

Public document

# ESPERE User Guide

## Version 2

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Géosciences pour une Terre durable

**brgm**

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## Synopsis

ESPERE is an MS Excel application which allows to apply several commonly-used methods to rapidly and simultaneously estimate groundwater recharge. According to the available data, the user can apply and compare the results of three empirical methods (Guttman, Turc and Kessler), three slightly different water budget methods (Thornthwaite, Dingman and Edijatno & Michel), the water table fluctuation (WTF) method and three hydrograph separation algorithms (Wallingford, Chapman and Eckhardt).

The first version of ESPERE (v1.52) can be freely downloaded on the BRGM website since 2016. To account for user feedbacks, ESPERE has been recently improved and new facilities were added. A new release is now available (v2.44 available in April 2020) which includes the following developments:

- WTF method implementation accounts for the continuously aquifer drainage (correction for the unrealized recessions are added to the water level rise);
- ESPERE version 2 proposes automatic estimation of several parameters such as the effective precipitation infiltration ratio for water budget methods, the specific yield for WTF, the recession coefficient and BFI<sub>max</sub> for the hydrograph separation algorithms;
- The Edijatno & Michel water budget method was added in ESPERE version 2;
- Missing values in water level time series and discharge time series are automatically filled in.

This User Guide rapidly describes the new facilities included in ESPERE version 2. It also comprises a step-by-step tutorial to run a simulation with ESPERE version 2. All the improvements and corrections implemented since the release 1.52 are listed in Annex.

More details may be found in the report BRGM/RP-69538-FR (in french).



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# 1 What is ESPERE?

ESPERE (Lanini et al., 2016) is a numerical tool that makes it possible to rapidly and simultaneously use several different methods to estimate aquifer recharge.

Groundwater recharge can be defined as the downward flow of water through the unsaturated zone to the water table, increasing the quantity of water stored in the aquifer formation (De Vries and Simmers, 2002). It mainly comes from the fraction of rainfall that infiltrates and replenishes the aquifer. It depends not only on the meteorological context, but also on geomorphological characteristics (slope, hydraulic roughness, etc.), the surface of the catchment area, soil properties (vegetation, soil type, available water capacity), and the hydrodynamic properties of the subsurface formations.

Many methods to estimate groundwater recharge are described in the literature (e.g. Scanlon et al., 2002, Xu and Beekman, 2003 and more recently Healy, 2010). They vary depending on both the time scale (from a daily step to a yearly step) and the type of data used (meteorological or hydrologic). According to the type of data used and the way recharge is computed, these methods deal with different types of recharge (direct recharge only or total recharge including indirect recharge). Several studies have attempted to compare the results of different methods, notably in the United States in the 2000s (e.g. Flint et al., 2002 and Coes et al., 2007) and have shown that the accuracy of these methods varies depending on the type of aquifer being studied. Moreover, uncertainties related to the hypotheses on which they are based are variable (Halford and Mayer, 2000). Therefore, to obtain both a realistic estimation of groundwater recharge and a confidence interval at the hydrogeological basin scale, it is important to use a variety of approaches that complement each other (Scanlon et al., 2006). The numerical tool ESPERE was developed for this purpose.

ESPERE – an acronym for *Estimation de la Pluie Efficace et de la REcharge* (Estimation of Effective Rainfall and Groundwater Recharge) – is an Excel spreadsheet in which the user enters time series and parameter data for the aquifer being studied and that is able to rapidly calculate recharge using different methods. Tables and graphs of the results are automatically generated and enable the user to compare the results on a monthly and yearly scale.

The procedures included in ESPERE make it possible either to calculate recharge directly or to calculate effective rainfall and convert it into recharge using a partition coefficient (effective precipitation infiltration ratio). The version 2 of ESPERE includes ten methods for estimating recharge. They were chosen because they use readily available data time series, have few or no parameters that need to be entered by the user, and are suitable for numerical treatment using Visual Basic in Excel. They can be broken down into four categories – empirical, water budget, water-table fluctuation, and discharge filtering methods – and they operate with a daily or yearly time step.

The first version of ESPERE (v1.52) has been distributed since March 2016 on the BRGM website (<http://www.brgm.eu/espere> for the English version).





## 2 What is new in ESPERE version 2 ?

### 2.1 IMPLEMENTATION OF THE WTF METHOD

In the first version of ESPERE, the WTF implementation followed the RISE method has described by Healy (2002). In version 2, the implementation takes into account the unrealized recession, in a simplified version of the Episodic Master Recession method suggested by Nimmo et al. (2015).

