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Estimating Groundwater Recharge Using MRC Techniques and Meyboom Method, A Case Study: Seybouse Watershed, Algeria

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Abstract: Groundwater recharge to an aquifer depends on the amount of precipitation, land use and other factors. Direct measurement of recharge components is not possible. The purpose of this paper is to estimate groundwater recharge based on the hydrograph analysis. Two methods of hydrograph recession analysis were employed in a case study from the Seybouse watershed (6450 Km^2), Algeria. The first is automated technique was developed to calculate the slope of the baseflow recession curve from stream flow record which is commonly used as an indicator of the extent of baseflow. This technique is an adaptation of the Master Recession Curve (MRC) procedure. A second is the Meyboom method, the adapted method consists in fitting exponential regression model to baseflow recessions that precede and follow groundwater recharge. Regression equations are then used in calculating recharge volume using the same procedure as described by Meyboom (1961). These two methods gives quantitative information regarding the entities that make up the basic hydrologic equation, respectively show us that the dynamic resources of the Seybouse are relatively small.

Key words: Groundwater recharge · Hydrograph analysis · Master recession curves · Meyboom's method

INTRODUCTION

Estimating groundwater recharge is an important issue in hydrogeologic studies. In most cases, recharge is estimated by multiplying the magnitude of water-level fluctuations in wells by the specific yield of the aquifer material, or by applying the water budget model or by the water-balance method. For instance, Lee and others [1] and Chen and others [2] estimated groundwater recharge by adopting the water-budget model combining the rainfall data and soil parameters with the infiltration model. Simmons and Meyer [3] provided a simplified model for the transient water budget of a shallow unsaturated zone to estimate groundwater recharge and the flux of water that may transport a dissolved contaminant into the groundwater. Finch [4] used a simple water-balance model to study effects of land surface parameters on groundwater recharge. Lee and others [5] also applied the water-balance method in conjunction with an independent estimation of recharge from a finite-difference simulation of ground-water levels. With the purpose of inspecting recharge, estimation of the groundwater component of streamflow has been a research focus for more than a century. Following the work of Boussinesq [6], numerous studies [7-9] have investigated the recession of streamflow, particularly baseflow and have estimated the contribution of groundwater to streamflow. In some cases, the value of baseflow is assumed to be equal to groundwater recharge. The primary purpose of most research is to determine the groundwater component of streamflow. The study by Moore [8] was also concerned with fractured rock terrane. Nevertheless, only a handful of researchers, including Meyboom [10], Rorabaugh [11] and Rutledge [9], have focused on groundwater recharge through analyzing the streamflow data. Mau and Winter [12] have provided an instantaneous recharge method and a constant recharge method of hydrographic analysis to estimate recharge.

Most of the research on groundwater recharge is based on groundwater recession data with the implementation of a one-dimensional model of flow from groundwater to a stream Rorabaugh [11]. Implementing these models requires a set of rigid, simplified assumptions. For instance, that the stream fully penetrates the aquifer, the porous media is isotropic and the aquifer is underlain by impermeable rock.

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However, many natural groundwater systems do not meet these assumptions, particularly on a local scale. Studies pertain mainly to basins covering many square kilometers, where the local variability of geological materials is more likely to be averaged. Evaluating the application of the hydrograph analysis to small areas is ignored because the field conditions do not always meet the assumptions required by the above models.

