer. Applying the SWAT Model to watersheds, that overlap the Querença-Silves ,it allows the calculation of the annual recharge. The use of this model focuses on the integration of surface and groundwater resources.
The application of SWAT model to these basins lends itself to the suitability in karst regions. Since this model was designed to be used mainly in agriculture, it isn't evident that its application in karst regions is correct and it is also necessary to evaluate how the model simulates under these conditions.

Keywords *– Querença-Silves; SWAT; Hydrologic Modeling; Recharge; Water Resources.*

I. INTRODUCTION

In the past few years, water has increased its importance over the developed and undeveloped world. This increased importance comes, not only from the human daily needs, but also from the greater need to maintain and increase the water bodies' quality.

But the daily water necessities are quite high. According to the Portuguese National Water Plan (Plano Nacional da Água – PNA) the request for water is estimated in 7 500x10^{6}m^3.year^{-1}, being 87% (6 550x10^{6}m^3.year^{-1}) for agricultural proposes, 8% (570x10^{6}m^3.year^{-1}) for public supply and 5% (385x10^{6}m^3.year^{-1}) for industry.

Regarding the Algarve region, the consumptions of water by sector are:

- 230x10^{6}m^3.year^{-1} (72%) for agriculture;
- 70x10^{6}m^3.year^{-1} (22%) for public supply;
- 9x10^{6}m^3.year^{-1} (3%) for industry;
- 10x10^{6}m^3.year^{-1} (3%) for golf.

Of the total amount of water used in this region about 67% corresponds to groundwater and 33% to surface water. However, by studying sectors, the use of surface water represents 14% of total agriculture water demand and 94% of public supply. But the use of groundwater accounts for 86% in agriculture and 6% in the public supply (Do Ó & Monteiro, 2006).

With this analysis we can see the differences between each sector and the importance of groundwater resources for the Algarve region, especially for the agricultural sector. In fact, this region, is moving towards the use of surface water resources, although they are more exposed and more vulnerable to pollution, since they are often in direct contact with various anthropogenic activities.

Whereas, the groundwater resources are a natural defense to anthropogenic contamination. The soil, which is to separate the surface of the aquifer and where the water seeps to generate recharge, has natural purification capabilities.

Moreso, during infiltration, water is subjected to various natural processes of degradation, results of chemical, physical and biological processes. This is a clear advantage of the use of groundwater resources and also the lowest use of economic resources that the exploitation of groundwater resources requires (Ribeiro, 2004).

However, one can not analyze the surface and underground water resources differently. Both are, in fact, a single resource at different stages of its cycle. Analysing the water as a single resource, will the available water, in the Algarve region, be enough of its needs?

In a simplified form, the water balance, can be represented by:

$$Runoff = Precipitation - Real\ Evapotranspiration = Recharge + Surface\ Runoff$$

Since the average annual rainfall in Algarve is around 653mm, there is a total of 3 500x10^{6}m^3.year^{-1} and the real evapotranspiration, about 70%, remains about 1 000x10^{6}m^3 (Monteiro, 2007). As shown, the volume of water available in the Algarve is, on average, sufficient to meet the needs.

However, being enough in theory, there were already shortages of water in this region of the country the drought period of 2004-2005 is a nearby example of a critical situation for this region. The surface water reservoirs reached, in this period, to alarming levels, and it became necessary to make a back turn in the water supply system. The once abandoned boreholes became once again connected to the water supply system and made possible to supply the region during this period.

II. STUDY CASE

The study area is located in central Algarve, going from the south coast up to the mountain ranges to the north. In addition to the Algarve, the study area includes also a small part of Alentejo. With an area of 1 655km^2 comprises nine municipalities: two from Alentejo and the seven from Algarve.

The area is specially characterized by its topography and geological features. To the north it is limited by the higher areas of the Algarve region, in particular the Monchique mountains, contrasting with the South, which is bounded by the sea. It also contains at its core the Querença-Silves aquifer. This is the most important aquifer in the Algarve region. It has a karstic nature and it has a considerable thickness and size, as well as its ability to regulate the annual and interannual. Figure 3.2 represents the one described above.