#### 2.1.1 Water level recession identification

Recession begins when the derivative function of the water level time series changes:

$$\frac{dH}{dt}(t^0) \geq 0 \quad \text{and} \quad \frac{dH}{dt}(t^0 + 1) < 0, \text{ soit } H(t^0) \geq H(t^0-1) \text{ et } H(t^0) > H(t^0+1)$$

The recession lasts until the derivative function is negative, with a tolerance  $\alpha$  on the sign:  $\frac{dH}{dt}(t) < \alpha$ , soit  $H(t) < H(t-1) + \alpha$

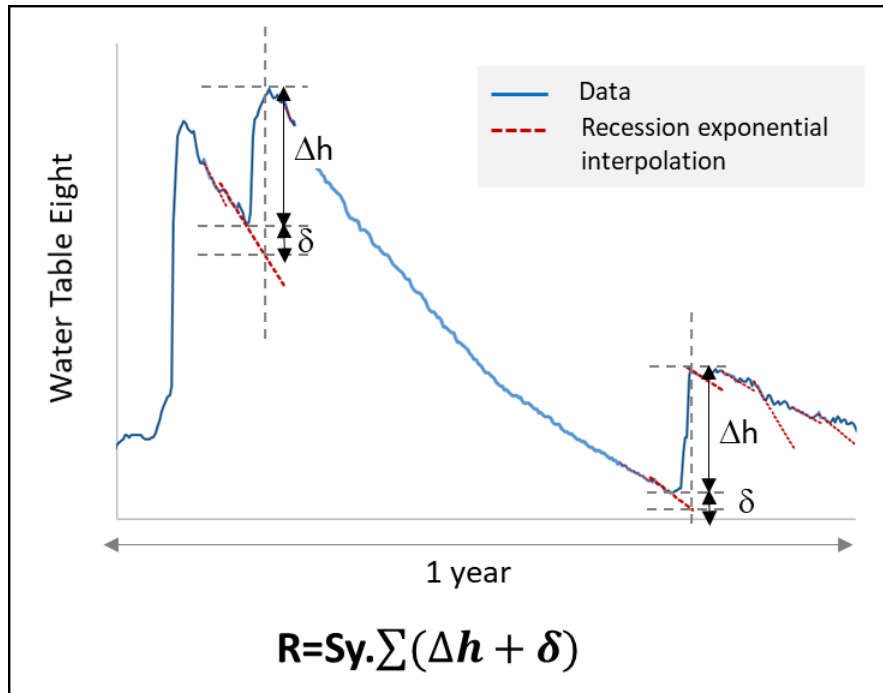
The tolerance  $\alpha$  aims at filtering the noise in water-table fluctuations. Only significant changes in water level behaviour are thus considered. Case studies application suggest a tolerance of the same order as the piezometric measuring device accuracy (values from 2 to 19.5 cm/day are retained in Nimmo et al., 2015 and 1 cm in Delottier et al., 2018). In ESPERE, the tolerance is imposed to 1 cm to identify recession within water level data.

#### 2.1.2 Recession duration

The storm recovery time corresponds to the minimum time interval between a precipitation and the following recession allowing excluding from the analysis water-table fluctuations directly linked to the precipitation event. In the published example about the event-based WTF application (Nimmo et al., 2015 and Delottier et al., 2018), this storm recovery time varies from 1.75 days (Masser case study) to 6 days (Bordeaux case study). In ESPERE, in order to integrate this concern, only identified recessions which last 6 days or more, are integrated in the WTF analysis.

#### 2.1.3 Recharge calculation

A decreasing exponential function is adjusted on each water level recession lasting 6 days or more. This exponential function is extrapolated until the start of the following recession. The correction added to the water rise is represented on Illustration 1.



*Illustration 1 : Accounting for unrealized recession in WTF method*

The annual recharge is equal to the sum of all the water-table level rises and corrections during the year, multiplied by the specific yield ( $Sy$ ):  $R = Sy \cdot \sum(\Delta h + \delta)$ .

#### 2.1.4 Comparison between the two implementations of WTF

On the « WTF » spreadsheet, ESPERE supplies the results for both methods: WTF implemented with RISE (same as in ESPERE v1.52), and WTF accounting for unrealized recession as described previously. Note that the summarising table on the « Results » spreadsheet only reports the corrected WTF result.

On a theoretical case test, Seguin (2016) showed that the recharge calculated with the corrected WTF method is 14% higher than that calculated with WTF-RISE. Our own tests on several case studies lead to differences comprised between 12 to 50% on the annual recharges estimated by both methods.

## 2.2 AUTOMATIC ESTIMATION OF PARAMETERS

Relying on research work and case study applications conducted in BRGM since several years (see for instance Caballero et al. 2020, rapport BRGM/RP-69217-FR), we can propose methods to give an estimation of the value of several parameters needed to apply the methods implemented in ESPERE. These facilities provided in ESPERE version 2 **do not replace the expert judgment**. The user should keep in mind that they rely on hypotheses which may not be acceptable for particular case studies (karstic systems for instance).

If the user can inform the parameter values, these one are always selected by ESPERE for the calculations.