There are various methods that one can use to estimate the groundwater recharge [13,14]. Two popular, inexpensive and independent methods, which use the stream flow partition techniques, are the seasonal recession method by Meyboom [10] and the recession curve displacement method by Rorabaugh [11]. These two methods basically use the concept that stream discharge can be partitioned into the contribution from direct runoff and contribution from groundwater baseflow in a watershed. The Meyboommethod identifies one large recharge and one large recession trend in a 12-month cycle utilizing multiyear data, while the Rorabaugh method identifies multiple significant recharge events in a 12-month cycle. A water budget method, which is developed by Charles *et al*. (1993) of the New Jersey Geological Survey, is also discussed for comparison. This latter method does not use the stream discharge in the watershed; rather, it uses weather, soil and vegetation coverage characters to calculate the runoff and evapotranspiration portion of the precipitation. Although the principles of the Meyboom and Rorabaugh methods are clear, the selection of daily and monthly river discharges for estimation of the ground recharge in the application still needs further examination. This paper systemizes the procedure for estimating the groundwater recharge by Meyboom. The adapted method consists in fitting exponential regression model to baseflow recessions that precede and follow groundwater recharge [16]. The use of exponential regression model for derivation of baseflow recession curves (i.e. regression equations), enables automation of the calculation procedure and allows automated processing of large amount of data with little effort and time involved.

Site Study

Geographic Presentation of the Seybouse: The Seybouse pouring basin situated in the north-east of Algeria occupies the third place by its surface after the El-kebir of Rumel rivulet and the Mellegue rivulet.

The Seybouse, Mediterranean rivulet, take its origin in the high semiarid plains on the southern reverse side of tellien atlas. It flows from south to north. The Seybouse basin comprises three principal zones (Fig. 1).

- The high Seybouse sub-basin
- The middle Seybouse sub-basin
- The low Seybouse sub-basin

The high Seybouse consists essentially of Sedrata plain and Tamlouka plain. The middle Seybouse consists of the low Charef, of the Bouhamdane rivulet basin, the Guelma low place and the Maleh rivulet basin. The low Seybouse constitutes principally of Annaba subsidence plain. It embraces the territory of 6570m^2 where the population of more than l 258 710 inhabitants lives and comprises 6 Wilayas and 68 communes; its vegetable covering is 30%. This is a region of agricultural destination with large modern irrigation perimeters