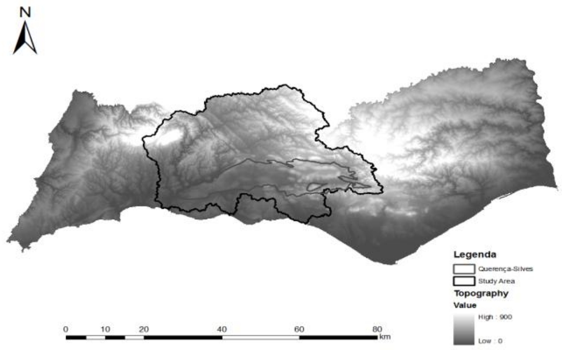


Figure 1 - Study area topography and Querença-Silves aquifer

A. Climate

The climate in the study area can be characterized as a Mediterranean. However, it’s under the influence of local features, such as proximity to the sea and altitude, which varies from sea level to about 900m, at Monchique mountains, giving it unique characteristics.

Concerning temperature, it is considered that this region has a moderate temperature ranging between 10°C minimum in winter and 30ºC maximum in summer. During winter, the range of average temperatures ranging from 6ºC in Monchique and 20ºC in areas near the sea. Days with temperatures below 0°C are rare in coastal areas, but frequently in the higher inland areas. On the other hand, temperatures above 25°C are frequently, occurring about 150 times a year, mostly in July and August (CCDR Algarve, 2004).

Regarding precipitation, and the fact that we are in a Mediterranean climate zone, it occurs mainly between October and April, and is however, quite mixed. The area of Monchique provides an average annual rainfall above 1 000mm and could reach to 1 650mm (INAG, 2000). In contrast, precipitation in coastal areas rarely exceeds 600mm annually.

Regarding moisture, the area under study is considered to be dry, with a value of annual average relative humidity below 75%, with the sole exception of mountainous areas where it is considered wet (INAG, 2000).

B. Hydrology

Surface Water Resources

The study area is characterized by three main water courses: the Arade-Odelouca river, the Alcantarilha creek and the Qauteira creek. Like other rivers in this region (with the exception of the Guadiana), those that are present in this study have their origin in the mountain ranges north of the existing basin.

Much of the water lines in this area, only have flow during rainy periods, or in the periods immediately after, remaining dry the rest of the year (INAG, 2000), due mainly to the hydrogeological characteristics of the region, more properly by the presence of the Querença-Silves aquifer with its karst features. Normally, these lines have a length less than 30km, with the exception of the Arade-Odelouca (CCDR Algarve, 2004).

The three rivers under study are mainly North-South directed, with a high slope in the beginning, which gradually decreases with the approach to coastal areas.

Groundwater Resources

Regarding to the hydrogeology, the study area includes two major configurations present in the Algarve: Ancient Massif and Sedimentary Basin. In terms of groundwater resources, only the second has a potential to the existence of water reserves of any significance.

It is in the sedimentary basin where the Querença-Slves aquifer is. This is the largest and most important aquifer of the Algarve region and therefore of the study area and was primarily responsible for water supply in 2005, when the surface reserves of water were no longer sufficient.

The Querança-Silves aquifer is characterized by formation dominated by limestones and dolomites, which give to it a karstic nature. This aquifer has an area of approximately 318km^2 and a thickness of about 200m. In terms of productivity can reach values 83.3l.s^{-1}, and the average value of 12.2l.s^{-1}.

The piezometric analysis demonstrates the existence of a preferential flow with East-West direction, there are, however, local anomalies. The flow is constrained by existing discharges in the Western limit of the aquifer, of which highlights the Estômbar spring, with an average flow 239l.s^{-1} (Tenreiro et al., 2009).

The waterways that cross the Querença-Silves aquifer have influential and effluent sections (Tenreiro et al., 2009). This factor makes the sub-units that characterize the aquifer become less independent. The fact that that there are influential and effluent sections shows the great influence from the aquifer on water courses that cross it. This influence is easily seen, since you can check that at the same time of year, a watercourse, that is presented in a dry area further upstream, may have a significant flow in an area further downstream, after entering the zone influence the aquifer. The stream of Quarteira is an example of a stream influenced by Querença-Silves, being fed by several springs along its course (springs Alte, Salir and Benémola).

The average renewable resources of this aquifer are 100Mm^3.year^{-1} (Mendes Oliveira et al., 2008), higher than the approximately 70Mm^3.year^{-1} that are distributed annually by the company Águas do Algarve S.A. throughout the Algarve has public water.