### 2.2.1 Specific yield (Sy)

Under strong hypotheses (homogeneous aquifer, piezometric data representative of the average water-table level, i.e. spatial variation with distance to river is neglected), during no precipitation periods, if there is no inter-basins exchanges nor vertical drainance, groundwater stock variation is only linked to aquifer drainage by the river, and is equal to the river base flow (Qb):

$$S_y = \frac{\sum Q_b \cdot \Delta t}{\Delta h \cdot S_{urf}}$$

If river discharge time-series data are available on the same period as the piezometric data, ESPERE will apply this formula to give an estimation of the specific yield Sy. The following rules are applied:

- No precipitation periods are assimilated to recession periods lasting more than 20 days;
- Baseflow is calculated with the Wallingford method;
- Sy is calculated for each recession period lasting more than 20 days. The final Sy estimation is the average of all calculated Sy. Standard deviation is also displayed in the summarizing table (« Results » spreadsheet »).

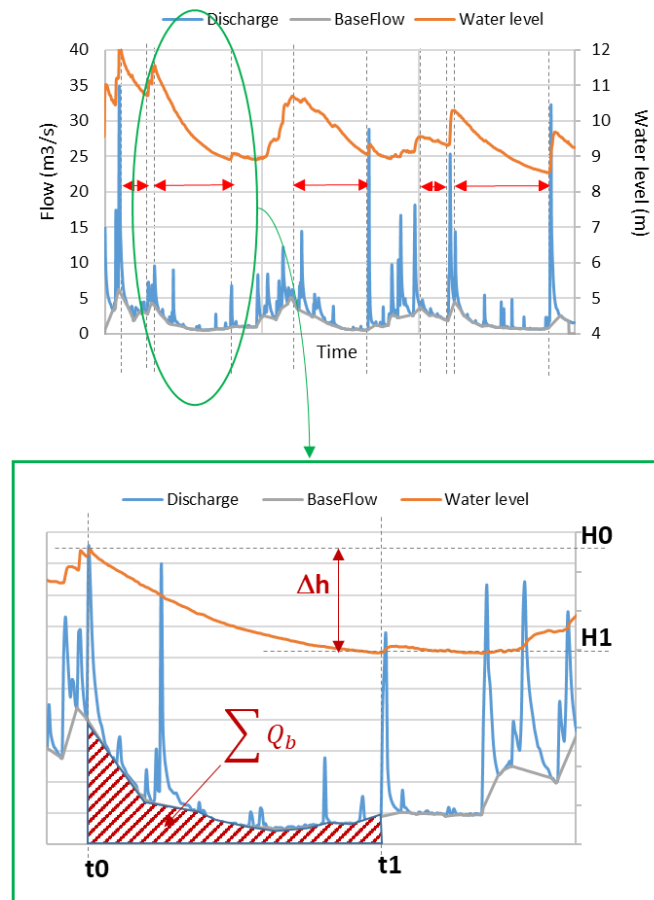


Illustration 2 : Graphical explanation for Sy estimation

### 2.2.2 Coefficient des lois de filtres de Chapman et d'Eckhardt (k)

Assuming that the river discharge recession follows the Maillet's law (with its  $\alpha$  recession coefficient), it can be demonstrated that the k parameter from the Chapman and Eckhardt hydrograph separation methods is linked to  $\alpha$  by:  $k = e^{-1/\alpha}$ .

If the user does not inform k on the « Parameters » spreadsheet, ESPERE version 2 automatically calculates the exponential Master Recession Curve for the discharge data, and calculates the k parameter from the recession coefficient. The MRC routine implemented in ESPERE code follows the methodology provided by Posavec et al. (2006). River discharge recession are identified by ESPERE with a 0.001 m<sup>3</sup>/s tolerance.

### 2.2.3 BFImax

If there is no value provided by the user for the BFImax parameter of the Eckhardt method, ESPERE uses the maximum value of annual BFI calculated by the Wallingford method.

### 2.2.4 Effective Precipitation Infiltration Ratio (EPIR)

If there is no value provided by the user for the EPIR and if discharge data are available, ESPERE uses the minimal annual BFI calculated by the Wallingford method to divide effective precipitation between runoff and infiltration (for the water budget methods).

## 2.3 AN ADDITIONAL WATER BUDGET METHOD

ESPERE version 1 includes two water budget methods: Thornthwaite (1948) and Dingman (2008). In version 2, the Edijatno & Michel (1989) method was added. This method is used in several rainfall-runoff models (e.g. GR4J from Perrin et al., 2003). These three methods vary by the way they calculate actual evapotranspiration and soil water storage.

At each time step, water balance calculates the difference between input by precipitation (rainfall plus snow melt) and potential evapotranspiration (PET). If this difference is negative, effective rainfall is zero and all available water is dedicated to evapotranspiration. The difference (PET – Precipitations) is thus withdrawn from soil storage:

- until soil storage is zero (Thornthwaite method),
- according to a decreasing exponential law (Dingman method),
- according to a quadratic law (Edijatno&Michel method).