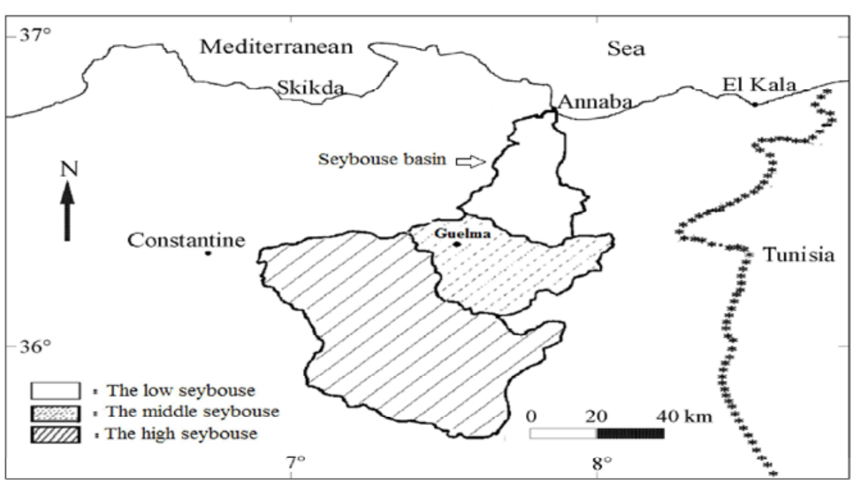

Fig. 1: Map of three Seybouse principal sub basins

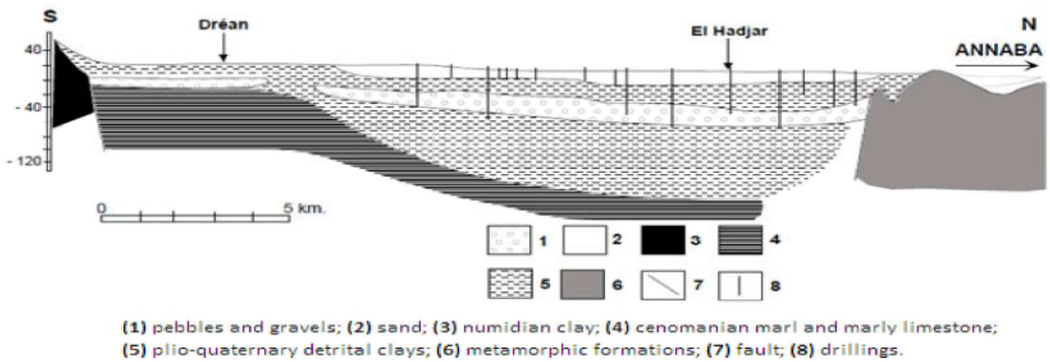

Fig. 2: Hydrogeology of the Seybouse riverbed in the plain of Annaba

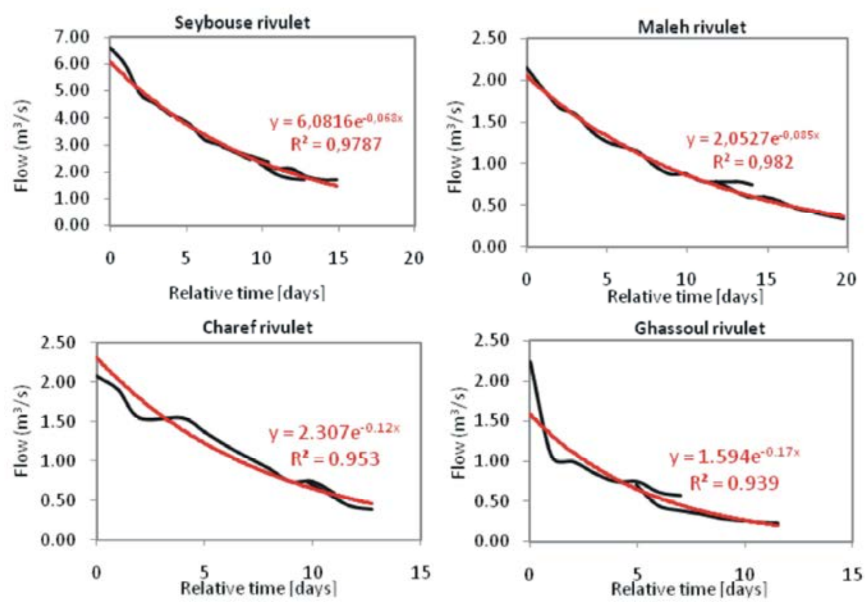

Fig. 3: Master Recession Curves of the Seybouse basin from 15~29 April, 1998

(by shrinkling). It includes twenty industrial units, five units being of great importance. The Seybouse basin presents a ramified hydrographic system of more than 3000 km, forty two rivulets having the length to l0 km. It presents very heterogeneous natural group that engenders different supply and flow ways.

Climate, Hydrology and Hydrogeology: The climate of the basin varies from typical Mediterranean along the coast to semi-arid. The mean annual precipitation ranges between 700 mm and 400 mm, reaching a monthly maximum in the range of 90-120 mm in December/January. Minimum and maximum temperatures are observed in December-January (less than 10°C) and in July or August (between 25°C and 30°C) respectively. The average annual infiltration is about 162 mm, whereas surface runoff accounts for 79 mm/yr.

In terms of hydrogeology, the Seybouse River flows through depressions containing an alluvial water table Djabri [17]. These formations distinguish two aquifers (Fig. 2), which communicate through the OuedMeboudja, the superficial aquifer of Annaba and the alluvial aquifer of high terraces Hani [18]. In the Guelma region, identified aquifers are alluvial and calcareous.

The lake Fedzara is the only significant aquatic ecosystem in the region and recently acquired official protection status through the RAMSAR Conventionthe dimensions of the lake are 17 km from west to east and 13 km from north to south and the lake water is characterized by high salinity.

