Reservoir water and recharge volume, aqueducts recharge volume percentage determination with the Maillet Formula

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Abstract: Shortage of water sources is one of the basic problems to consider especially in dry and semi dry countries of the world. Consequently, it is essential to calculate water sources for further water consumption pattern. In this essay, some aqueducts of Hashtgerd plain were studied and with due attention to obtain data and statistics and their further analysis, discharge-time hydrograph was drawn. From the descending curve equation of aqueducts and the Maillet method, reservoir volume, recharge volume and recharge percentage were determined. The water balance sheets of Hashtgerd plain in 1993-94 and 1996-97 water years were also prepared. The reported precipitation infiltration rate in these balance sheets was approximately 19.06 percent. However, the obtained values of the mentioned rate with the help of Schoeller and Maillet methods were 22.16 and 21.36, respectively. Regarding the three mentioned methods and having correct information, it can be understood that the Maillet method can be used for aqueducts with a high safety factor. This method can be used for other aqueducts in case its validity is proven.

Key-words: Aqueduct, Maillet method, reservoir volume, recharges volume, recharge percentage.

1 Introduction

Life and the survival of plants and animals is highly dependant on water and a lack of water will accelerate the total destruction of life.

The population growing trend in all human societies from the quantities point of view is often associated with a relative life standard growth which results in a dramatic increase in drinking water consumption pattern. Many parts of Iran suffer from water shortage because of limited sources and irregular water consumption within the last few years [7]. Studying water sources forming factors and correct ways of using it are the two most important steps to solve this problem. In addition, these results can be used widely by experts for exploitation, improvement and managing water sources. This case study, which is based on the usage of Maillet method for determining, is actually used for spring and has not been tested for aqueducts. Consequently, before this research has not been study about applying Maillet formula in aqueduct [3].

2 Method

When the topographic level cuts into the water level, water is discharged from the aqueduct as a result of the gravity force which is called natural drainage or a spring.

The drainage of a spring which consists of both a surface and underground water basins is influenced by [3, 9]:

-Amount of effective precipitation from infiltration or coefficient of permeability of the basin under the influence of the spring.

-Aquifer dimensions.

-Effective porosity or storage coefficient.

The amount of discharged water from aquifer which was once stored from hasn’t been fed times and dry seasons. While inspecting spring regimes, the reservoirs are considered as closed systems and the mere way of knowing them is from regional rain fall and the way the spring reacts towards it can lead us to have a better understanding of its operation. In other words, there are two different curves in here to be recognized. One is related to the rain fall regimes and the other is related to the spring source [3].

In fact, the spring source curve is divided into the ascending (or overflowing time) and descending parts.

The descending curve is also called the recession curve which is related to the end of precipitations. It would be easy to calculate water volume and the discharge of the spring and determine the real recharge coefficient of the aquifer from this curve [9] (Fig.1 a, b).

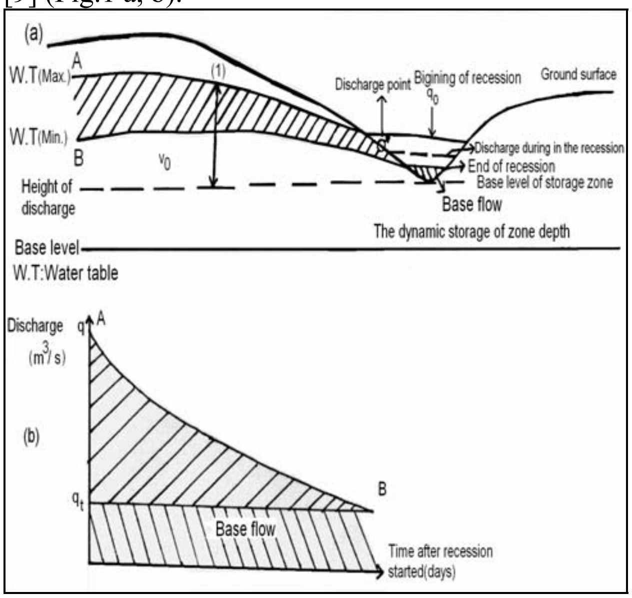

Fig. 1 (a) The discharge of aquifer's that the recharge of river, (b) semi-log graph of time versus discharge for the recession period [9, 11]

Recession coefficient would be calculated by using the following formula that was once used by Maillet equation, which is more commonly used, is an exponential [1, 11] (Eq.1):

$$Q_t = Q_0 e^{-\alpha (t - t_0)} \qquad (1)$$

Where,

Q_t = the flow at specified time (m^3/s)

q_0 = on the flow at the beginning of recession (m^3/s)

t (or $t-t_0$) = time or the time between two selected water discharges (day)

α = coefficient of discharge (recession or tarissement coefficient) which depends upon the aquifer's transmissivity and specific yield. The gradient of the descending curve is a straight line with the value of -0.4343 α (day^{-1}). If an aqueduct or a spring with a discharge of q_0 in the eve of subsiding starts discharging in a constant non-recharge regime, it takes t_0 time long for it to reach the store zone.