C. Land Use

The land use in the study area is characterized by a significant difference between the North and the South. This inequality derives, essentially, from the soil type and topography of these distinct sub-regions.

The area to the North is largely occupied by montado (oak-savannah) and Mediterranean shrub land, in contrast the southern area is densely populated by trees and citrus orchards.

To characterize the land use in this area we used the following datasets: Corine Land Cover 2000 and the National Forest Inventory.

Since the SWAT database didn't have some of the agriculture data needed for these studies, it was necessary to complete its database in order to use this model.

The CLC2000 legend was condensed and reclassified, both to correlate the map with the vegetation cover types present in the SWAT database (Neitsch et al., 2004), and to limit model parameterization to the most important vegetation types. Land use characteristics for Mediterranean vegetation types — vineyards, montado (oak savannah), eucalyptus forests, Mediterranean shrub lands, dense slerophyll forest and citrus orchard were taken from a literature survey (Table I) and form Nunes, et al. 2008, with missing values taken from the SWAT database

Table 1 - References for SWAT land use parameters

Culture Name	References
Montado - oak savannah	PEÑUELAS, J. et al., 1997; Hoff, C. et al., 2002; Bussotti, F. et al., 2003; García-Mozo, H. et al., 2002; Tognetti, R. et al., 1998; Lhomme, J.P. et al., 2001; Rapp, M. et al., 1999; A. BOMBELLI, A. e GRATANI, L., 2003; Pereira, T.C. et al., 2009; Naburs, G.J. et al., 2003; Penman, J. et al., 2009; Deguchi, A. et al., 2006
Dense sclerophyll forest	PEÑUELAS, J. et al., 1997; Hoff, C. et al., 2002; Bussotti, F. et al., 2003; García-Mozo, H. et al., 2002; Tognetti, R. et al., 1998; Lhomme, J.P. et al., 2001; Rapp, M. et al., 1999; A. BOMBELLI, A. e GRATANI, L., 2003; Pereira, T.C. et al., 2009; Naburs, G.J. et al., 2003; Penman, J. et al., 2009; Deguchi, A. et al., 2006
Citrus orchard	Ribeiro, R.V. e Machado, E.C., 2007; Sandhu, C.S.S., 2003; StenzelI N.M.C. et al., 2006; Pérez Latorre, A.V. e Cabezudo, B., 2002; A. BOMBELLI, A. e GRATANI, L., 2003; Pereira, T.C. et al., 2009; Naburs, G.J. et al., 2003; Penman, J. et al., 2009; Deguchi, A. et al., 2006
Eucalyptus forest	Pereira, T.C. et al., 2009; Naburs, G.J. et al., 2003; Penman, J. et al., 2009; Deguchi, A. et al., 2006
Vineyard	Pereira, T.C. et al., 2009; Naburs, G.J. et al., 2003; Penman, J. et al., 2009; Deguchi, A. et al., 2006

D. Soil Type

According to the soil map of the Environmental Atlas (Atlas do Ambiente) of 1971, in the study area four soil types can be found: Entisols, Alfisols, Inceptisols and Riverine (according to the classification system FAO 1976). All derive from early material, from ancient carbonate formations, until recent sediments and shoals. These are the primitive materials that determine the most important characteristics of the soil, as the possibility of breakdown, soil depth, the trend of erosion, nutrients, among others (Kopp, 2000).

The distribution of this soil type along the study area is not homogeneous, distinguishing, as in previous features, the most mountainous region north of the South flattest region. It was evident the greater relevance of Entisols, in contrast to the smaller presence of Riverine.

E. Data Gathering

Sampling of climatic data in the area under study is taken from the Water Institute of Portugal (INAG) and also of Meteorological Institute of Portugal (IM). INAG stations used are available in the SNIRH (Water Resources National Information System - Sistema Nacional de Informação sobre Recursos Hídricos), from the IM was used the Faro airport station, available at the WMO.

In the study area there are only five climate monitoring stations from INAG, adding the IM station, it was possible to have a total of six weather stations in this study. These stations have available data on precipitation, temperature, relative humidity, wind speed and solar radiation (only for the stations of the INAG).

Regarding the data on precipitation, INAG has available a much more complete network. Thus, it was possible to use a total of 21 stations with precipitation data (including the five meteorological stations mentioned above and the IM station). For most of these stations was also possible to collect data on wind speed.