Methodology

Master Recession Curve: The technique of Master Recession Curves (MRC) consists to extract all periods of

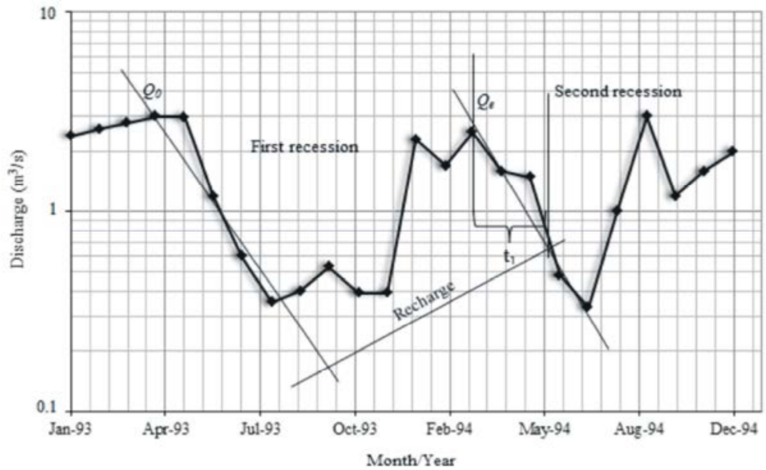

Fig. 4: Semilogarithmic plots of Monthlyriver discharge hydrograph. at the Bouchegouf gauging station in the Maleh rivulet sub basin.

hydrograph recession and to form a new curve by combination of different recessions [19]. The MRC represents the recession curve of long-term of a watershed, in the absence of new inputs of rain. Figure 3 presents the MRC of various sub basins of the Seybouse. The slope of the straight regression line tells us the recession parameter K, More K is low, more flow recession is slow and most important is the low river discharge sustained. During a recession period the flow rate Q is only dependent on inflows of water stored in the reservoir (aquifer and soil).

- The lowest reservoir coefficientsare those of Maleh rivulet and Seybouse rivulet. Both sub basins have a tank drain time high. This is explained by a large volume of water stored in the aquifer to support low flows even during droughts.
- The highest reservoir coefficientsare those of Charef rivulet and Ghassoul rivulet. These marly sub basins have low groundwater reserves located in the soil, surficial and / or possible layers sandstone or limestone.

Estimation of Recharge by Seasonal Recession Method (Srm) (Or Meyboom Method): The idea of seasonal recession method byMeyboom [10] is to first identify one large recession trend and one large recharge trend in a semi-logarithmic seasonal hydrograph over a 12-month period for two or more consecutive years. If the exponentially decayed recession trend is plotted on a semilogarithmic paper, it will be a straight line. The assumption is that the discharge of the stream during this large recession period below the recession trend line will be entirely due to the groundwater contribution. Then, the total groundwater recharge is calculated by using the total potential groundwater discharge volume at the beginning of the recession minus the volume of the potential groundwater discharge left at the end of the recession.

Based on the method of similar triangles, from the semilogarithmic hydrography recession curve (Fig.4), one could derive the discharge Qat any time of t during the recession by:

$$Q = \frac{Q_0}{10^{t/t_1}} \tag{1}$$

where t is the time length of interest and Q_o is the flow rate at the beginning of the recession. t_1 is the time required for one log cycle of recession and is calculated by:

$$t_1 = \frac{(t_e - t_0)*1.0}{\left(\log(Q_0) - \log(Q_e)\right)} \tag{2}$$

where$t_e$is the time and $Q_e$is the flow rate at the end of the recession respectively. $t_o$is the time at the beginning of the recession and $Q_o$is as stated previously. If one integrates the discharge Qin (1) over a time period of recession t, one would get the total groundwater discharge volume from $t_o$to$t$:

$$GroundwaterDischargeVolume = \int_{t_0}^{t} Q dt = -(Q_0 t_1 / 2.3)/10^{t/t_1} \tag{3}$$