If at the end of the recharge season, the discharge of the spring were q_0, then the water volume of the reservoir (v_0) would be [5, 9, and 11] (Fig.1,a) (Eq.2, 3):

$$V_0 = \int_0^\infty q_0 e^{-\alpha t} \rightarrow V_0 = q_0 . t_0 \qquad (2)$$

$$V_0 = q_0 / \alpha \qquad (3)$$

Considering the second equation, the moment water volume of the reservoir would be (Eq.4):

$$V = q . t_0 \qquad (4)$$

If the aqueduct is fed with several underground springs, the total moment water volume from different reservoirs would be obtained as follows (Eq.5):

$$V = q_1 t_{01} + q_2 t_{02} \qquad (5)$$

Regarding the above equation, it would be possible to calculate the water volume both at the beginning and at the end of the recharge season. The amount of recharge in this period equals to the change of reservoir water volume plus the amount of water that was discharged by the spring within that period (Eq.6):

$$R = V_2 - V_1 + \Sigma Q \qquad (6)$$

Having the rain fall and the annual spring recharge amounts, it is possible to calculate the recharge percentage from the rain fall.

An aqueduct is an underground canal with a gentle slope in alluvial and sometimes in hard structures. It is dug along with a number of wells that are called Bars (boreholes) and this way water can flow on the surface without using any dynamic or other man-made devices (Fig.2, a).In the figure, general characteristics of an aqueduct with a straight canal called a forge are shown. This canal which leads water towards the outside and consist of two parts: the wet and the dry parts.

- The wet part: in this part, the floor of the canal is below the water level and these results in the drainage and the movement of the underground water towards the outside (where water is discharged on the surface) (fig.2,a).
- The dry part: which starts from the water level intersection to the water is discharged on the surface (fig.2,a).

The slope of the aqueduct floor differs from place to place and is actually dependant on the local situation and ranges from 1/1000 to 1 in several thousands. The experimental value of the slope is selected in a way that helps water flow with an appropriate speed but does not destroy the aqueduct itself.

The last well which is the deepest is called mother well. Water discharging ability of an aqueduct depends on several different factors such as:

Ground structure (water-bearing layer permeability, shape, size and grain fitting), regional recharge and discharging ratios, water level fluctuation, length and the structure of the aqueduct. Aqueducts like wells do influence water level which causes it to decrease in and around its neighboring areas (Fig.2, b).

If the influenced area of an aqueduct intersects the influenced areas of another aqueduct or well, the amount of water absorption in the aqueduct would definitely decrease. The fore mentioned decrease depends on hydraulic characteristics of the water-bearing layer, aqueduct or well distance and the exploitation debit amount. Before using the Maillet method for aqueducts, balance sheet and Schoeller methods had been used in this formula. Regarding the balance sheet method, it would be possible to calculate the permeability percentage from rainfall amount and reservoir volume changes which is 19.06 %.In Schoeller's method, $A=(1-Qr)Cl_p/Cl_q$ have always been used to calculate the permeability percentage[8]. In this method, the amounts of runoff (Q_r) and the mean rain chloride are 46 % and 0.11meq/L, respectively. The considering the mentioned explanations for aqueducts and wells, balance sheet and the mean aqueduct chloride is shown in the Table2 and the value of permeability percentage is 22.16 %.

Methods, it would be possible to analyze the dynamic source volume of an aquifer which feeds different aqueducts with the help of the Maillet formula. Consequently, some aqueducts that were located in Hashtgerd area (in Tehran province) were used for doing further analysis of the matter (Fig.3).