At the opposite, if the difference (PET – Precipitations) is positive, it will:

- first replenish the soil reservoir. When it reaches its maximal capacity, the surplus will generate effective rainfall (Thornthwaite and Dingman methods);
- be distributed between effective rainfall and soil storage according to a quadratic law (Edijatno&Michel method).

In ESPERE, temperature data are used to estimate snow melt. They can also be used to estimate PET with the Hamon formula.

## **2.4      AUTOMATIC GAP FILLING**

ESPERE version 2 proposes an automatic filling of missing values in water level time series and discharge time series. Only short gaps are filled in (less than 5 days for piezometric data, 3 days for discharge data). The filling is done by linear interpolation of bound values. Interpolated data will appear in red in the time series (« Data » spreadsheet).



## 3 Tutorial

### 3.1 INSTALLATION

#### 3.1.1 About ESPERE

ESPERE was developed with Excel Office 2016 under Windows 10. It is available in French (ESPERE\_v2.44FR.xlsm) and in English (ESPERE\_v2.44EN.xlsm). On the 01/04/2020, the last update is version 2.44.

#### 3.1.2 Installation

Just copy ESPERE\_v2.4EN.xlsm on your computer in any directory. Excel need to be installed on your computer to open the ESPERE file.

#### 3.1.3 Excel options

Excel options must allow Macros to run ESPERE.

### 3.2 HOW TO RUN ESPERE

1. Open ESPERE\_v2.44EN.xlsm.

ESPERE is a french acronym for *ES*timation de la *P*luie *E*fficace et de la *RE*charge selon différentes méthodes

Multi-Method Effective Rainfall and Groundwater Recharge Estimation																																														
<b>Guidelines</b> 1) If needed, click on "data cleaning" to remove old data and parameters from all Spreadsheets. Enter new time series data on the "Data" sheet. 2) Select the methods you want to apply, and fill in the parameter table below. 3) Select "Hydrological year" if you want the annual results to be displayed from September 1 to August 31 (instead of January 1 to December 31). 4) RUN the simulation. 5) At the end of calculation, you can save the simulation in a new Excel file by clicking on SAVE.			<div style="text-align: center; margin-bottom: 10px;"> <span style="background-color: #5b9bd5; color: white; padding: 5px 10px; border: 1px solid black;">Data cleaning</span> </div> <input type="checkbox"/> Hydrological year																																											
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<div style="display: flex; justify-content: space-between; align-items: center;"> <div style="width: 30%;"> <p>BFI - Filtre Chapman&amp;Maxwell ou Eckardt</p> <p>BFImax (ranging between 0 and 1)</p> <p>k (ranging between 0 and 1)</p> </div> <div style="width: 65%; text-align: center;"> <p style="font-size: small;">ESPERE v2 automatically estimates ERI, Sy, BFImax and k. But if a value is supplied for one of these parameters, this supplied value will be used for computation.</p> </div> </div>																																														
<div style="display: flex; justify-content: space-around; align-items: center;"> <div style="text-align: center;"> <span style="background-color: #5b9bd5; color: white; padding: 10px 20px; border: 1px solid black; font-weight: bold;">RUN</span> </div> <div style="text-align: center;"> <span style="color: #5b9bd5; font-weight: bold; font-size: 1.2em;">Ready</span> </div> <div style="text-align: center;"> <span style="background-color: #5b9bd5; color: white; padding: 10px 20px; border: 1px solid black; font-weight: bold;">SAVE</span> </div> </div>																																														

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Illustration 3 : ESPERE welcome window («Parameters» spreadsheet)

2. Spreadsheet «Data»: paste here your daily data. At least «Dates» and «Precipitations» columns must be filled. Time series data begin on the 1th of January and end on the 31th of December. Missing data are not allowed in meteorological series. Lines 3 and 4 are for free comments. If both rainfall and snow are available, enter rainfall in column B (precipitations) and snow in column D (snow). Else enter total precipitation in column B, and "NA" in cell D6.

Enter daily data (dates and values) that will be used by ESPERE to evaluate effective rainfall and groundwater recharge. If Snow or Temperature data are not available, please enter "NA" in the first cell of the column (cell D6 or E6).						
At least, precipitation (column B) and ETP (column C) must be filled in. Data should begin on January 1 and end on December 31. No missing dates possible for meteorological data. Missing values are automatically linearly filled if gaps last less than 3 days for discharge data and 5 days for piezometric data.						
Data source						
Date	PRECIPITATIONS or RAINFALL (mm)	ETP (mm)	SNOW (mm)	Temperature (°C)	Discharge (m3/s)	Water level (m)

Illustration 4 : «Data» spreadsheet

3. Spreadsheet «Models»: You can paste here the results obtained with other models. These results will be included in the final comparison graphs. The «Dates» column is automatically filled in. It is advised to supply daily data for full years, in order to ensure accurate results comparisons.

