OREGON STATE UNIVERSITY – CORVALLIS – UNITED STATES OF AMERICA

ENSEEIHT – TOULOUSE - FRANCE

03/20/2012 – 09/01/2012

Estimation of hourly evapotranspiration by diurnal water table fluctuations: integration of the profile of hysteretic soil water content in the White method.

Camillle SAMPIC – camille.sampic@etu.enseeiht.fr

ABSTRACT

Computing evapotranspiration is important to manage groundwater and understand ecosystem processes. In 1932, White invented a method to find both daily evapotranspiration and net groundwater upwelling from high-resolution observation of water table fluctuations. We improve the White method in order to compute the hourly evapotranspiration which requires taking into account a process neglected by White and which is important during transition between net loss and net gain: the profile of hysteretic soil water content. A simplified “square profile” model for hysteresis is implemented to compute hourly evapotranspiration with the White method. Numerical simulations were undertaken using field data to demonstrate the model. The simple representation of hysteresis provided predictions which appear to accurately model evapotranspration.

INTRODUCTION

Sallow water table fluctuations in riparian areas can be generated by the diurnal cycle evapotranspiration (ET). The link between variations in the groundwater level and ET were first described by White (1932) based on his observations in Escalante Valley, Utah. Plants water use from the riparian zone was characterized by direct supply from the saturated zone due to early-season depletion of water from the unsaturated zone. In riparian areas the local hydraulic gradient often provided for the replenishment with groundwater from the saturated zone.

As an example of these flood-plain processes, figure 1 shows diurnal fluctuations of the groundwater level recorded in the riparian zone of the John Day River, Oregon. During the daylight hours, when solar radiation is most intense, plants uses water and the water table drops from several millimeters. On the contrary, during the night, transpiration is minimal and groundwater level rises thanks to the net groundwater recovery from regional drainage to this lowest spot in the landscape. Over long periods of time, the supply of water from groundwater upwelling influences ET, in that if the water table declines, ET will also be reduced due to the difficulty of extraction from greater depth. Note that if groundwater is replenished, then twice a day ET will be equal to the net groundwater recovery. During drought periods, the balance between recharge and ET is generally negative leading to overall seasonal decline in water table levels.

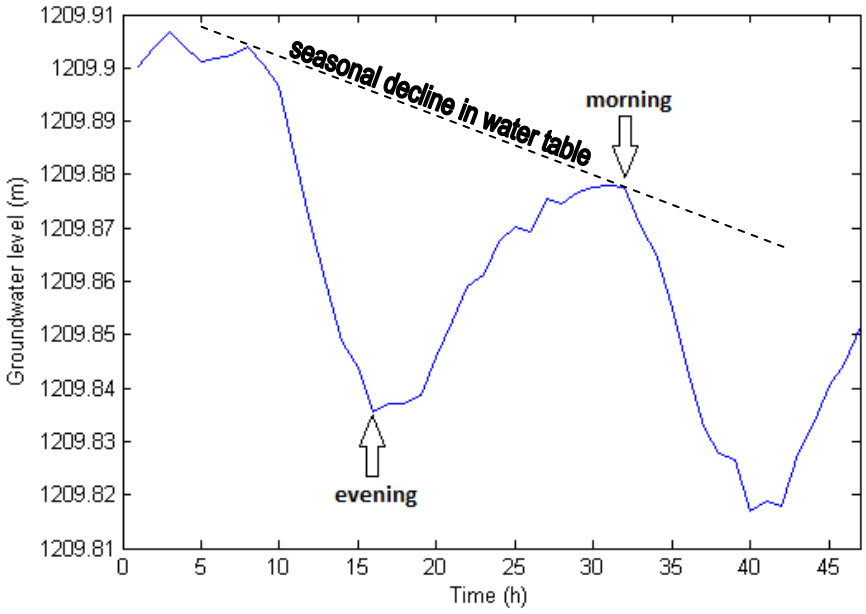


Figure 1. Groundwater fluctuations in the riparian zone of the John Day River recorded from 06/23/11 at 0:00 am to 06/24/11 at 11:00 pm with illustration of seasonal water table decline.

White developed a method to estimate ET based on quantification of variations in riparian water table levels recorded in shallow wells. Several assumptions were used by White: (1) groundwater recovery r_y is constant over the daily timescale; (2) transpiration may be between 1am and 4am; (3) that any change in water table position indicated a loss or gain of water equal to the change in depth multiplied by a specific yield; and (4) rain events do not appear during drought period. These assumptions allowed him to consider that the slope of the tangential line of the curve in the figure 1 between 1am and 4am as an estimate for the groundwater recovery r_y. Losses of water over the day are approximated by groundwater level difference upon duration of 24h. White method has the following expression:

$$ET = S_y(24\, r_y \pm S) \qquad [1]$$

where ET is the daily evapotranspiration [mm], S_y is the dimensionless specific yield, r_y is the groundwater recovery rate [mm/h] and S is the difference in the groundwater level during 24h period [mm] (Figure 2).

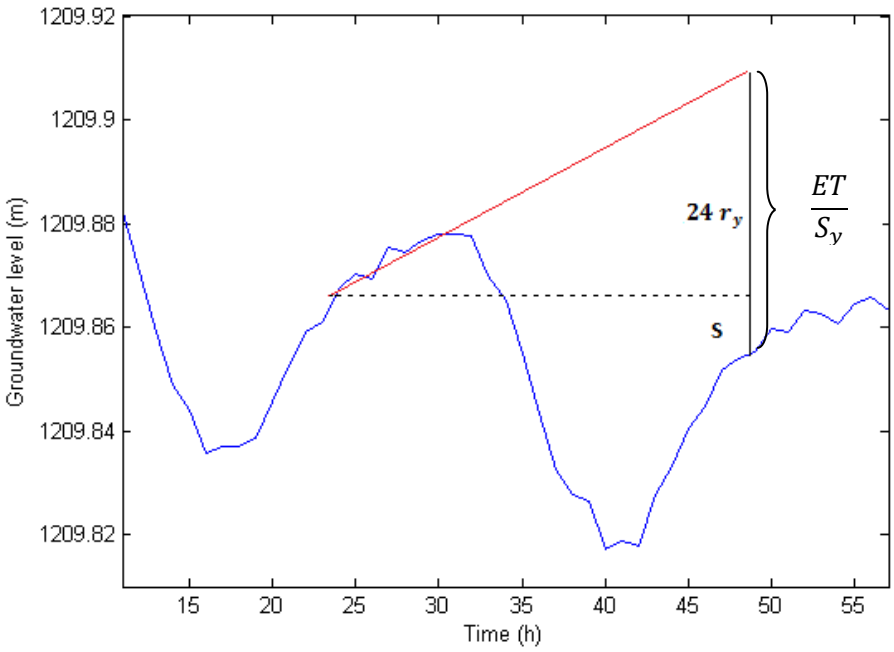


Figure 2. Graphical representation of estimation of ET by the White method.

The White method has many appealing features: (1) it is relatively simple and low-cost in implementation, (2) it generates daily ET and (3) it is broadly applicable. The most important source of error arises from the estimation for the specific yield S_y. In 1932 White defined the specific yield with the profile of the water content into the ground: $S_y = \theta_s - \theta_r$. Meyboom (1967) demonstrated that this value is too high, suggesting it should be halved. He named this new yield the “readily available specific yield.” Duke (1972) gave an expression for specific yield based on the depth to the surface. Finally, in 2002, Nachabe used the water content profile of Brook & Corey (1964) to provide a specific yield including the time of drainage.

Several studies have sought to improve the White method and to improve the estimate of specific yield: Healy and Cook (2002), Loheide et al. (2005 and 2008), Gibrovski et al. (2008), Soylu et al. (2011). However, none of these papers have considered that the water content versus water table relationship would be expected to be hysteretic. This is curious in that the White method specifically concerns itself with sequential wetting and draining processes which are strongly affected by hysteresis, (Figure 3.a).