If $t_o$equals zero and t equals infinity, one would have the total potential discharge Q_{tp}at the beginning of the recession calculated by:

$$Q_{tp} = \frac{Q_0 t_1}{2.3026} \tag{4}$$

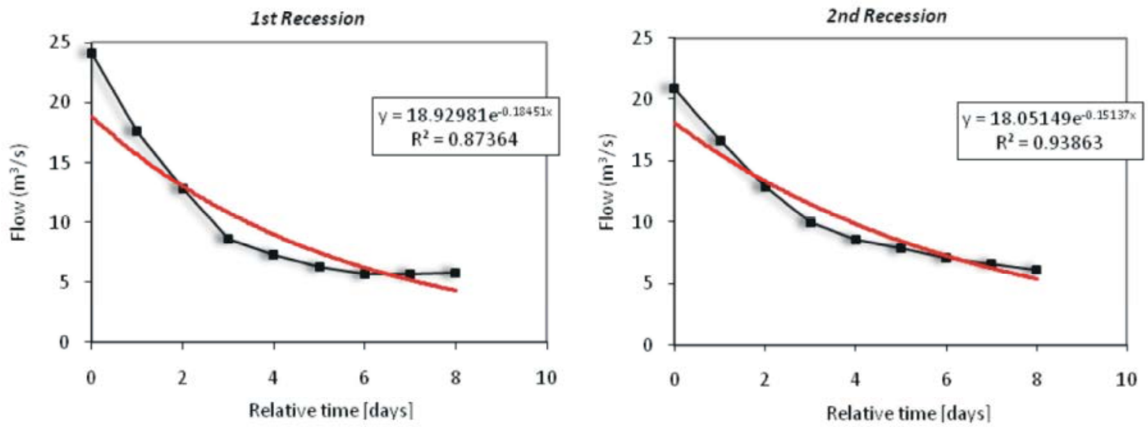

Fig. 5: An example of estimated groundwater recharge at the Mirebek gauging station in the Seybouse rivulet sub basin.

Table 1: Calculation results for the first recession in the Seybouse basin

Sub basin	Recession period Start Date	End Date	Q_0 (m^3/s)	Q_{tp} (m^3)	Q_{remain} (m^3)	T(1log) [days]
The high Seybouse	25/02/1998	09/03/1998	3,050	1 591 446	1 406 954	14
Malehrivuletsub basin	25/02/1998	09/03/1998	3,850	4 118 865	2 678 852	28
Ghassoulrivuletsub basin	27/02/1998	10/03/1998	0,301	374 989	212 180	33
The middle Seybouse	17/02/1998	25/02/1998	24,140	10 121 756	8 178 531	11

Table 2: Calculation results for the second recession and calculated groundwater recharge in the Seybouse basin

Sub basin	Recession period Start Date	End Date	Q_0 (m^3/s)	$T_{(1log)}$ [days]	Q_{tp} (m^3)	R (m^3)
The high Seybouse	25/03/1998	09/04/1998	1,980	22	1 656 176	1 471 685
Malehrivuletsub basin	13/04/1998	29/04/1998	5,970	33	7 412 795	5 972 782
Ghassoulrivuletsub basin	31/03/1998	09/04/1998	0,332	31	385 546	222 736
The middle Seybouse	12/04/1998	20/04/1998	20,913	14	11 186 553	9 243 329

If using the total potential groundwater discharge at the beginning of the next recession minus the remaining groundwater discharge at the end of a given recession, then one would obtain the groundwater recharge rate that takes place between recessions as calculated by:

$$Groundwater\ Recharge = \frac{Q_{2nd_0} t_1}{2.3026} - Q_{remain} \quad (5)$$

where$Q_{2ndo}$is the total potential discharge at the beginning of the 2^{nd} recession and $Q_{remain}$is the discharge remaining at the end of the first recession as calculated by :

$$Q_{remain} = \left(\frac{Q_0 t_1}{2.3}\right) - \left(\frac{\frac{Q_0 t_1}{2.3}}{10^{\frac{t}{t_1}}}\right) \quad (6)$$

Example illustrates estimating groundwater recharge from spring hydrograph in the Maleh rivulet, Graphs showing first and second recession with exponential regression curve and equation are created at the end of processing. The recharge between two recessions (Fig. 5), are given in Tables 1 and 2, respectively.