Concerning hydrologic stations, there are nine hydrometric stations operated by INAG, with data available through the SNIRH. These stations have daily data flow for three main watercourses. However, the available data in these stations is not always from the same period and, therefore, it was needed to filter these stations according with the period analyzed.

From the analysis conducted to the hydrologic stations, the study period was defined: it goes from October of 1998 to September of 2007 (in Portugal the hydrological year goes from October to September).

III. METHODOLOGY

The data used to run the SWAT model will also be applied to two analytical methods to calculate the recharge. These methods, both different, have the advantage of requiring a smaller amount of data having a most immediate application.

The first method used, for calculating recharge, is the Penman-Grindley, which is based on water balance equation. The second is an empirical method, developed by Kessler especially for karst aquifers.

Benefiting from the need to calculate the ETP in the Penman-Grindley method, the results of three empirical methods - Hargreaves, Thornthwaite and Turc will be compared to the results of the SWAT model, calculated by Penman-Monteith.

A comparison of results obtained from the analytical methods used to calculate the recharge and the ETP, with the results from the SWAT model allows determining the predictive ability of it. This analysis leads to identify the method that best approximates the existing hydrological / hydrogeological data from study area. Finally, the performance of SWAT when applied to areas with karst hydrogeological characteristics will be criticized.

A. Filling the Climate Data Gaps

The analysis of climatic data showed the existence of missing values in the required series, such as total absence of data for the first year (1998 to 2001), or small gaps along the period analyzed. So that data could be used SWAT model it was necessary to complete these series.

Due to the different methodologies used, the analysis for missing data will be divided into three sections: data on temperature and relative humidity data on wind speed and solar radiation data.

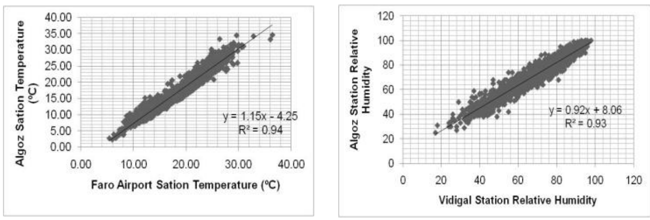
Temperature and Relative Humidity

To estimate the data, for the INAG stations, between 1998 and 2001, the collected temperature data was related to the Faro airport station from IM. For better matching the data of all stations was compared with the Faro airport station, constructing linear regressions between existing data. This way, it was possible to build the climate series with all the necessary data for the period in question.

Regarding the filling of missing data, it was found the best match between the six existing stations. With this method it was possible to fill the remaining gaps, and complete data series for temperature, between 1st October 1998 and September 30th, 2007.

For the relative humidity, and since the INAG had data available for the entire period analyzed, it was only necessary to fill gaps in specific data. The six stations used were compared and was adopted the best relation between two of them so that the series could completed.

In Figure 2 it's presented an example of the relation between stations.



a) b)

Figure 2 - Relation between stations a) Temperature data; b) Relative humidity data

Wind Speed

As for the other climate variables, also for wind speed data are available only from 2001. Due to the spatial variability of this parameter was not feasible to apply the previous method. So we took as valid as the value of wind speed for the missing days would be equal to the average of this month in several years with available data.

For this parameter there are a total of 19 stations with available information in SNIRH.

Solar Radiation

To calculate the solar radiation the method followed was the proposed by Samani, in 2000 and dubbed himself the Hargreaves-Samani equation. This method arises from the need to estimate solar radiation with a minimum of climatic data available and adapting the method described by Hargreaves and Samani, 1982.

According to the original method of solar radiation (Rs in $MJ.m^{-2}.d^{-1}$) should be estimated according to the following equation:

$$Rs = (KT)(R_a)(TD)^{0.5} \quad \textbf{Equation 1}$$

Being:
TD – difference between maximum and minimum temperature (ºC);
Rs – Extraterrestrial radiation ($Mj.m^{-2}.d^{-1}$);
KT – Empiric coefficient.

Samani (2000) adds that KT should be calculated by checking the quadratic relationship between radiation and the actual difference between the minimum and maximum temperature.