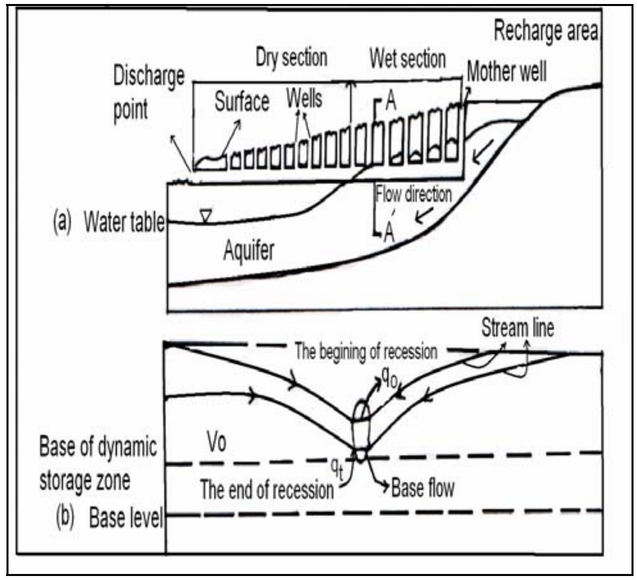

Fig. 2 (a) Different parts of an aqueduct (b) A-A′ cross section from a [9]

The studied zone, which is located in the northwest of Tehran and its total area is over 700km^2.Its geographical coordinates are 35°- 45′ to36° - 05′ (north latitude) and 50°-30′ to 50°-55′ (east longitude), respectively. It is bordered by Alborz Mountains in the north, Halghehdar Mountains in the south, Karaj plain in the east and Ghazvin plain in the west. There are not many water sources in the area since it has dry or semi dry climatic condition [4].

Some aqueducts and their characteristics and the geographical locations are shown in table1 and fig.3. From the Geological point of view, the highest northern part of the studied area consists of lime, marl sediments and together with Tuff, lime stone, shale, andesine and basalt (Eocene Karaj Formation). The northern parts of the plain are made up of A series sediments such as: cemented sediments of gravel, sand and clay. The upon A series sediments, uncommented but compact sediments of B series are located which are made up of gravel, sand and clay. The B series is covered by C series. In these sediments, grain size becomes smaller as we go from the north to the south and the percentages of clay, Increases[2, 4]. C series sediments make the main aquifer in Hashtgerd plain [4, 6]. Generally, 35 aqueducts have been dug in Hashtgerd region which almost cover the whole area. A great effort has been made to choose and study different aqueducts from different places in the area (Fig.3). The discharge of Hashtgerd aqueducts range is from 9 to 90 L /s [4]. The recharge- time and rainfall curves were drawn with the help of tarissement coefficient and the dynamic storing volume of aqueducts. It is a good idea to start explaining some of these aqueducts.

2.1 Shalamzar Aqueduct (18Q)

Shalamzar aqueduct is dug in the north- west part of the studied area in hard formations (limestone and sands with marl) (Fig. 4, Table 1).

The recharge- rainfall and the semi logarithmic descending curves of the aqueduct are drawn in Fig.4. It takes 90 days for this aqueduct which had 203294 m^3 stored water at the beginning of descending to be discharged. It is also possible to discharge it in 58 days with a non-recharge regime and constants debit of q_0 to make it reach to the dynamic storage zone.

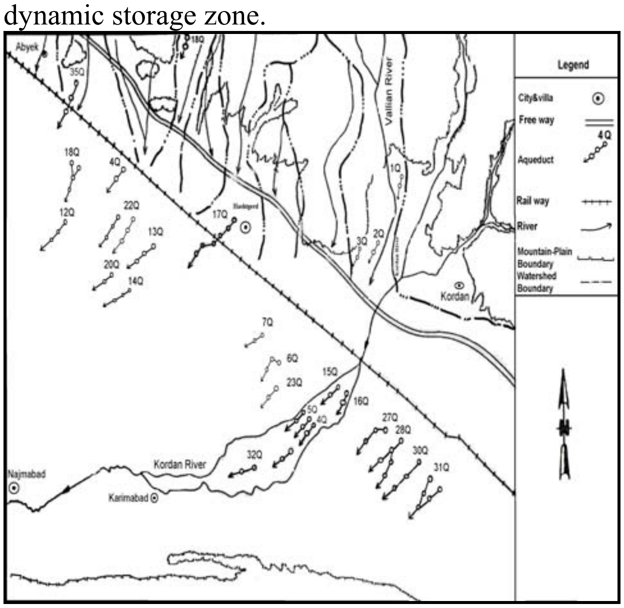

Fig.3 the situation of aqueducts in Hashtgard plain [4, 6]

The first Equation tarissement coefficient (α_1) is $4.34x10^{-3}$ and the second equation tarissement coefficient (α_2) is $1.7x10^{-2}$ which their formulas are $q_{t1}=q_{01}e^{-0.0434t}$ and $q_{t2}=q_{02}e^{-0.017t}$ respectively. The annual effective volume of the aqueduct (R), recharge percentage (C) and its aqueduct water reservoir volume (V), was shown as follows:

$R = 1.079x10^6\ m^3$

$C = R/P = 1.079/158.06 = 0.67\%$

$V = 0.579x10^6$ and $0.5x\ 10^6\ m^3$ Water was discharged from the aqueduct in the studied time [4].