RESULTS AND DISCUSSION

The low Seybouse is not very permeable in the up-river sector, despite dense vegetation covering soil and rainfall it doesn't practically contain subterranean water. At last quaternary alluvia of the west plain of Annaba are permeable and contain considerable water bearing levels.

In the whole the Seybouse basin is poor in subterranean water. Taking into consideration great rock lithology and permeability, there are many small scattered shrouds and those of limited supply in the basin (Table 3).

Table 3 Mobilized water volume in the seybouse basin

Sub basin	Gauging station	Rivulet	Averageannual recharge (Mm^3) 1973-2003
The high Seybouse	Moulin Rochefort	Charefrivulet	0.74
Malehrivuletsub basin	Bouchegouf	Malehrivulet	4.46
Ghassoulrivuletsub basin	Ain Berda	Ghassoulrivulet	1.14
The middle Seybouse	Mirebek	Seybouse rivulet	11.13
Total			15.47

In the high Seybouse phreatic shrouds presenting not deep water reserves in sedimentary materials with interstice permeability being exploited by 13 bore holes and wells, where the expenditures vary from 2 l/s to 20 l/s, can be found.

In the middle Seybouse or more precisely in Guelma low place there are two shrouds. The first is formed by gravels, sands and pebbles. lt can be noticed that this valley substratum is constituted of gypsum and clay marls in the western part of the plain and of clay and numidien sand stone in the eastern part. This shroud depth increases to the east; it is about 8 m in the north of Guelma town and reaches l6 m in the north-east of Boumahra. The second shroud is presented by an important water bearing system situated in the south of the Seybouse rivulet; it is formed of plio-quarternary alluvia (pebbles, sandstone, gravel, sand and some clay levels). The surface stratum shows pure clay affinity while quaternary alluvia are thickened and less raised than pliocene ones. On the contrary the formations constituting the substratum are the miocene part. They are spread on the surface for 330 km^2. These two shrouds are drained by 23 bore holes and wells, their expenditure varying from 7l l/s to 23 l/s.

The other very important subterranean water reserve is situated in the Maleh rivulet basin named Bouchegouf shroud, its water is generally manifesting sodium chloride that corroborates strong salinity of this subterranean water represented by a shroud with average water bearing thickness 70 m. This shroud is exploited essentially by 11 bore holes and wells with expenditure varying between 3 l/s and 30 l/s that supply Bouchegouf town and close agglomeration.

In the low Seybouse there are two shroud types situated in the west plain of Annaba town. They are located in plio-quaternary alluvia and dunaire massif. The first is situated on the metamorphic massif flank of Annaba, with thickness l5 m, drained by 34 bore holes and wells with expenditure varying from 3 l/s to 22 l/s. The second is a free shroud of dunaire vein, its thickness varying from l5 m (in Annaba) to l20 in the east, exploited by expenditure varying from 3 l/s to 25 l/s.

It seems that water bearing system of the low Seybouse globalizes the subterranean water potential of 58 Mm^3. That one of Bouchegouf plain totalizes a potential reserve of 35 Mm^3; unfortunately it is characterized by strong salinity. As for Guelma low place water bearing system, it shows a potential volume of 22 Mm^3. These reserves are situated in plio-quaternary formations with volume of about l42 Mm^3 with extracted subterranean mobilization of different bore holes and wells of 5l, 25 Mm^3 that is 36% of therenewablereserve of the Seybouse basin water bearing system. That illustrates well this large basin poverty in exploited and renewable subterranean water.

CONCLUSION

Estimating groundwater recharge from stream or spring hydrographs using the adapted method applied by Meyboom (1961) is described and applied in a case study from the Seybouse watershed, Algeria. The adapted method consists in fitting exponential regression model to baseflow recessions that precede and follow groundwater recharge. Regression equations are then used in calculating recharge volume using the same procedure as described by Meyboom (1961). This method gives quantitative information regarding the entities that make up the basic hydrologic equation, respectively show us that the dynamic resources in the whole the Seybouse basin are relatively small. The presented method is fast, reliable and applicable to larger data sets compared to traditional methods owing that makes the results less random and easier to use.

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