The extraterrestrial radiation (Ra in MJ.m-2.d-1) was calculated using the method described in Neitsch (2005) and based on the following set of equations:

$$R_a = \frac{24}{\pi} I_{sc} E_0 [\omega T_{sr}(\sin\delta \sin\emptyset) + (\cos\delta \cos\emptyset \sin(\omega T_{sr}))]$$

Equation 2

Being:
Isc – Solar Constant (4 921$Mj.m^{-2}.h^{-1}$);
E0 –eccentricity correction factor of the earth's orbit;
ω – angular velocity of the earth's rotation (0.2618$rad.h^{-1}$);
Tsr – sunraise hour;
δ –solar delcination;
Φ – geographical latitude (rad).

Equations 3 to 5 calculate the correction factor of the solar position (E0), the time the sunrises (Tsr) and solar declination (δ).

$$E_0 = 1 + 0.033\cos\left[\left(\frac{2\pi d_n}{365}\right)\right] \quad \textbf{Equation 3}$$

$$T_{sr} = \frac{\cos^{-1}[-\tan\delta \tan\emptyset]}{\omega} \quad \textbf{Equation 4}$$

$$\delta = sin^{-1}\left\{0.4sin\left[\frac{2\pi}{365}(d_n - 82)\right]\right\} \quad \textbf{Equation 5}$$

Being:
dn – day of the year (between 0 e 365)

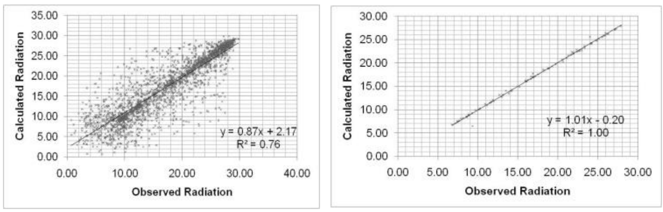
The first step towards the calculation of solar radiation was set of the equations that correspond to the relationship between the extraterrestrial solar radiation and the difference between the minimum and maximum temperature. This ratio can be found in Table 2, and the values of a, b and c correspond to the parameters of quadratic equations for the calculation of KT.

Table 2 - Relation between temperature differences and extraterrestrial radiation

Station i	a	B	c	R^2
ALGOZ (31H/02C)	-0.0015	0.0510	0.2231	0.3495
BARRAGEM DO ARADE (30G/03C)	-0.0018	0.0567	0.1950	0.2559
MONCHIQUE (30F/01C)	-0.0057	0.1218	0.0368	0.5023
SÃO BRÁS DE ALPORTEL (31J/01C)	-0.0042	0.1099	0.0615	0.6318
VIDIGAL (30F/05C)	-0.0024	0.0755	0.072	0.4362

$$\text{KT (Station i)} = \text{aTD}^2 \times \text{bTD} + \text{c} \quad \textbf{Equation 6}$$

In Figure 3 it's showed the results of the application of the Hargreaves-Samani equation.



a) b)

Figure 3 - Relation between observed and calculated solar radiation; a) daily values; b) month daily average

B. Recharge Analytical Methods

Penman-Grindley´s Method

The Penman-Grindley's method is a way of calculating the recharge based on water balance equation. Penman (1948) suggested a method, to calculate real evapotranspiration, based on the need of water from soil.

According to the author, as the soil water availability declines, increasing the deficit (soil water deficit - DAS) becomes more difficult to pass water from the soil into the atmosphere, therefore diminishing the real evapotranspiration.

DAS is controlled by the factor that Penman called the root constant (RC), which is a characteristic of the existing vegetation and influence the ease with which the ground may or may not release water.

When there is a shortage of water in the soil, ig, when DAS is zero, the water that reaches the soil could contribute to infiltration.

This method uses a daily time step, so they may withdraw from the daily values of recharge.

Kessler's Method

Kessler's method was developed as a way to optimize the calculation of recharge in carbonate aquifers, where the amount of water in the soil takes a lesser role for recharging. This method uses monthly precipitation values and requires the use of calendar years.

Applying this method starts with the calculation of μ from the equation:

$$\mu = \frac{P_{Set-Dez} - \bar{P}_{Set-Dez}}{\bar{P}_{Set-Dez}} \quad \textbf{Equation 7}$$

Being:
$P_{Set-Dez}$ – precipitation from the last 4 months of the year.
$\bar{P}_{Set-Dez}$ – average of the precipitation from the last 4 months of the year for a relatively long period

Using the following table the μ values were listed and related with the values of the correction factor k.