A first question is White method create an error in the estimation of ET by ignoring this process? The goals of this paper are: (1) understand impact of hysteresis in the pressure-water content relationship on groundwater level fluctuations seen in wells (2) to integrate a tractable representation of hysteresis in

the White method to improve its accuracy and (3) validate this new model. To achieve these goals numerical simulations have been realized to integrate hysteretic profile of the groundwater content in the White method. Data provided by five wells near the John Day River, Oregon, have been used to make a comparison.

THEORY

For over 80 years the relation between water content and pressure has been recognized as being hysteretic (Haines 1930, Topp & Miller 1966). Many studies have given mathematical parametric models for the wetting curve (θ_w) and the drying curve (θ_d) to characterize the hysteretic profile: e.g., Mualem (1977) and Parlange (1988). Nevertheless, we seek a much simpler representation consistent with the level of approximation of the White model. As figure 3 shows, this new model consists in the representation of the water content by a step-function. Specifically, the wetting and drying curves are separated by the distance Δh (we will see next how this parameter could be estimated).

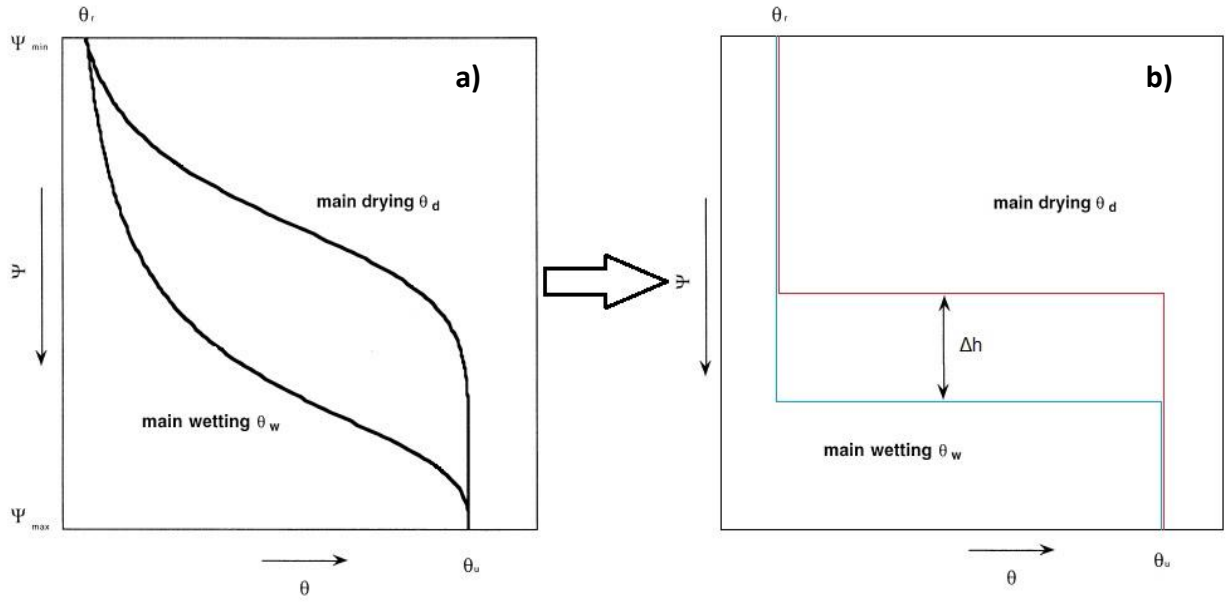


Figure 3. Illustration of the outer-envelope of hysteretic profiles of the water content versus pressure (3.a) and the new hysteretic profile (3.b).

With this model, it is easier to explain the implication of the hysteretic profile over time. During the night, a recovery process of the soil occurs and the water table rises. The water table fits the wetting curve as shown in figure 4.a. Around 7am, ET starts. When its value is higher than the groundwater recovery the water table drops and water content is equal to the drying curve. Consequently, at this moment there is a lack of water in the unsaturated zone as we can see in the figure 4.b. Thus, during the time Δt, the water table must drop without changing the shape of the water

content (cf figure 4.c). Consequently, during Δt the water table should drop because of two processes: (1) evapotranspiration with the rate $\frac{R-ET}{S_y}$ [mm/h] and (2) hysteresis with the rate $\frac{\Delta h}{\Delta t}$ [mm/h]. This acceleration of the dropping rate is due to the capillarity forces created by the hysteresis process. At the end of this process, the water content is equal to the drying curve and the water table can drop normally (cf figure 4.d). The same process happens at the end of the afternoon because there is a supply of water in the unsaturated zone, thus the water content must switch from the drying curve to the wetting curve in the figure 4.e.

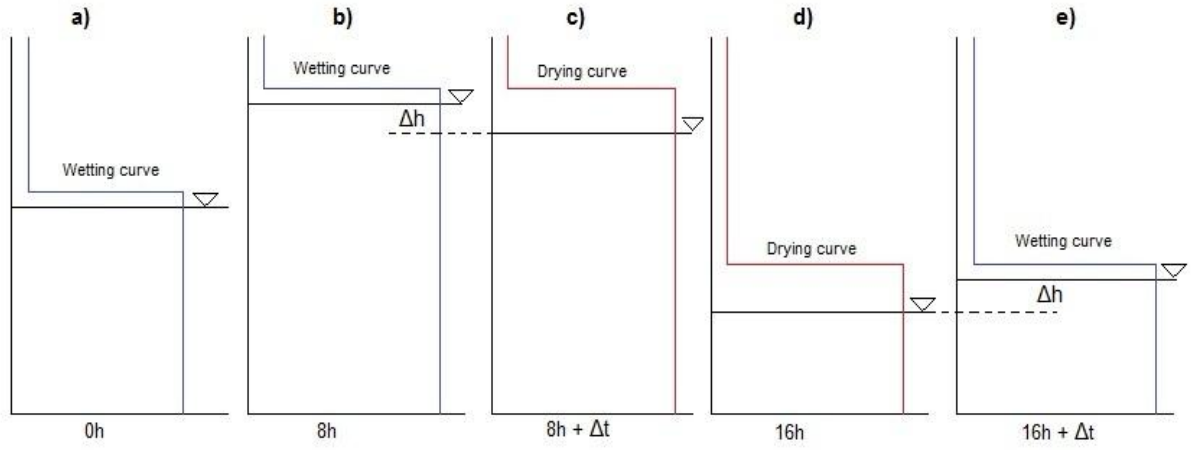


Figure 4. Schematization of the hysteresis process over time.

According to the previous explanations, computing water table elevation may be done with the following formula:

[2]
$$\begin{cases} for\ 0h < t < t_1 : h(t) = h(t-1) + \dfrac{R - ET(t)}{S_y} \\ for\ t_1 < t < t_1 + \Delta t : h(t) = h(t-1) + \dfrac{R - ET(t)}{S_y} - \dfrac{\Delta h}{\Delta t} \\ for\ t_1 + \Delta t < t < t_2 : h(t) = h(t-1) + \dfrac{R - ET(t)}{S_y} \\ for\ t_2 < t < t_2 + \Delta t : h(t) = h(t-1) + \dfrac{R - ET(t)}{S_y} + \dfrac{\Delta h}{\Delta t} \\ for\ t_2 + \Delta t < t < 24h : h(t) = h(t-1) + \dfrac{R - ET(t)}{S_y} \end{cases}$$

Where t_1 and t_2 follow $ET(t_1) = ET(t_2) = S_y r_y$, Δt is the time to switch from the wetting curve to the drying curve and Δh is the distance between these two curves and $R = S_y r_y$ is the net hourly groundwater recovery [mm].

It is a relevant question to wonder how these parameters Δt and Δh can be estimated. It can be found graphically as shown on the figure 5. Time Δt is the time interval between the lowest level of the water table and the breaking point of the slope when water table rises. Distance Δh is the elevation difference between these two moments. For typical and constant meteorological conditions, these parameters are constant over the period for each site.