OPTIONAL						
You can paste below the results (effective rainfall and/or recharge) obtained with other models. These results will be included in the final comparison graphs and statistics. Do not change de "Date" values as they are automatically equal to those of the "Data" spreadsheet. Nevertheless, columns B to G may be empty or partially filled in. You are advised to supply daily data for full years, in order to ensure accurate results comparisons.						
	Model 1		Model 2		Model 3	
Model Name	Modèle1		Modèle2		Modèle3	
Free Comment						
Associated Surface (km2)						
Date	Effective Rainfall (mm)	Recharge (mm)	Effective Rainfall (mm)	Recharge (mm)	Effective Rainfall (mm)	Recharge (mm)
00/01/1900						
00/01/1900						
00/01/1900						
00/01/1900						
00/01/1900						
00/01/1900						
00/01/1900						
00/01/1900						
00/01/1900						
00/01/1900						

Illustration 5 : «Models» spreadsheet

4. Back to the «Parameters» spreadsheet

- 4.1 Select the methods you want to apply. Remember that the discharge filter methods and WTF method cannot be applied if streamflow data (respectively piezometric data) are not available. If temperature data are not available, Turc and Dingman with Hamon PET methods will be automatically disabled.
- 4.2 Fill in the parameter table. If no values are entered and time-series data are available, ESPERE will propose values for almost all the parameters (except recharge area, soil water storage capacity and latitude).
- 4.3 If you want the annual results to be displayed for hydrological year (rather than civil year), check the box.



- 4.4 To account for ground vegetal cover in the water budget methods, click on the button. A form appears in a new window (Illustration 6). It allows entering the six parameters of the trapezoidal function that describes the crop coefficient variation over the year ( $K_{cmin}$ ,  $K_{cmax}$ ,  $M1$ ,  $M2$ ,  $M3$ ,  $M4$ ).

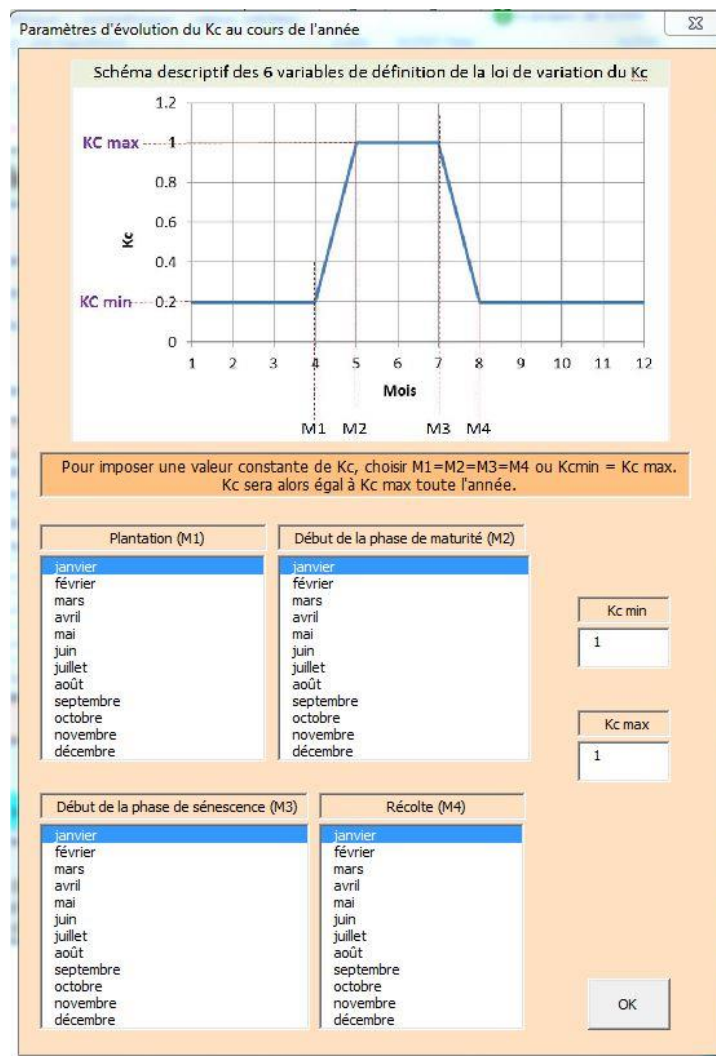


Illustration 6 : Form to enter the crop coefficient parameters

- 4.5 Run the simulation. At the end of the calculation, a message is displayed. You can save the spreadsheets with the parameters, the data and the results of your simulations in a new Excel file by clicking on the "Save" button.

### 3.3 RESULT PRESENTATION

For information, daily data cumulated at monthly and annual time steps are displayed on the "SumData" spreadsheet.