Table 3 - Correction k factors for μ values

μ	k
0-5	0
6-15	1
16-25	2
26-35	3
36-45	4
46-55	5
56-60	7
61-65	10
66-70	13
>70	15

The value of k should be added or subtracted, as the difference of precipitation fallen in the first four months of the year (January to April) and rainfall of the last four months of year as the difference is positive or negative.

After this correction to the value of μ, the recharge value is set with the following function.

$$Recharge = 2 \times 10^{-7}x^5 - 2 \times 10^{-5}x^4 - 0.0002x^3 - 0.034x^2 - 0.5775 \quad \textbf{Equation 7}$$

C. Potential Evapotranspiration Analytical Models

To calculate the ETP it was used three different methods: Hargreaves' method, Thornthwaite's method and the Turc's method.

Hargreaves' Method

For the calculation of the potential evapotranspiration, Hargraves propose the follow equations:

$$\lambda ETP = 0.0023(T_m + 17.8)(T_{max} - T_{min})^{0.5}Rs \quad \textbf{Equation 8}$$

$$\lambda = 2.501 - 2.361 \times 10^{-3} \times T_m \quad \textbf{Equation 9}$$

Being:
ETP – potential evapotranspiration ($mm.day^{-1}$);
T_m – average daily temperature (ºC);
T_{max} – maximum daily temperature (ºC);
T_{min} – minimum daily temperature (ºC);
Rs – solar radiation ($Mj.m^{-2}.dia^{-1}$);
Λ – latent heat of vaporization ($MJ.kg^{-1}$);

Thornthwaite's Method

Thornthwaite proposed, in 1948, an alternative method for calculating the ETP through an empirical relation based on the average air temperature. The formula to calculate the ETP is in the following equation.

$$ETP = 16\left(\frac{10T}{I}\right)^{a} \quad \textbf{Equation 10}$$

Being
ETP – potential evapotranspiration (mm.mounth^{-1});
T – average monthly temperature (ºC);
I – heat index;
a –regional thermal index.

The value of I depends on the annual variability of temperature and is calculated using equation 11.

$$I = \sum_{j=1}^{12}\left(0.2T_j\right)^{1.514} \quad \textbf{Equation 11}$$

The a value varies with the value of I and it can be calculated with the equation

$$a = 6.75\times10^{-7}I^3 - 7.71\times10^{-5}I^2 + 1.7912\times10^{-2}I + 0.49239 \quad \textbf{Equation 12}$$

Turc's Method

Turc proposed, in 1961, a different calculation method for the ETP. This method is based on solar radiation and daily mean temperature and applies according to the following equation:

$$ETP = 0.013(23.88Rs + 50)T(T+15)^{-1} \quad \textbf{Equation 13}$$

Being:
ETP – potential evapotranspiration (mm.day^{-1});
T – average daily temperature(º C);
Rs – solar radiation (Mj.m^{-2}.day^{-1}).

D. SWAT Model

SWAT is the acronym for Soil and Water Assessment Tool. A river basin or watershed, scale model was developed to predict the impact of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils, land use and management conditions over long periods of time (Neitsch S. L., et al., 2005).

This is a deterministic model, with spatial and continuous distribution, it is based on hydrological equations and using the input data, provides estimates of spatially distributed within the study area, for a given sub-basin, making continuous simulations (Neitsch, S.L., et al., 2005).

Although the model has been designed to be applied to a complete basin,it allows the creation of sub-basins, with a view to refining the parameters and spatial resolution. These sub-basins are linked in a cascading structure along the lines of water. This cascading structure causes the upstream sub-basin drainage system in the sub-basin immediately downstream of this and so on. SWAT considers a single stream by sub-basin and each has a similar physiographic and climatic characteristics.

The sub-basins are divided into hydrological response units (HRU). The HRU is defined within the sub-basins as an area with a single soil type, land use and agricultural practice and slope. HRU are homogeneous regarding to plant growth, runoff and soil erosion.

The water balance is calculated independently for each HRU and results are summed to calculate the totals of the sub-basin. Each HRU is characterized by two boundaries: one corresponding to an upper surface, and a lower one corresponding to the deep aquifer. The upper boundary receives water directly from precipitation, which becomes part of runoff, a part infiltrates and another part evaporates. The water that infiltrates the soil is subject to various factors, which can be transpired, percolated into the deeper aquifer or transported laterally along the soil profile.