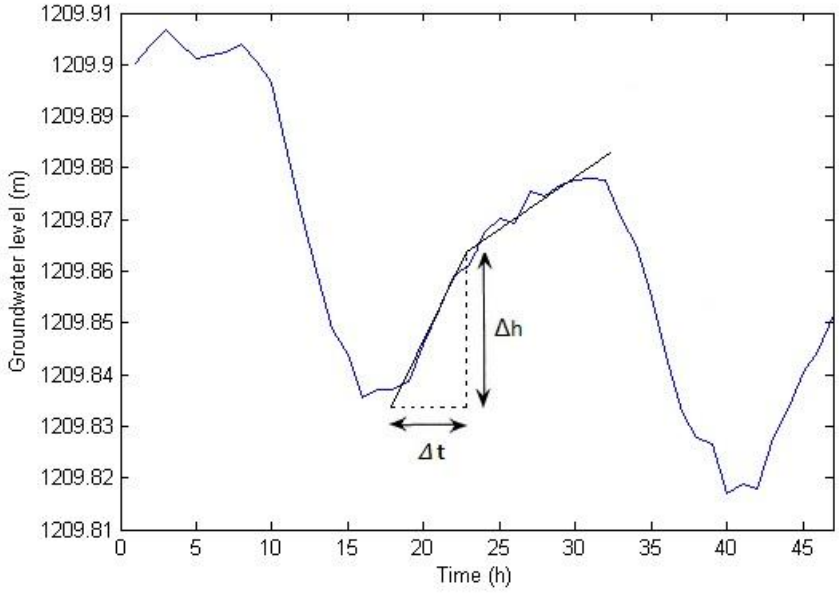


Figure 5. Graphic determination of the parameters Δt and Δh.

It is also possible to compute Δh if wetting and drying curves are completely known with the following expression:

$$\Delta h = \frac{1}{S_y}\int_0^{\infty} \theta_d(h)dh - \frac{1}{S_y}\int_0^{\infty} \theta_w(h)dh \qquad [3]$$

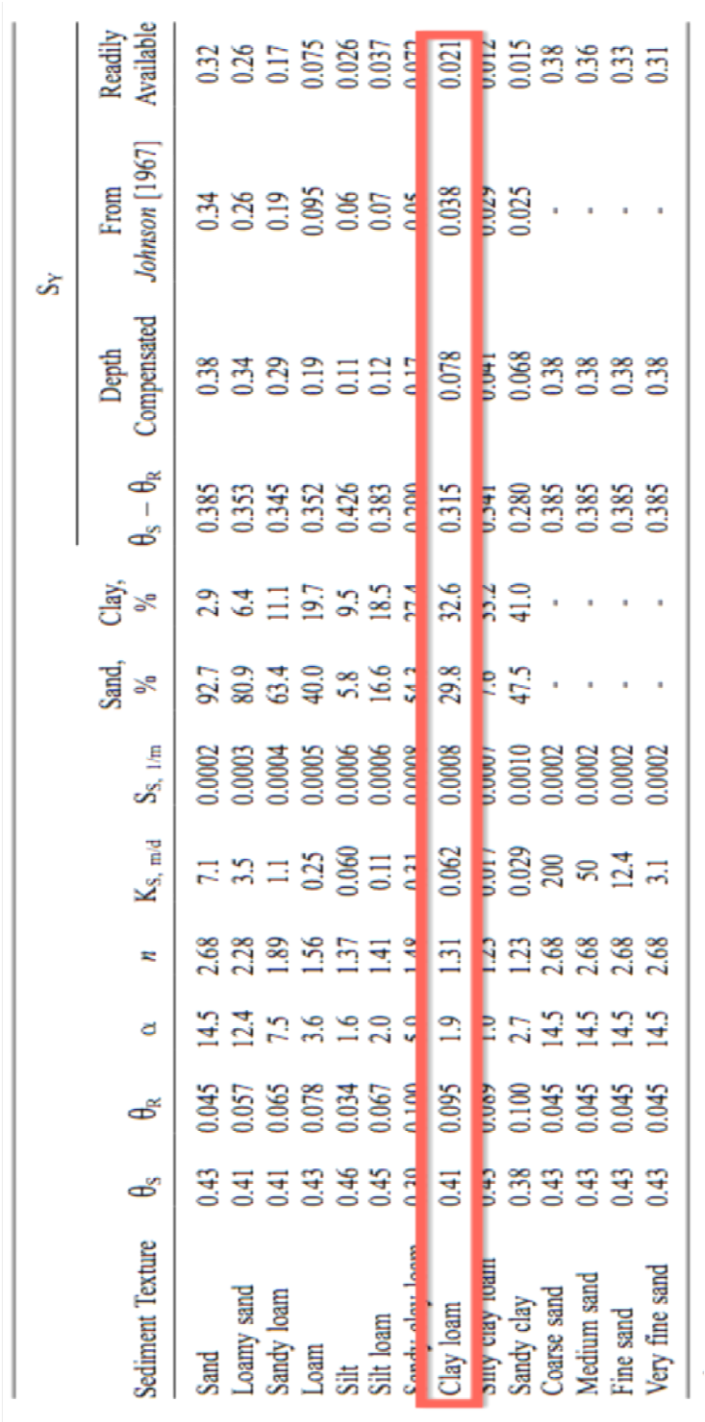
METHOD

After completing two mains aims of this paper ie understand the role of the hysteretic profile and create a model that integrates this process (formula [2]), numerical simulations were realized to validate this model. These simulations were done with data provided by five wells of the John Day River area, Oregon, United States and AgriMET data from Prairie City meteorological station. This station

computes reference evapotranspiration ET_0 thanks to the Kimberly-Penman formulation. Available data are groundwater level every hour for each wells and daily reference evapotranspiration. As a consequence, it seems wiser to compute hourly water table level then make a comparison with data from wells

Specific yield is considered to be constant and equal to the readily available specific yield of Meyboom. According to the report of the United States Department of Agriculture « Soil survey of Grant County » (Dyksterhuis, 1981), the soil is mostly consisting of clay and loam. Thanks to Loheide (2005), the value of the specific yield can be estimated to 0.02 (table 1). Groundwater recovery r_y is the slope of groundwater level between 1am and 4am, thus net groundwater recovery can be found because $R = S_y r_y$.

Table 1. Determination of the specific yield by Loheide (2005).



Sediment Texture	θ_S	θ_R	α	n	$K_{S,\ m/d}$	$S_{S,\ 1/m}$	Sand, %	Clay, %	S_Y		
									$\theta_S - \theta_R$	Depth Compensated	From *Johnson* [1967]	Readily Available
Sand	0.43	0.045	14.5	2.68	7.1	0.0002	92.7	2.9	0.385	0.38	0.34	0.32
Loamy sand	0.41	0.057	12.4	2.28	3.5	0.0003	80.9	6.4	0.353	0.34	0.26	0.26
Sandy loam	0.41	0.065	7.5	1.89	1.1	0.0004	63.4	11.1	0.345	0.29	0.19	0.17
Loam	0.43	0.078	3.6	1.56	0.25	0.0005	40.0	19.7	0.352	0.19	0.095	0.075
Silt	0.46	0.034	1.6	1.37	0.060	0.0006	5.8	9.5	0.426	0.11	0.06	0.026
Silt loam	0.45	0.067	2.0	1.41	0.11	0.0006	16.6	18.5	0.383	0.12	0.07	0.037
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Clay loam	0.41	0.095	1.9	1.31	0.062	0.0008	29.8	32.6	0.315	0.078	0.038	0.021
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Sandy clay	0.38	0.100	2.7	1.23	0.029	0.0010	47.5	41.0	0.280	0.068	0.025	0.015
Coarse sand	0.43	0.045	14.5	2.68	200	0.0002	-	-	0.385	0.38	-	0.38
Medium sand	0.43	0.045	14.5	2.68	50	0.0002	-	-	0.385	0.38	-	0.36
Fine sand	0.43	0.045	14.5	2.68	12.4	0.0002	-	-	0.385	0.38	-	0.33
Very fine sand	0.43	0.045	14.5	2.68	3.1	0.0002	-	-	0.385	0.38	-	0.31