Monthly sum (precipitations of ETP) or monthly mean (temperature and flowrates)								CALENDAR YEAR						
Year	Month	Rainfall (mm)	Snow (mm)	Precipitations (mm)	ETP (mm)	T (°C)	Q (m3/s)	Year	Rainfall (mm)	Snow (mm)	Precipitations (mm)	ETP (mm)	T (°C)	Q (m3/s)
1998	1	38.9	0.0	38.9	37.3	6.4	3.8	1998	641.0	0.9	642.0	1043.5	13.4	1.6
1998	2	23.8	0.0	23.8	49.0	6.8	2.5	1999	830.5	0.2	830.7	1009.1	13.7	1.7
1998	3	7.2	0.0	7.2	81.7	9.5	1.4	2000	825.6	7.5	833.1	982.9	13.7	1.4
1998	4	165.1	0.0	165.1	66.5	10.8	2.7	2001	907.1	7.9	915.0	1050.0	13.8	2.1
1998	5	99.2	0.0	99.2	112.7	15.9	3.4	2002	1345.4	0.0	1345.4	1000.7	13.9	2.3
1998	6	9.9	0.0	9.9	129.6	20.5	2.3	2003	1231.4	9.4	1240.7	1053.8	14.1	2.4
1998	7	11.3	0.0	11.3	186.3	24.2	1.0	2004	830.7	2.1	832.8	1025.8	13.3	2.2
1998	8	21.3	0.0	21.3	154.9	22.8	0.6	2005	756.2	0.2	756.4	1131.9	13.1	1.4
1998	9	121.9	0.0	121.9	84.7	17.5	0.4	2006	771.7	16.4	788.1	1125.3	14.2	1.8
1998	10	29.3	0.0	29.3	59.7	13.3	0.3	2007	602.0	1.9	603.9	1092.9	13.7	1.3
1998	11	16.1	0.9	17.0	44.4	6.3	0.3	2008	1185.1	0.6	1185.6	1011.1	13.5	2.0
1998	12	96.2	0.0	96.2	38.9	5.2	0.5	2009	838.9	1.9	840.5	1099.5	14.2	2.0
1999	1	59.7	0.0	59.7	36.6	6.4	2.5	2010	1051.4	34.0	1085.4	1052.7	12.9	2.1
1999	2	1.2	0.2	1.4	57.0	5.8	1.1	2011	982.9	0.5	983.4	1075.4	14.2	1.8
1999	3	52.7	0.0	52.7	67.0	9.6	1.2							

Illustration 7 : «SumData» spreadsheet

The “Results” spreadsheet shows tables summarizing the results of all the methods at different time steps (daily, monthly, inter-annual monthly mean, annual). Any results of other models are also included (if supplied by the user in the “Models” spreadsheet). Scaling is done automatically and makes it possible to compare the results of all of the methods and models for a given recharge area surface. To facilitate the comparison of methods, the results are automatically displayed as bar graphs.

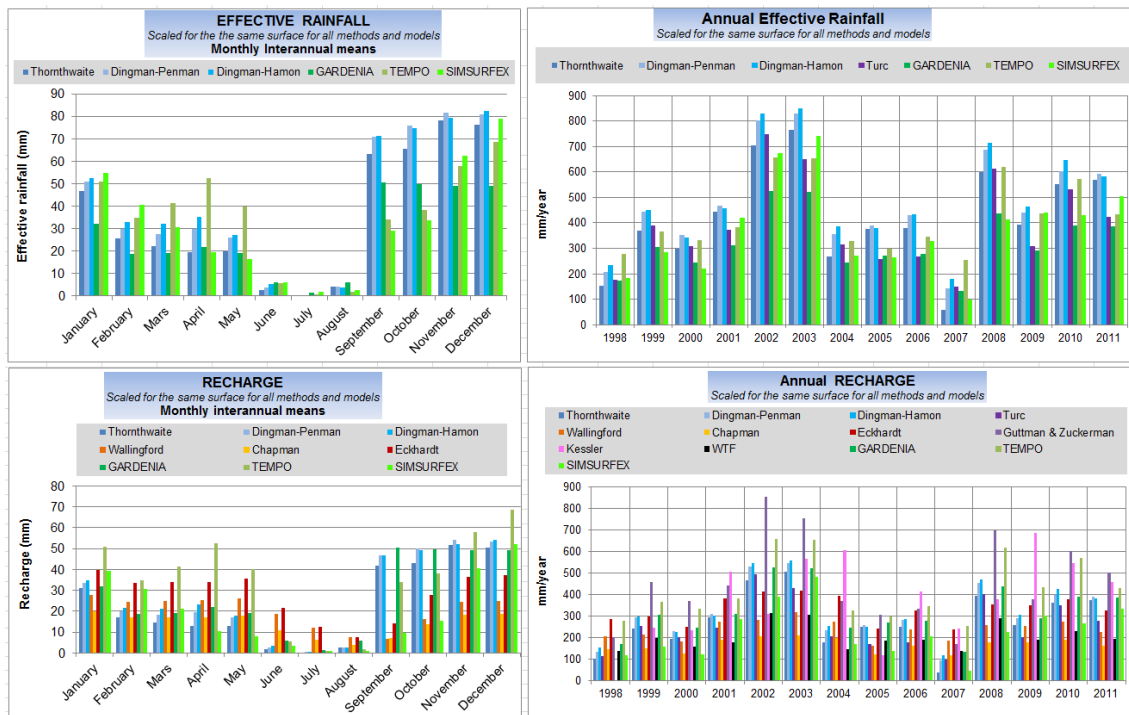
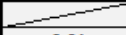
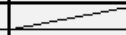