The base of the SWAT model is based on daily water balance calculation for each sub-basin. The mass balance model is made by the following equation:

$$SW_t = SW_0 + \left(P - Q_{sup} - ET - I_d - Q_{sub}\right) \quad \textbf{Equation 14}$$

Being:
SW_t – soil water content in time t (mm)
t – simulation time (day)
SW_0 – soil water content in the beginning of simulation (mm)
P – precipitation during time t (mm)
Q_{sup} – surface flow during time t (mm)
ET – evapotranspiration during time t (mm)
I_d – recharge for deep aquifer during time t (mm)
Q_{sub} – sub-surface flow during time t (mm)

IV. RESULTS

For the SWAT model calibration, and due to the distribution of the hydrometric stations not being the best to represent the study area, it was chosen to use three stations, in order to represent the recharge to the aquifer.

The stations chosen were Ponta da Ribeira do Rio Seco and Querença, since they are on the same watercourse, upstream and downstream, respectively, of Querença-Silves aquifer. The third station was Quinta Passagem because its hydrological features are representative of the area located downstream to the Querença-Silves aquifer.

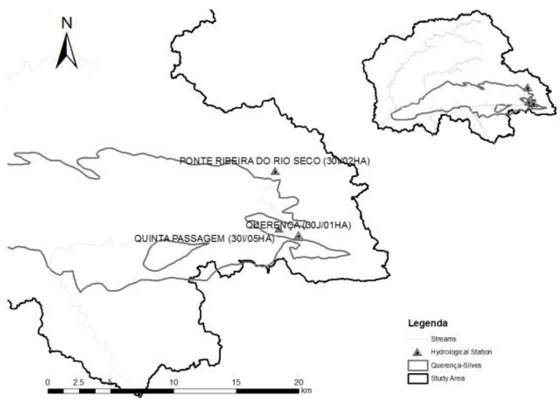


Figure 4 - Hydrological stations used for calibration

A. Potential Evapotranspiration

To calculate the potential evapotranspiration three analytical models were used, along with the SWAT model, which uses the Penman-Monteith method.

The first method applied was the Hargreaves' method. This presented the smallest values of the four methods, with an average of 620.43mm.year^{-1}. This method offered significant differences between the Monchique station (on the mountains) and the other stations (closer to the sea). The Monchique station had an average of 467.79mm.year^{-1}.

The Thornthwaite's method gave results similar to what was expected and similar to the reference values, with an average of 813.77mm.year^{-1}. Also in this method, the Monchique station revealed the smallest values, but with less difference to the others station as the ones showed in the Hargraves' method.

The average potential evapotranpiration taken from the Turc's model was the highest one, with 1 186.31mm.year^{-1}. With this method, Monchique station revealed values similar to the rest of the analysed stations.

The SWAT model, or Penman-Monteith's method, results were much similar to the results of the Thotnthwaite's, and also similar to the referenced ones, with 856.81mm.year^{-1}. The major difference between this method and the Thornthwaite's was the smaller differences between the analysed stations.

B. Recharge

Concerning the analysis of recharge, and aiming to the goal of this work, we compare the different methods presented before. Data analysis will be made based on calendar years, rather than hydrological years, since the Kessler's method calculates the percentage of recharge from precipitation, given calendar year. Thus we examine the calendar years 1999 to 2006, since the years 1998 and 2007 are incomplete.

The Penaman-Grindley's method is the one with the highest values of recharge. Annually, the recharge varies from 167.84mm in the year 2005 (year of extreme drought throughout the Portuguese territory) and 629.13mm in 2001. The average recharge for this method is 369.74mm.

The Kessler's method presents values of recharge with a similar behaviour to the ones observed in the previous method. The values are, except for the first year, lower than those calculated by the Penman-Grindley's. Again, the lowest value of recharge, 108.75mm, coincides with the dry period, and the highest value of recharge, 510.93mm, coincides with the year 2001. The average recharge is 290.03mm.

The fact that, in the first year, the Kessler's method has a greater value than the Penman-Grindley method, is easily explained. In the first instant of calculation, the Penman-Grindley's consider a particular content soil water (in this case it was considered that at time 0 the water content in soil is equal to the root constant). After this initial time, the method calculates which the water content in soil is, at any time, not returning to the initial situation.