As previously stated, we just have the daily reference evapotranspiration. It is necessary to reproduce the total hourly evapotranspiration ET. To do that, two steps are useful. Firstly, hourly reference evapotranspiration sould be recreated. The ET was considered equal to zero between 8pm and 8am because solar radiations are

low. During the daylight, thus between 8am and 8pm, ET was modeled with sinusoidal signal:

$$Considering\ the\ d\ day\ and\ 8am \leq t \leq 8pm \quad ET_0^d(t) = A(d)\sin\left(\frac{2\pi}{24}t - \frac{2\pi}{3}\right) \qquad [4]$$

$$And \quad A(d) = ET_0(d)\left[\int_{8am}^{8pm} \sin\left(\frac{2\pi}{24}t - \frac{2\pi}{3}\right)dt\right]^{-1} \qquad [5]$$

Where $ET_0(d)$ is the reference evapotranspiration for the d day and $ET_0^d(t)$ is the recreated reference evapotranspiration for the d day and the time t.

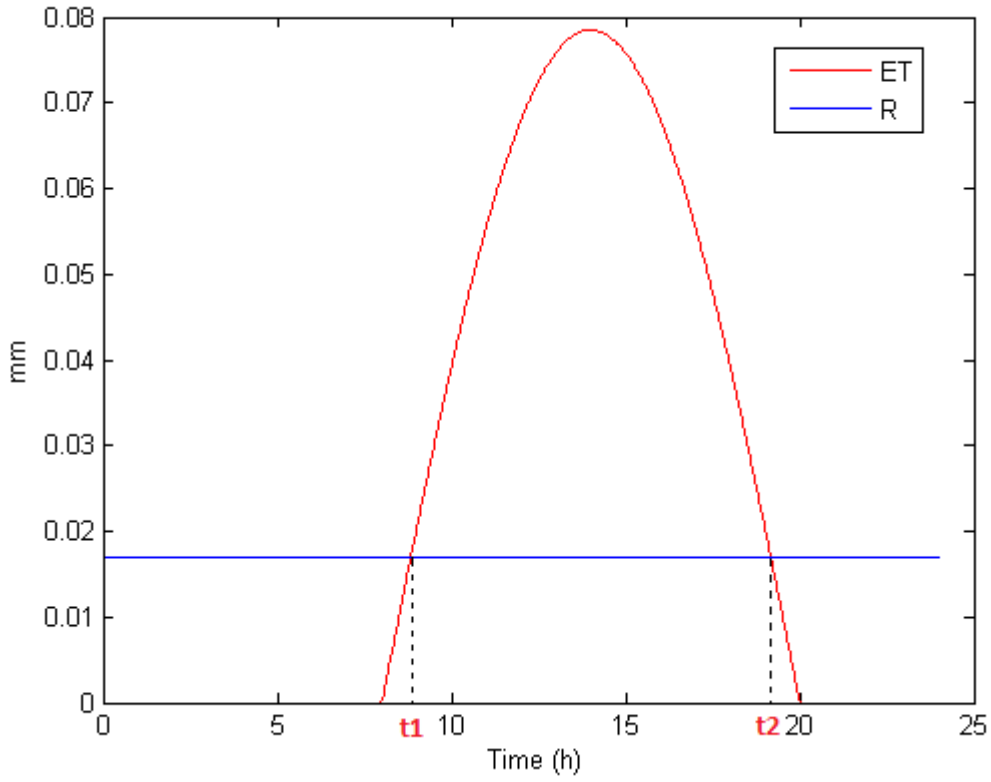


Figure 6. Reconstitution of the hourly evapotranspiration from $\boldsymbol{ET_0}$.

Secondly, crop coefficient has to be determined because it permits to compute the total evapotranspiration with the reference evapotranspiration thanks to the next formula:

$$ET(t) = K_c\, ET_0^j(t) \qquad [6]$$

Where K_c is the crop coefficient [dimensionless]. This parameter was considered constant for each well and for one week period. The determination of this parameter can be done by calibration to fit slopes of the mean elevation given by the data and formula [2].

From the data of the water table fluctuations over time and for each well, it is possible to find graphically the value of Δt and Δh.

Each element of the formula [2] are now perfectly known, consequently it is possible to compute this formula by iteration with Matlab in order to find hourly groundwater level for each data sample.

RESULTS

The model was evaluated with data sample provided by five wells located in the John Day River (Table 2). Sample duration is approximately one week. The reason of this choice is that during one week, parameters S_y, K_c, Δt and Δh are constant. Moreover, net daily consumption $\frac{1}{S_y}$ $(R - ET(t))$ is also constant by approximation over a short period. Thus, the calibration to find the crop coefficient is facilitated.

Table 2. Sample data description.

Sample name	Station	Well	Beginning	End
F3-6	Forrest	3	21/06/11 à 0h00	26/06/11 à 23h00
F3-7	Forrest	3	02/07/11 à 0h00	12/07/11 à 23h00
F17-6	Forrest	17	21/06/11 à 0h00	26/06/11 à 23h00
F18-6	Forrest	18	21/06/11 à 0h00	26/06/11 à 23h00
F17-7	Forrest	17	02/07/11 à 0h00	13/07/11 à 23h00
F18-7	Forrest	18	02/07/11 à 0h00	13/07/11 à 23h00
O33-6	Oxbow	33	21/06/11 à 0h00	28/06/11 à 23h00
O34-6	Oxbow	34	21/06/11 à 0h00	28/06/11 à 23h00

For each sample, calibration between the mean slope of the data and formula [2] was made by varying crop coefficient K_c. Results are shown in table 3. It is now possible for each sample to compute the total hourly evapotranspiration knowing the crop coefficient and the daily reference evapotranspiration (provided by AgriMet). Figure 9 presents the hourly evapotranspiration for the six day period sample of Forest 18.

Table 3. Crop coefficient.

Sample name	Crop coefficient K_c
F3-6	0.1 ± 0.01
F3-7	0.13 ± 0.02
F17-6	0.07 ± 0.02
F18-6	0.21 ± 0.02
F17-7	0.15 ± 0.03
F18-7	0.19 ± 0.03
O33-6	0.1 ± 0.01
O34-6	0.28 ± 0.02

Graphically, Δt and Δh were determined for each sample data, results are presented in table 4, we can see that Δt is almost constant and Δh does not vary a lot.

Table 4. Comparison between Δt, Δh and R^2. The coefficient of determination R^2 gives the sameness between data and results.

			Coefficient of determination R^2 (%)	
Sample name	**Δt (hour)**	**Δh (mm)**	Without Hysteresis	With Hysteresis
F3-6	3	17	68.9	94.1
F3-7	3	15	94.4	98.5
F17-6	4	15	55.1	88.1
F18-6	3	15	74.9	95.5
F17-7	3	13	95.2	98.0
F18-7	3	11	89.2	97.0
O33-6	5	28	56.7	91.1
O34-6	3	13	62.0	83.4

Knowledge of these parameters allows us to compute formula [2]. Thus, we obtained, for each well, the hourly water table fluctuations taking into account the hysteresis process. For every sample, result has been compared with well data and with the result without hysteresis process. This comparison gives the influence and the importance of the hysteresis process in the White method. Figure 10 shows the difference between the original White method and the new model that is more realistic because considering the hysteresis process.

To quantify the gap between these models, the coefficient of determination was calculated in table 4. This coefficient compares results from one model and well data. Thus, water table fluctuations reconstitution by the new model gives better results compared to the original White method.