Illustration 8 : «Results» spreadsheet

A table summarises the parameters of simulation, and supplies a comparison of annual recharge evaluated by all the methods (interannual mean on the overall period of data availability).

Parameter overview		
SURFACE (km2)		
Water budget methods		265
Guttman&Zuckerman		265
Kessler		265
Turc		265
WTF		265
Model1_name		265
Model2_name		265
Model3_name		265
Soil Storage Capacity (mm)		
Water budget methods		82
Infiltration coefficient		
Water budget methods and Turc	0.61	
Filter parameters		
	BFI <sub>max</sub>	k
Chapman		0.938
Eckardt		
	0.64	
Specific yield		
WTF	0.042	

Parameter overview		
SURFACE (km2)		
Water budget methods		265
Guttman&Zuckerman		265
Kessler		265
Turc		265
WTF		265
Model1_name		265
Model2_name		265
Model3_name		265
Soil Storage Capacity (mm)		
Water budget methods		82
Infiltration coefficient		
Water budget methods and Turc	0.61	Estimated value, equal to the minimum annual BFI
Filter parameters		
	BFI <sub>max</sub>	k
Chapman		0.938
Eckardt		
	0.64	
Specific yield		
Mean	0.0422	11 recessions > 20 days were used to estimate Sy
Std deviation	0.0165	

Annual RECHARGE (mm/year)	
Interannual means	
Thornthwaite	125
Dingman with Hamon PET	175
Dingman	158
Edijatno & Michel	172
Guttman&Zuckerman	
Kessler	
Turc	119
WTF	164
Wallingford	218
Chapman	172
Eckhardt	219

Annual RECHARGE (mm/year)	
Interannual means	
Thornthwaite	125
Dingman with Hamon PET	175
Dingman	158
Edijatno & Michel	172
Guttman&Zuckerman	
Kessler	
Turc	119
WTF	165
Wallingford	218
Chapman	172
Eckhardt	219

Illustration 9 : Summarizing table (« Results » spreadsheet)  
 Left: when parameters are given by the user. right: when parameters are evaluated by ESPERE

## 3.4 FREQUENTLY ASKED QUESTIONS

### 3.4.1 Crop coefficient

For information and verification, daily values of Kc are displayed in the result columns of the Thornthwaite spreadsheet.

### 3.4.2 Data

Empirical methods (Turc, Kessler and Guttman) are applied with the total precipitation data, which means column B (precipitation) + column D (snow). The “snow” column may be empty.

### **3.4.3 Models**

Model results (effective rainfall and/or recharge) must be supplied for complete and consecutive years (from January 1 to December 31). The periods can be different for each model, and can also begin after and/or end before the data period.

### **3.4.4 Results**

Annual comparison graphs (effective rainfall, recharge and water volume) automatically include 60 years of results.

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## Annex 1

### List of modifications since version 1.52

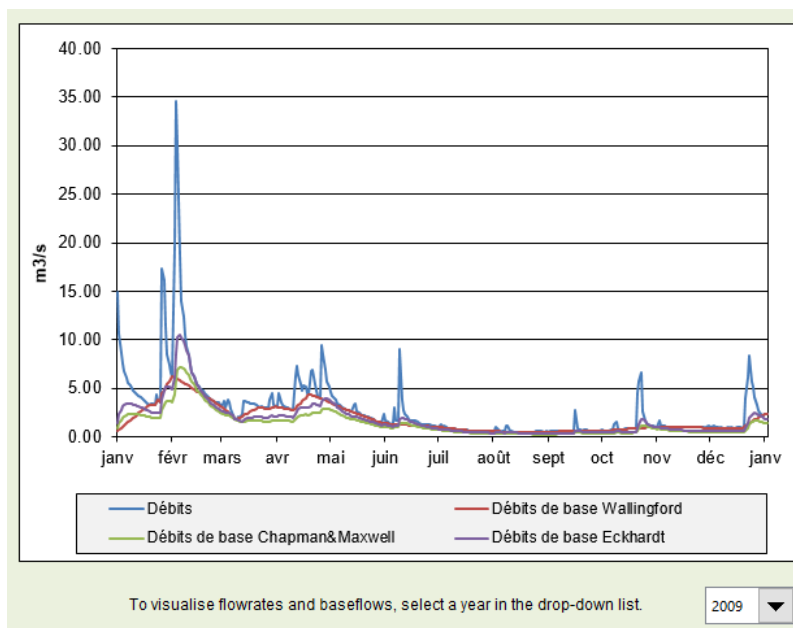
Up to date for the version 2.44 (April 2020).