The SWAT model also needs a warm-up period as the Penman-Grindley's method. So, once again, the first year as a lower value than the remaining years, except 2004 and 2005 which reflect the results of drought. The highest recharge lies, unlike other methods, in 2006 with 425.62mm. The SWAT model has similar values to the Kessler method. The average value is 245.06mm.

The three used methods for calculating the recharge exhibit similar behaviour, showing, however, different values between them. Table 4 shows the values of recharge obtained by different methods, shown in mm and hm^3.

Table 4 - Recharge value for the three different methods used

Year	Penman –Grindley		Kessler		SWAT	
	mm.year^{-1}	hm^3.year^{-1}	mm.year^{-1}	hm^3.year^{-1}	mm.year^{-1}	hm^3.year^{-1}
1999	225.44	71.25	237.25	74.98	126.71	40.05
2000	451.77	142.78	362.45	114.55	316.76	100.11
2001	629.13	198.84	510.93	161.48	281.36	88.92
2002	490.10	154.90	346.36	109.47	322.29	101.86
2003	463.62	146.53	354.60	112.07	379.64	119.99
2004	220.67	69.74	160.78	50.81	103.18	32.61
2005	167.84	53.05	108.75	34.37	154.56	48.85
2006	509.75	161.11	350.20	110.68	425.62	134.52

C. Results discussion

With regard to parameterization data of SWAT model, this study contributes to increasing the number of available data, regarding the type of Portuguese crops. Since this model is developed in the United States of America, its database refers to this country. Therefore, and based on the work of Nunes, J. P., et al., (2008), it represents an evolution, parameterizing the main crops in the Algarve region.

Regarding the results of ETP, and after applied the four methods proposed, several conclusions are in order.

According to the water balance, and in a simplistic way, recharge is calculated through the amount of precipitation minus evapotranspiration and runoff, it became evident the importance of analyzing the values of potential evapotranspiration using analytical and numerical methods.

It may be inferred that the values obtained by simulation in SWAT model are quite similar to those obtained by the method of Thornthwaite. However, the ETP values obtained by SWAT have a much smaller geographical variability, than those obtained by the method of Thornthwaite.

This shows that not only precipitation and solar radiation contribute to for the ETP, as described by simplistic models. Variables such as wind speed and relative humidity, also contribute to this parameter in a major way. It was still in check, and this is in SWAT model possibility, the influence of altitude in ETP. Specifically the variation in temperature and precipitation with altitude, may pose to the ETP.

It is, however, to be noted that the Thornthwaite's method is a much more expeditious and simple for ETP calculation. Besides, the results presented can be compared with those obtained by a much more complex method, such as Penman –Monteith's used in SWAT.

Regarding specifically to recharge, and having as source of data validation, reference values of several studies in the aquifer Querença-Silves, it appears that the Kessler's method have values very similar to those expected.

Penman-Grindley's have values too high. These values may result from this method depends significantly on the set of roots constant used for the calculation of evapotranspiration. The values used were taken from the original method, optimized for the UK, and were not subject to calibration. Thus, the values obtained here for recharge, with the application of this method, may be subject to correction by calibration of the roots constant, giving greater confidence in results.

It is still needed to analyze what impact the change of the roots constant in this method, and which are the root constant that are best suited to each national territory and, in this case, to the Algarve region.

Regarding the SWAT model, the results were also very similar to the referenced ones. Presuppose that a better model calibration, result in better fitness values of recharge to the aquifer. Despite this limitation the results obtained allow some conclusions.

Given the largely agricultural and surface vocation of this model it's normal that the model have found some difficulties to simulate particular environments, such as a region on a karst aquifer. However, in spite of not having the tools that could give greater suitability for this type of scenarios, the results are not at all abnormal. This model has other advantages, such as determining the loss of water from the aquifer along the waterways. This is a value that other models do not have, and that in such aquifers are extremely important.

V. CONCLUSION

In this study it is proved that the SWAT model is suitable for hydrological modelling in basins over karst aquifers. Even if the results aren't the best, they are quite similar to what was expected.

With a more extensive calibration, a longer study period and more available data, the results could be better.

Therefore, this study concludes that, even if SWAT isn't a model faced to groundwater modelling, it gives good results, even in such difficult areas, such as a karst region.

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