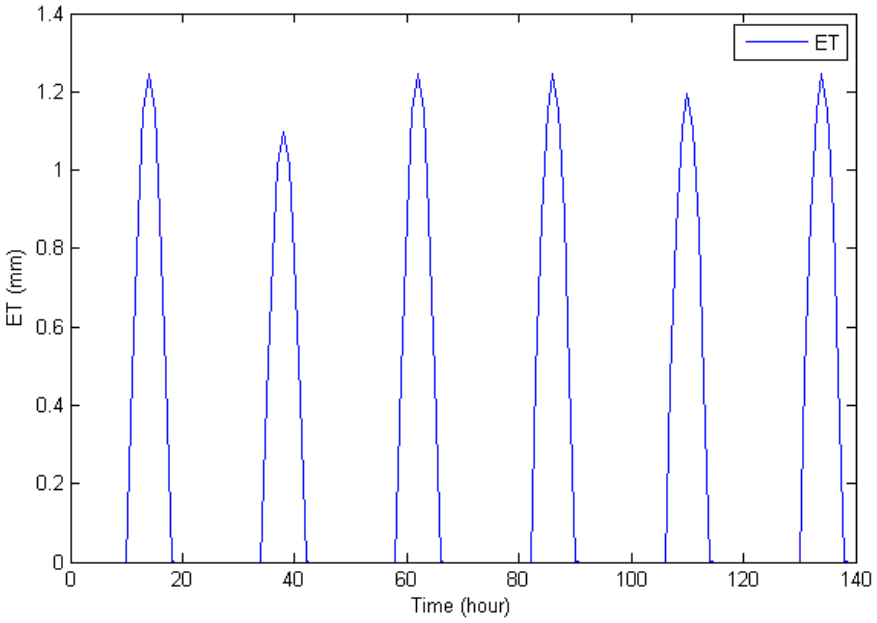


Figure 4. Hourly evapotranspiration for the F18-6 sample data.

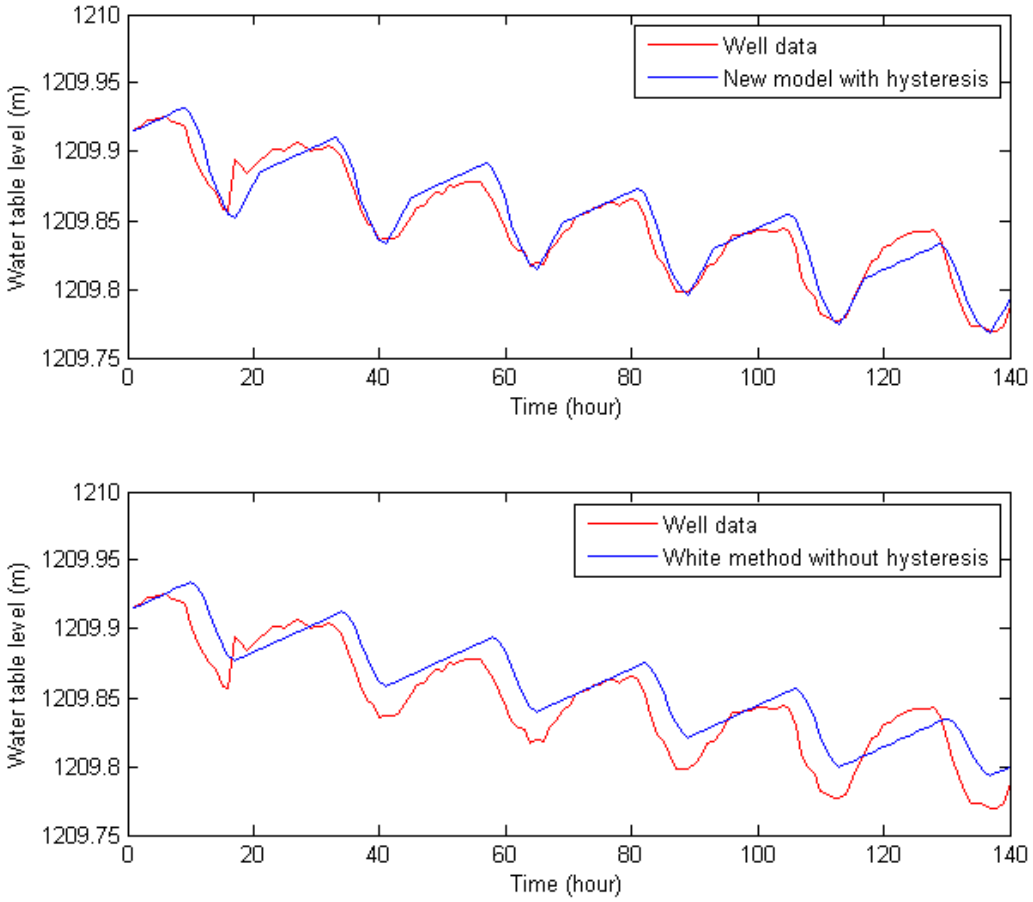


Figure 5. Comparison between the new model considering hysteresis process and the original White model to the groundwater level reconstitution (F18-6).

DISCUSSION

The method explained in this paper shows a greater estimation of the hourly evapotranspiration towards the general White method. Indeed, White method provides daily evapotranspiration from water table fluctuations. However, the calculation of the hourly evapotranspiration is not possible with the White method because it does not consider water budget in the vadose zone due to the hysteretic profile. The main modification follows the fact that water variations are decreased the morning and increased before the night because of the hysteresis.

The development of this new model needs to use several parameters. Specific yield, which is the most important source of error in the White method, was estimated by the readily available specific yield from Meyboom. The used value was 0.02 but despite the fact that this value is perfectly compatible with the soil, the real value could be slightly different. Indeed, according to Loheide (2005), for clay loam soil and under 1m depth, specific yield varies between 0.01 and 0.05. Therefore, the value we used is correct but could be refined considering the depth (Duke 1972) or the time of drainage (Nachabe 2002).

Crop coefficient K_c has an average of 0.15 in June and 0.16 in July. According to AgriMET site, for alfalfa land cover, K_c should varie from 0.15 at the beginning of growth season to 0.85 at the end of this period. The growth season is approximately from the beginning of May until the end of July, thus we can assert that these values are lower than reality. This gap can be explained by the fact that Prairie City station is located 20km away from our field. It is strongly probable that ET is greater in this station because it is less sheltered than the zone where wells are located. Consequently, crop coefficient is logically lower to drop the ET. However, crop coefficient rises with growth period and respects this trend.

Time Δt, which is fundamental to the change between wetting and drying curve, was graphically found. As shown in table 4, this time is almost constant. Nonetheless, it is possible to consider the net consumption $\frac{1}{S_y}\ (R - ET(t))$ to find this parameter. In fact, Δt is the time that needs net consumption to consume the among of water contained between wetting and drying curve from the time t_1. Thus, Δt varies with soil, groundwater recovery and ET. Yet, these parameters are very close between wells and it seems normal to find the same value for each of them.

We also can have a reflection about time period where ET is not neglected. Hourly evapotranspiration reconstitution from daily reference evapotranspiration was made with several assumptions: it is a sinusoidal signal and ET is neglected between 8pm and 8am. This period, yet realistic, should be slightly different because of the place, the month or meteorological conditions. These two moments are crucial because water table level is clearly dependent on them. Consequently, it is possible to plan a calibration of these parameters in order to increase precision.

It is also important to stay cautious with data provided by wells because it may induce errors. The reason could be degradation over time period or construction problems. Samples have been selected to have the greater data and the most realistic.

According to what was said previously, many parameters could induce several errors. Nonetheless, as shown in table 4, comparison between White method and the new model reveals that the new one gives the best prediction of the water table level and reproduces the shape of the fluctuations.