2.2 Soleymankhani Aqueduct (1Q)

This aqueduct is dug in big- sized alluvial sediments in the north- west of Kordan village (Fig.5 ,Table 1). The recharge-rainfall and the semi logarithmic descending tarissement curves are drawn in Fig. 5 . As it can be seen in the figure, four descending slopes which their information is as follows are determined.Tarissement coefficients (α) of the first, second, third and fourth curves are $2.6x10^{-2}$, $1.15x10^{-3}$, $5.2x10^{-3}$, and $5.3x10^{-3}$.

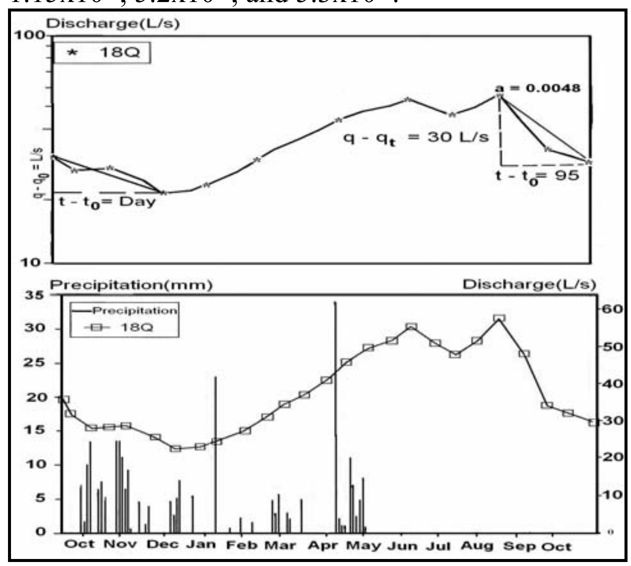

Fig. 4 The recharge- rainfall changing curve (a), the recession curve of the aqueduct 18Q (b) [4]

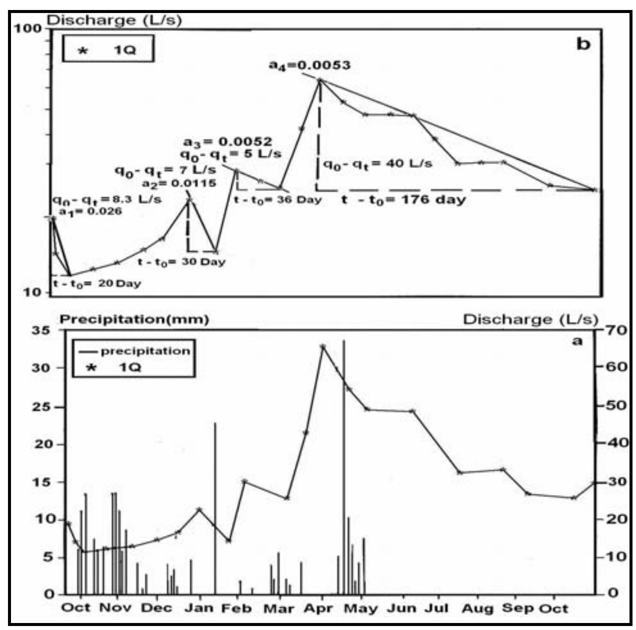

Fig. 5 The recharge- rainfall changing curve (a), the recession curve of the aqueduct 1Q (b) [4]

The required discharging time for the first curve with a constant recharge was 38 days, for the second curve with a constant recharge was 87 days, for the third curve with a constant recharge was 192 and for the fourth one with a constant recharge was 188 days. The discharged water volume during the studying period was $0.72x10^6m^3$, and as a result the aqueduct water volume (V), the annual recharge volume (R) and the recharge percentage (C) were calculated $0.815x10^6$, $1.535x10^6$ and 0.97 % respectively [4] .