#### ERROR CORRECTIONS

- Hydrograph separation methods and « Filters » spreadsheet

The condition:  $Q_b \leq Q_{total}$  (forgotten in v1.52) is added in Eckhardt and Chapman formula implementation.

Discharge display is corrected (in version 1.52, displayed graphs corresponded to the year N-1 of the scrolling menu).



- Monthly interannual means of recharge estimated by discharge filtering methods: corrected to take into account the case when discharge data availability period is shorter than that of meteorological data.
- Crop coefficient initialisation

In version 1.52, it might happen that  $K_c$  took a default zero value (instead of 1). This initialisation error has been corrected. Nevertheless, in case of doubt, the user may verify the  $K_c$  value actually used for simulation (spreadsheet « Thornthwaite », column G).

- Turc formula

The Turc formula has been corrected.  $L=300+25.T+0.05.T^3$  instead of  $L=300+25.T+0.05.T^2$ .

## MODIFICATIONS

- Dingman method

Dingman-Penman method was renamed as Dingman. Actually, this method is applied with the PET supplied by the user, which can come whatever method.

- PET calculation with Hamon method

Hamon formula (1963):

$PET = k.D.\rho_t$  with  $k=0.0065$ ,  $D$  daylength (in 12h periods),  $\rho_t$  saturated vapor density (g/m<sup>3</sup>) and PET in inch. With  $\rho_t = \frac{M}{R} \cdot \frac{e^*}{T+273.15}$  for water vapor ( $R=8.314 \text{ J./K}^{\circ}\text{.mol}^{-1}$ ,  $M=18,01 \text{ g/mol}$ ,  $T$  in °C, and  $e^*$  saturated vapor tension in Pa). Finally, PET in mm/j is given by the Hamon formula cited by Dingman (2008) :

$$PET = 29,8. D. \frac{e^*}{T+273.2} \quad (\text{with } D \text{ in hours, } e^* \text{ in Pa and } T \text{ in } ^{\circ}\text{C}).$$

Formulas used in ESPERE v1.52 to calculate the daylength imposed a zero value for latitudes > 66.5°N or 66.5°S. They are now replaced by formulas from Forsythe et al. (1995):

$$D = 2. \arccos(\tan\delta. \tan\lambda) / \left(\frac{2\pi}{24}\right)$$

$$D = 24 \text{ si } \tan\delta. \tan\lambda > 1 \quad \text{et} \quad D = 0 \text{ si } \tan\delta. \tan\lambda < -1$$

$$\delta = \arcsin(0.39795. \cos(\theta))$$

$$\theta = 0.2163108 + 2. \arctan(0.9671396. \tan(0.00860. (J - 186)))$$

with  $J$  the julian day (between 1 and 365) and  $\delta$  the solar declination, comprised between -23.5° et +23.5°.

## INFORMATION ADDED

- Comment in cell H4: annual BFI calculated from Chapman and Eckhardt baseflows are almost constant (respectively equal to 0.5 and BFI<sub>max</sub>). The annual recharge is thus directly proportional to the annual discharge (comment in cells EA38 and EA39 on spreadsheet « results »).
- Addition of a summarizing table with interannual mean recharge in spreadsheet « Results »

Annual RECHARGE (mm/year) Interannual means	
Thornthwaite	
Dingman with Hamon PET	
Dingman	158
Edijatno & Michel	172
Guttman&Zuckerman	
Kessler	
Turc	119
WTF	
Wallingford	218
Chapman	172
Eckhardt	219

- If the Master Recession Curve for discharge time-serie data is calculated to evaluate the k parameter for Chapman and Eckardt filter methods, its coefficient are displayed on spreadsheet « Filters »

Master Recession Curve	
$Q(t)=Q_0.exp(-t/alfa)$	
<b>Qo</b>	<b>6.78</b>
<b>1/alfa</b>	<b>0.0635</b>

- Warning popup :
  - if k or BFI<sub>max</sub> values supplied by the user are not comprised between 0 and 1.
  - if there is no value for the infiltration ratio, and discharge data are not available to estimate it.

## SUPPRESSION

- The complete version of ESPERE linked with XLSTAT is no longer maintained. All references to XLSTAT were deleted in the code and in the interface of ESPERE v2.
- Automatic graphs with Infiltrated volumes are deleted, but these volumes are always calculated and appear in the table on the « results » spreadsheet.





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