Water table fluctuations process in the vadose zone can be explained. The lack of water at the end of the day is packed and reduced it in the morning. The modification of the wetting curve to the drying curve is now simulated. The model shows the increase of capillarity forces which implies a transfer of water from saturated to unsaturated zone. At this moment, two recoveries are present: (1) groundwater recovery and (2) flow from hysteresis process. Total recovery is obviously greater during this period of time, ie between 7pm and 10pm. This difference allows us to explain the breaking point of the slope at 10pm. As shown in figure 10, White method does not report this change but it is perfectly done with the new method.

The model created in this paper gives the best reconstitution of the water table fluctuations. As it was said previously, the change in the slope, which is a consequence of the hysteretic profile, is perfectly represented by this method. Furthermore, the amplitude of the fluctuations is closer to the reality in this model than the hourly original White method (cf figure 10). We can also remark that the amount of water is overestimated in the White method, consequently ET is underestimated.

MODELISATION OF THE HYSTERESIS BY MACROSPORES.

In this part, we will explain another way to understand and modelize the hysteresis process in the White method. Despite the fact that this explanation is physically better, the result is not as good as we expected. However it is interested to understand this point of view.

The previous representation is actually validated for an idealized soil which is homogeneous. Most of the time, soil porosity can be considered to be composed with almost 90% of microspore and 10% of macrospore. These macrospores can be

generated by plant roots, soil cracks or by aggregation of soil particles. To differentiate these pores, we will consider the Laplace equation for the capillarity pressure in a tube (figure 11):

$$P = \frac{-2\sigma}{r} \quad [7]$$

Where P is the pressure on the top of the tube [N/m²], $\sigma = 73.10^{-3}\ N/m$ is the water surface tension and 2r the tube diameter (m). We considered a micropore if the elevation h is greater than 5mm and macrospore otherwise. Pressure P is hydrostatic: $P=\rho gh$. Thus we will consider macrospore if the radius is greater than $r = \frac{2\sigma}{\rho g h} = 3mm$.

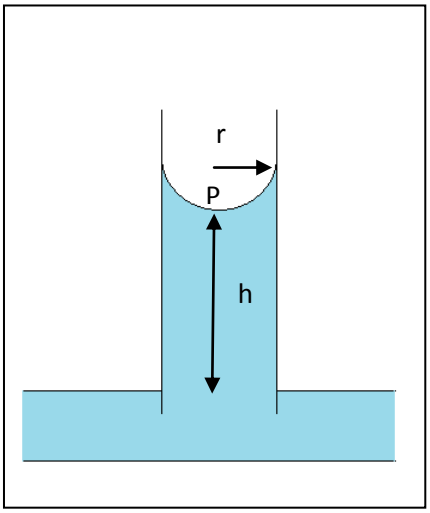


Figure 11. Modelisation of the pores by a tube

We can see that there is a competition between two processes. Water transport into macrospores is faster than into microspores because capillarity effects are lower. As a result, water content for real soil, it means soil with both macrospores and microspores can be represented as shown in figure 12.

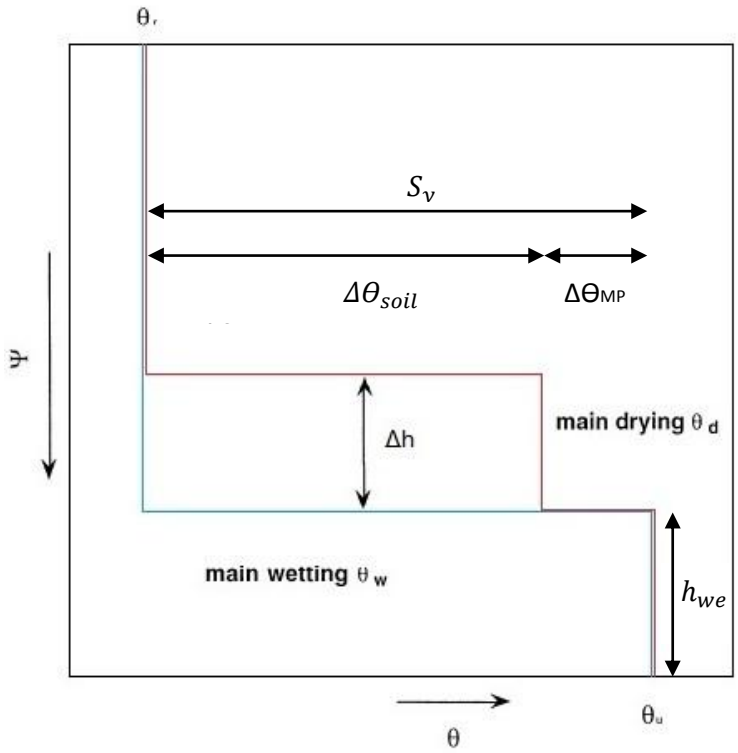


Figure 12. New water content profile with microspore and macrospore comportment.

Within this model framework, it is easier to explain the implication of the hysteretic profile over time. During the night, a recovery process of the soil occurs due to groundwater upwelling in the absence of ET, and the water table rises without water filling the soil until the water table is exactly h_{we} below the height of the capillary fringe (cf figure 12). With additional increase in the water table, the capillary fringe rises as well, resulting in a net increase in stored soil water. This process occurs again when the water table starts to drop, when ET is no longer negligible.

Around 7am, ET starts. When its value is higher than the groundwater recovery water content has to be equal to the drying curve to permit water table to drop, this moment is named t_1. As it was said before, water transport is easier into macrospores because capillarity forces can be neglected. As a consequence, water content change is generated by water transport into macrospores during Δt hours (figure 13, stage A). Compared to the original White method, water table diminution by drainage has to be amplified by the value $\frac{R}{\Delta\theta_{MP}}$ where $R = S_y r_y$ is the net hourly groundwater recovery [mm] and $\Delta\theta_{MP}$ is the equivalent specific yield for macrospore. During stage B, water is drained by both macrospores and microspores, consequently, the specific yield is S_y. At the end of the daylight time, at the time t_2 net recovery becomes greater than ET and water table starts the rising process. Firstly water content changes from the drying curve to the wetting curve. Then, when water table rises, water transport starts into macrospores (figure 13, stage C). As a

consequence elevation is pretty fast during the time Δt because during stage C elevation has to be greater from the value $\frac{R}{\Delta\theta_{MP}}$ compared to the original White method. When elevation, created by macrospores reaches Δh, hydraulic pressure is too important and water have to rise by macrospores and microspores simultaneously (Figure 13, stage D). Thus, elevation becomes slower and breaking point appears between stage C and D. Table 5 resumes the components which characterize each stage.

Table 5. Resume of the different stages over a 24h-period.

Stage	A	B	C	D
Duration	$t_1 \rightarrow t_1 + \Delta t$	$t_1 + \Delta t \rightarrow t_2$	$t_2 \rightarrow t_2 + \Delta t$	$t_2 + \Delta t \rightarrow t_1$
ET	Yes	Yes	No	No
Pore type	Macro	Macro + Micro	Macro	Macro + Micro