3 Conclusions

The following results were obtained from this work:

- The recharge process in aqueducts is done through the joints in hard lime, sand and marl sediments in the north-west part of the area which is 0.43%.As you travel to the north-eastern parts, aqueducts drain more water.
- The recharge process in north-eastern parts and in Karaj igneous formations is done through the present
- joints and the rainfall absorption percentage is 0.8 to 1%.
- In the northern parts from east to west, the amount of absorption is reduced. The recharge percentage varies between 0.4-0.7% in south-west and eastern parts of the area. It can be understood from the statistics that the recharge percentage of Karaj formation's much more than the north-west sediments (lime sediments of Shemshak For.) due to the present joint sets.
- Alluvial sediments become finer when traveling to the central and southern parts of the area and there seem to be a rise in the amount of clay. So, the amount of recharge percentage from the rainfall is especially more in the northern and central parts than the southern part which is 1.96% in the center of the studied area. Since the sediments vary from coarse to mean sized-grain, the recharge percentage
- would reach to its maximum rate (aqueduct 7Q equals 1.96 %).
- The recharge amount in the eastern and western parts of the area is less than the central part since the grains grow more coarse but it is almost the
- same in either sides and is approximately 0.8 %(table 1).
- Two other methods were used to approve the Maillet method and to determine the recharge percentage.In the first method, the recharge percentage was calculated by preparing the water balance sheet. In this method that used the information of the last 20 years, the total rainfall volume was$158.06x10^6$ and consequently , the amount of absorption , was almost 19.06 %.
- In the second method, the recharge amount was calculated from the Schoeller's method. The calculated amount of absorption percentage from this method was % 22.16 (Table 2).
- To approve the Maillet method regarding the scattering of the aqueducts in Hashtgard plain and their characteristics in chart 1,It can be seen that the calculated values for each aqueduct does not cover the whole basin but its own neighboring area. Considering the scattering and the number of aqueducts(35 nets),it can be estimated from the Maillet method that the recharge volume(C) amount is almost 21.36 % .If the number of the aqueducts increases, there seem to be no change in the recharge percentage because of the reduction of the amount of discharged water from each aqueduct.
- It is important to remember that the obtained amounts from the three methods are almost approximate. Since there is not enough certainty in the statistical discharge of aqueducts, different methods are used to choose the most suitable value for the recharge percentage.

As it was mentioned before, the Maillet method and the obtained data from that were used for aqueducts. There are some points to consider when using this method:

- More results that are exact will be obtained in case more correct and exact information is available.
- As a result of having more exact information, water source reservoir volume, recharge volume and recharge percentage from the rainfall can be calculated more exactly so, it would be possible to plan better for using water sources. There is a good agreement (regarding recharge from the rainfall) among the different obtained values.
- As it is noted in different sources, The Maillet method is merely used for springs. However,

- this method can be successfully used in Hashtgerd aqueducts.
- 3-The descending equation can be obtained by drawing recharge -rainfall curve and its semi logarithmic descending curve.

On the other hand, tarissement coefficient of each aqueduct must be calculated when reservoir water volume, recharge volume and the recharge percentage are determined. So, for having more exact descending equation and tarissement coefficient, we need to run exact and long statistical data.

Table 1 Information related to the number of aqueducts and Reservoir water volume, recharge volume and aqueducts recharge volume percentage in Hashtgerd plain

No Aqua	q_0 (L/s)	qt (L/s)	$t-t_0$ (day)	α (1/day)	V $m^3.10^6$	Discharge $m^3.10^6$ 1993-94	R $m^3.10^6$	C %
20Q	18 17.5 15	14 26 19.3	43 60 45	0.005 0.006 0.005	236.1	0.867	1.1	0.69
18Q	60 40	40 3.6	90 137	0.004 0.001	579	0..5	1.079	0.67
7Q	19 15	8 42.7	35 125	0.024 0.008	328	2.77	3.1	1.96
6Q	22 20 19	20 16.6 14.5	85 29 150	0.001 0.006 0.002	430	0.788	1.218	0.77
12Q	55	25	95	0.008	305.66	0.7	1.006	0.95
16Q	83	22	150	0.008	602.33	0.12	0.722	0.63
9Q	39.9 65	29.7 35	86 105	0.003 0.005	955.01	0.47	0.916	0.57
8Q	36	5	151	0.012	219.6	0.175	0.4	0.25
3Q	44	17	120	0.008	399.6	0.876	1.275	0.8
19Q	42.5	4	303	0.007	426.46	0.419	0.845	0.53
21Q	52.8	11.3	152	0.01	351.52	0.69	1.04	0.65

Table2 Information related to the determination of the infiltration from rainfall according to the Schoeller's method (rain fall chloride is0.11meq /L).

Chemical Analysis Aqueduct	Cl (meq/L)	$\%A = (1 - Q_r)\, Cl_p / Cl_q$
18Q	0.32	24.4
9Q	4	1.9
13Q	0.6	13
12Q	0.4	19
7Q	0.37	21
4Q	0.46	17
6Q	0.47	16.6
5Q	0.55	14.2
Kordan River(north plain)	0.27	28.4
Kordan River(south plain)	0.17	45.4

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