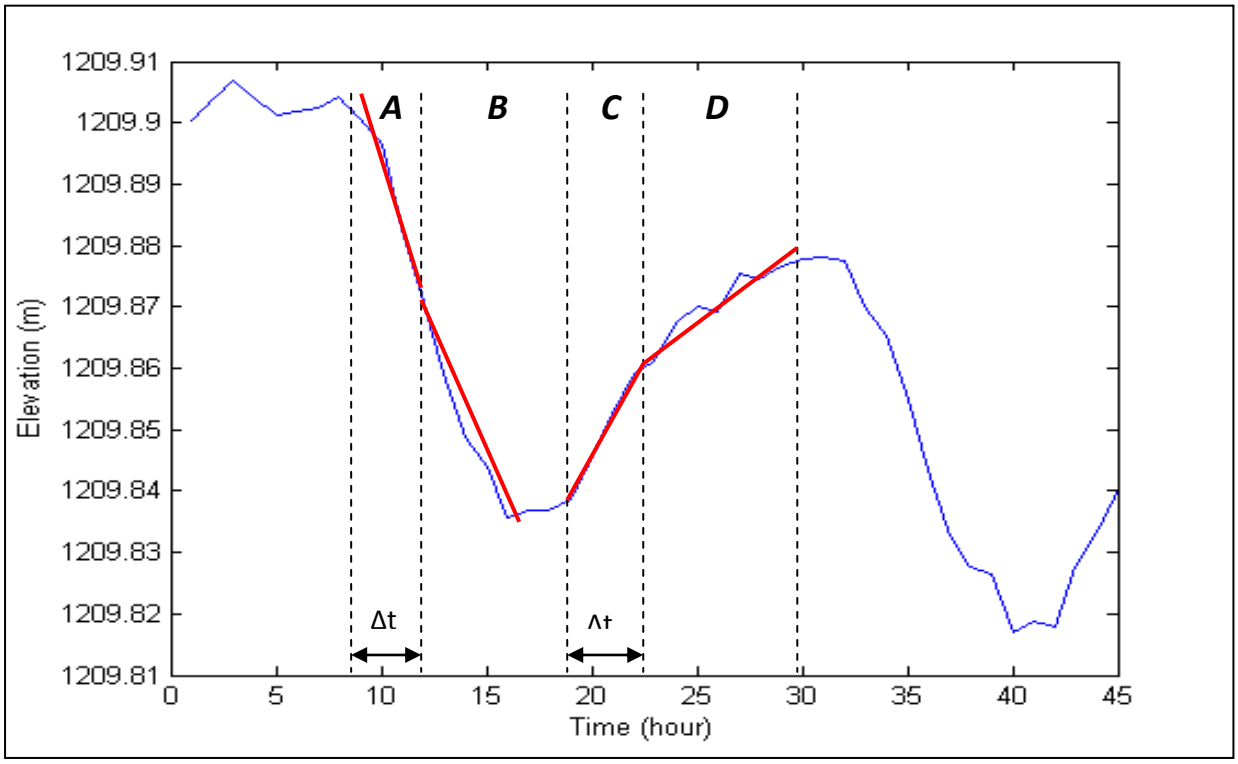


Figure 13. Identification of the 4 stages that occur during 24h-period. These stages are generated by hysteretic process and macrospore/microspore soil representation.

According to the previous explanation, this model can be written with the following expression:

$$[8] \quad \begin{cases} for\ 0h < t < t_1 \ :\ h(t) = h(t-1) + \frac{R-ET(t)}{S_y} \\ for\ t_1 < t < t_1 + \Delta t :\ h(t) = h(t-1) + \dfrac{R - ET(t)}{S_{yMP}} \\ for\ t_1 + \Delta t < t < t_2 \ :\ h(t) = h(t-1) + \dfrac{R - ET(t)}{S_y} \\ for\ t_2 < t < t_2 + \Delta t :\ h(t) = h(t-1) + \dfrac{R - ET(t)}{S_{yMP}} \\ for\ t_2 + \Delta t < t < 24h :\ h(t) = h(t-1) + \dfrac{R - ET(t)}{S_y} \end{cases}$$

Where $S_y = \Delta\theta_{soil} + \Delta\Theta_{MP}$ is the specific yield and $S_{yMP} = \Delta\Theta_{MP}$ is the specific yield for the macrospores.

The same method than in the first model have been employed to find Δt and Δh (figure 5), ET and R.

To find the mean $S_y\ and\ S_{yMP}$, we firstly fit this model with the data by modification of these two parameters for each well. We found an average of 0.05 for S_y and 0.007 for S_{yMP}, it means that $S_{yMP} = 14\%\ S_y$. These parameters seems to have relevant values because as we said before we need to have $0.01 < S_y < 0.05$ and $S_{yMP} \approx 10\%\ S_y$.

With all the parameters, we computed the water table elevation vs the data (figure 14). The coefficient of determination allows us to see how the model is good (table 7).

Table 6. Crop coefficient.

Sample name	Crop coefficient K_c
F3-6	0.05 ± 0.01
F3-7	0.06 ± 0.02
F17-6	0.03 ± 0.02
F18-6	0.18 ± 0.02
F17-7	0.3 ± 0.03
F18-7	0.16 ± 0.03
O33-6	0.04 ± 0.01
O34-6	0.45 ± 0.02

Table 7. Comparison between Δt, Δh and R^2. The coefficient of determination R^2 gives the sameness between data and results. We can compare the first model and the second one with the macrospore.

			Coefficient of determination R^2 (%)	
Sample name	**Δt (hour)**	**Δh (mm)**	With Hysteresis (Method 1)	With Hysteresis (Method 2)
F3-6	3	17	94.1	55.5
F3-7	3	15	98.5	60.1
F17-6	4	15	88.1	35.4
F18-6	3	15	95.5	85.2
F17-7	3	13	98.0	89.9
F18-7	3	11	97.0	95.5
O33-6	5	28	91.1	50.2
O34-6	3	13	83.4	56.8

As we can remark on the figure 14, represented the comparison between this model and the data, the amplitude of the fluctuation is not as great as it should be. Furthermore, with this model, we have two breaking points at $t_1 + \Delta t \; and \; t_2 + \Delta t$ but as we said previously the data shows just one breaking point at $t_2 + \Delta t$. As it was explained before, this difference is due to the fact that gravity helps water dropping during the day and, as a consequence, smoothes change of slope at $t_1 + \Delta t$. Thus, and considering that the amplitude is not as good as in the first model (table 7), we can conclude that this model is not really convincing. Despite the fact that the coefficient of determination is lower than in the hourly White method, the fluctuations are closer to the data. As a conclusion, this model is better than the hourly White method but not as good as the first model.

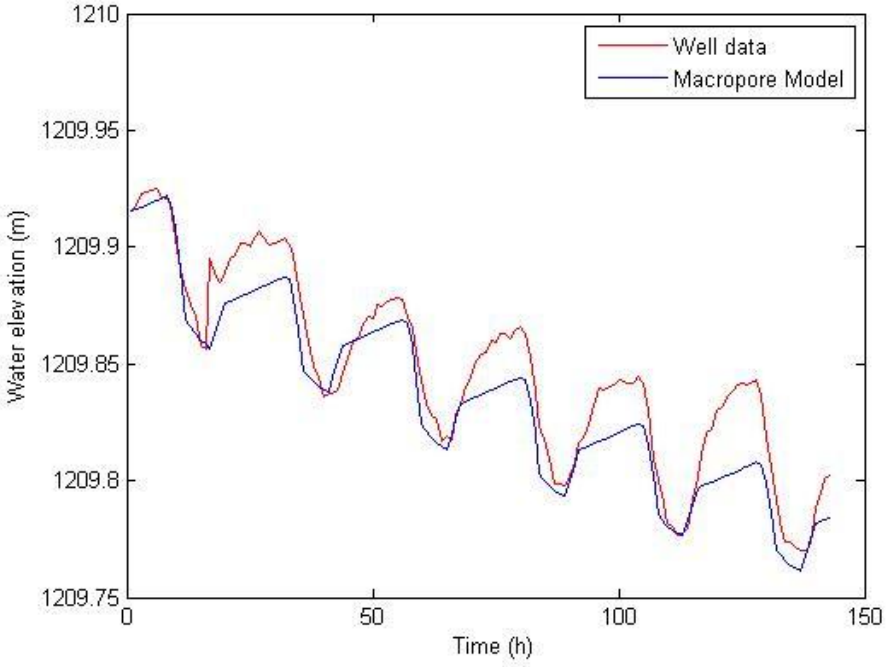


Figure 14. Comparison between data and the macrospore model for the well F18-6.

CONCLUSION

To conclude, reconstitution of the water table fluctuations is more suitable with the two models developed in this paper than the White method. The hourly White method is only possible by integration of the hysteresis process.

The first model has been realized with a simple square to modelize the hysteresis. Making a comparison between the White method without hysteresis and the model with the hysteresis it has been shown that the capillarity forces creates an acceleration of the flux at the beginning of the night and deceleration at the beginning of the day.

The second model explains this change of acceleration considering an inhomogeneous soil. The presence of macrospores changes the specific yield twice a day.

The comparison of all the models leads to the conclusion than the hourly White method needs to take into account the hysteresis process. Both models have a best fitting compared to the original White model. However the second model gives the best representation of the water table fluctuations.

REFERENCES

Duke, H. R. (1972), Capillary properties of soils—Influence upon specific yield, Trans. ASAE, 15(4), 688–691.

Dyksterhuis, E. (1981), Soil Survey of the Grant County, Oregon, Central part. http://soils.usda.gov/survey/online_surveys/oregon/OR633/Grant.pdf

Gribovszki, Z., J. Szilágyi, and P. Kalicz (2010), Diurnal fluctuations in shallow groundwater levels and streamflow rates and their interpretation – A review. *J.Hydrol., 385*, 371–383. doi:10.1016/j.jhydrol.2010.02.001.

Gribovszki, Z., P. Kalicz, J. Szilágyi, and M. Kucsara (2008), Riparian zone evapotranspiration estimation from diurnal groundwater level fluctuations. *J.Hydrol., 349*, 6–17. doi:10.1016/j.jhydrol.2007.10.049.

Haines, W.B. 1930. Studies in the physical properties of soil – V: The hysteresis effect in capillary properties and the modes of water distribution associated therewith. Journal of Agricultural Science, **20**: 97–116.

Healy, R.W., and P.G. Cook (2002), Using groundwater levels to estimate recharge. *Hydrogeol. J., 10*, 91– 109. doi:10.1007/s10040-001-0178-0.

Loheide, II SP. (2008), A method for estimating subdaily evapotranspiration of shallow groundwater using diurnal water table fluctuations. *Ecohydrology, 1*, 59–66.doi:10.1002/eco.7.

Loheide, II S.P., Jr J.J. Butler, and S.M. Gorelick (2005), Estimation of groundwater consumption by phreatophytes using diurnal water table fluctuations: A saturatedunsaturated flow assessment. *Water Resour. Res., 41*, W07030.doi:10.1029/2005WR003942.

Martinet, M.C., E.R. Vivoni, J.R. Cleverly, J.R. Thibault, J.F. Schuetz, and C.N. Dahm (2009), On groundwater fluctuations, evapotranspiration, and understory removal in riparian corridors. *Water Resour. Res., 45*, W05425. doi:10.1029/2008WR007152.

Meyboom, P. (1967), Groundwater studies in the Assiniboine River drainage basin—part II: Hydrologic characteristics of phreatophytic vegetation in south-central Saskatchewan, Bull. Geol. Surv. Can., 139.

Mualem, Y. 1977. Extension of the similarity hypothesis used for modeling the soil water characteristics. Water Resources Research, **13**: 773–780.

Nachabe, M. H. (2002), Analytical expressions for transient specific yield and shallow water table drainage, Water Resour. Res., 38(10), 1193, doi:10.1029/2001WR001071.

Parlange, J-Y. 1976. Capillary hysteresis and relationship between drying and wetting curves, Water Resour. Res., Vol. 12, pp. 224-228.

Schilling, K.E., and J.R. Kiniry (2007). Estimation of evapotranspiration by reed canary grass using field observations and model simulations. *J. Hydrol., 337*, 356–363. doi:10.1016/j.jhydrol.2007.02.003.

Soylu, M.E., E. Istanbulluoglu, J.D. Lenters, and T. Wang (2011), Quantifying the impact of groundwater depth on evapotranspiration in a semi-arid grassland region. *Hydrol. Earth Syst. Sc., 15*, 787-806. doi:10.5194/hess-15-787-2011.

Topp, G.C. and Miller, E. E. 1966. Hysteresis moisture characteristics and hydraulic conductivities for glassbead media, Soil. Sci. Amer. Proc. 30 : pp. 156-162.

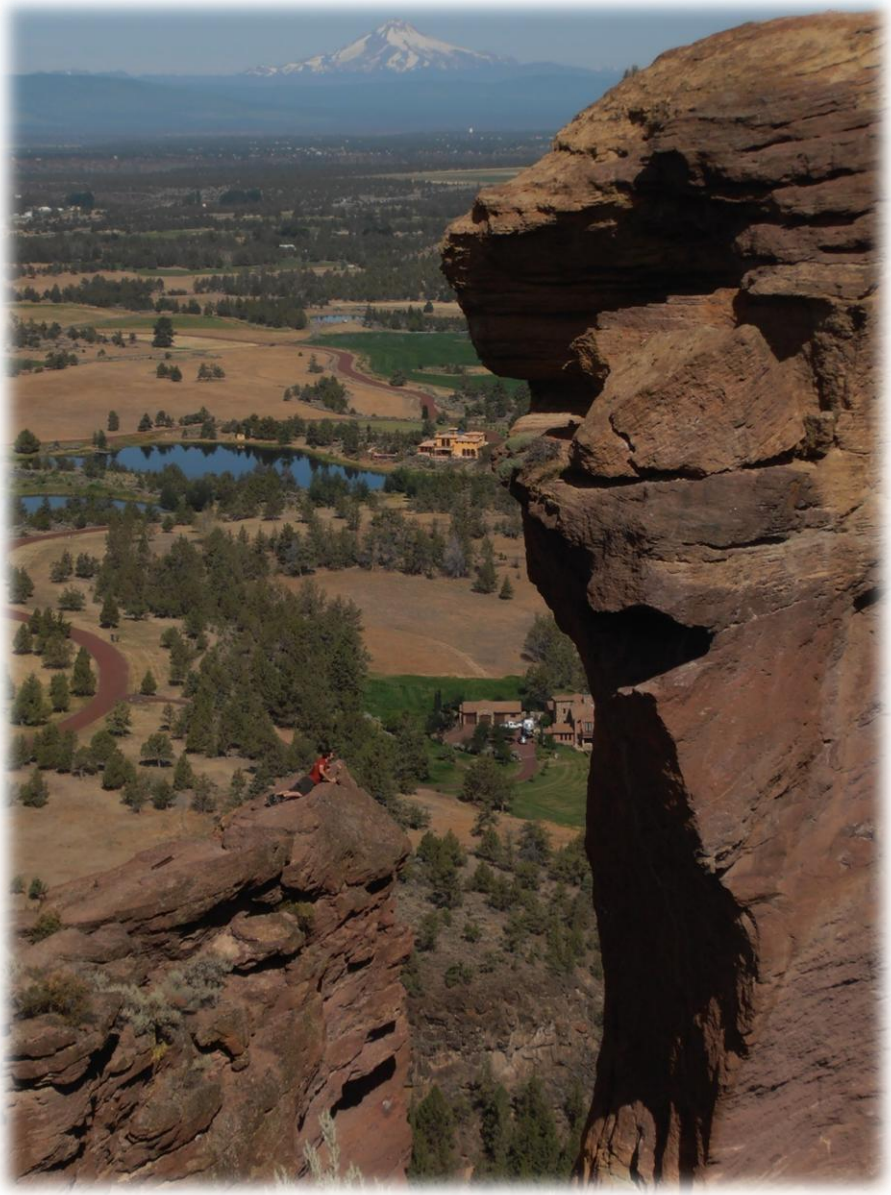
White, W.N. (1932), A method of estimating ground-water supplies based on discharge by plants and evaporation from soil: Results of investigations in Escalante Valley, Utah.
U.S,Geol. Survey Water Supply Paper 659-A.

TRIPS IN THE US.

- Durty Dash Mud Race (July 2012)

- Mt Jefferson (July 2012)

- Smith Rock (August 2012)



- California (August 2012)