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Baseflow Recession and Groundwater Recharge Estimation in Pyungchang River Basin

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Abstract

It is not easy to represent the characteristics of the groundwater recession curve in streamflow, but a linear recession model has generally been used. However, some studies have shown that a nonlinear model is more appropriate, and nonlinear analyses have been conducted to describe the relationship between groundwater discharge and storage. The objective of this study is to identify and quantify the main components of the groundwater water balance—namely, discharge, evapotranspiration, storage, and recharge—by applying a nonlinear model to streamflow data from the Pyungchang River basin. In particular, this study proposes a method for separating baseflow using the streamflow hydrograph and peak groundwater stage, and groundwater recharge was also estimated based on unit effective rainfall. The analysis of baseflow revealed that the recession curve shows seasonal variation. Groundwater storage was estimated using a nonlinear model, and groundwater recharge was analyzed in relation to effective rainfall. We found that groundwater recharge continued for up to two days after effective rainfall in the Pyungchang River basin. Using the methodology developed in this study, it is possible to estimate groundwater recharge solely based on effective rainfall.

Key words : Baseflow recession, Evapotranspiration, Baseflow separation, Groundwater recharge

1. Introduction

It is well known that much of the observed streamflow of many rivers in many different hydrological and climatic settings is the outflow from the shallow groundwater reservoirs of the associated basins. Such groundwater reservoirs are also important water resources both for the maintenance of the natural environment as well as for human needs. Understanding and quantification of the water balance of these shallow groundwaters, which take part in the seasonal water cycle, expressed in the form of the time series of storage, discharge and evapotranspiration (outflows), recharge (inflow), and the relationship of the latter to rainfall inputs, are important for their monitoring and management.

The last remaining component of the groundwater balance is depletion due to evapotranspiration, which may be important depending on climate, soil properties, and especially vegetation (Nichols, 1994). In studies and practical work, the evapotranspiration is mostly considered as a negligible component in moderate climate zones, this loss may actually surpass baseflow under arid and semi-arid conditions. Over long time periods, baseflow discharge added to rates of evapotranspiration should, and do, balance rates of recharge to groundwater.

The rate at which a groundwater store discharges in the absence of recharge must be one of the earliest fields of investigation on hydrology, and according to Appleby (1970), has "developed into a closed system of repetitive discovery and rediscovery". The applications of recession analysis since the early 1900s have been numerous and include such areas as low-flow forecasting, separation of

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base flow from surface runoff, and the assessment of evapotranspiration loss. An excellent review of the origins and uses of recession analysis is provided by Hall(1968).

Thomas et al.(2015) developed and tested a comprehensive scientific approach for the characterization and estimation of theoretical baseflow hydrograph models which should enable improvements in our ability to understand and predict the behavior of watershed hydrograph recessions. There is considerable controversy over the assumption that watersheds exhibit a fixed time constant, known as the baseflow recession constant, in the relation between aquifer storage and baseflow discharge(Zecharias and Brutsaert, 1988; Troch et al., 1993; Vogel and Kroll, 1996; Wittenberg and Sivapalan, 1999, 2003; Eng and Milly, 2007; Harman and Sivapalan, 2009).

In recent study, Basso et al.(2021) used satellite derived soil moisture for characterizing hydrograph. The availability of remote sensing products targeting components of the water balance recently prompted attempts to study the relation between storage and baseflow of large river basins (e.g., the Amazon and the Mississippi) at coarse spatial and temporal scales. Anomalies of terrestrial water storage provided by the Gravity Recovery and Climate Experiment have been mainly employed (Tourian et al., 2018; Ehalt Macedo et al., 2019; Riegger, 2020), with few exceptions (e.g., Bouaziz et al., 2020) adopting remotely sensed soil moisture as explanatory variable.

The previous studies have derived and analyzed the nonlinear equation for pilot studies and the recent studies tried to use the remote sensing for connection between soil moisture and the baseflow recession. However, we may need more practical applications of the equations and methods for improving the analysis methodology and for reflecting the regional characteristics.

Therefore, this study derives the baseflow recession curve equation from the relationship of storage and discharge and examines the variation of the parameter involved in the equation. Also, the impact of evapotranspiration on baseflow is investigated and baseflow separation method is proposed. Then the effective rainfall is estimated using Φ-index method and the ground water recharge response hydrograph to the rainfall is estimated.

2. Methodology

2.1 Storage-discharge relationship and baseflow recession

Ever since Mailet (1905), the exponential function $Q_t = Q_0 \times \exp(-t/k)$ has been widely used to describe the baseflow recession, where Q_t is the discharge at the time t, Q_0 is the initial discharge, and k the recession constant which can be considered to represent average response times in storage. The exponential function implies that the groundwater aquifer behaves like a single linear reservoir with storage linearly proportional to outflow, namely $S = kQ$.

It is, however, evident that the parameter k fitted to different discharge ranges of the recession curves in actual rivers dose not remain as a constant but increases systematically with the decrease of streamflow(Wittenberg, 1994; Moore, 1997), which is a strong indication of nonlinearity. The convenient assumption that the baseflow may be the outflow form, two or more parallel (i.e. independent) linear reservoirs, representing components of different response times is often made(Moore, 1997), and does result in better fits to the observed recession curves. However, this is perhaps only because there are more parameters to be calibrated, giving more degrees of freedom for curves fitting. In most basins it is unlikely that the dynamic groundwater aquifer can be divided so neatly into such independent storage zones.

Thus, the use of a single but nonlinear reservoir is considered to be more physically realistic. Nonlinear reservoir algorithm have been proposed and implemented in a large number of basins around world(Wittenberg, 1994; Wittenberg and Sivapalan, 1999; Chapman, 1999; Brutsaert and Lopez, 1998), and are used. To allow for nonlinearity the linear storage-discharge relationship is generalized by adding an exponent b as follows:

$$S = a \times Q^b \quad \cdots \ (1)$$

where the unit of S(storage) is m^3 and Q(discharge) in m^3/s. The factor a has the dimension $m^{3-3b}s^b$. If the volumes are expressed in depth, then S is in mm, Q in mm/d and a will be in $mm^{1-b}d^b$. The exponent b is dimensionless. The linear reservoir is a special case of Eq.(1), i.e. when $b=1$. Combining Eq.(1) with the continuity equation for a reservoir without inflow, $dS/dt = -Q$, yields the recession curve equation for the nonlinear reservoir starting at any initial discharge Q_0

$$Q_t = Q_0 \left(1 + \frac{(1-b)\,{Q_0}^{1-b}}{ab} t\right)^{1/(b-1)} \quad \cdots \ (2)$$

This corresponds to the expression found by Coutague and its derivation is given in detail in Wittenberg and

Sivapalan (1999). Given the streamflow recession data the parameter values a and b can be determined by an iterative least squares fitting method (Wittenberg, 1994). By systematically varying the parameter b the value of parameter a is solved at each iteration step, with the condition that the computed outflow volume during the considered time period is equal to that of the observed recession curve. The set of a and b values providing the best fit to the observed curve is considered as representing the properties of the aquifer. Eq.(2) has only one optimal combination of a and b and no restriction was imposed on the value of b. When fitting Eq.(2) to recession data, in almost all cases no significant variation of the parameters a and b was found over different parts of the recession curve, unlike k in the linear case, which has been shown to exhibit strong systematic variation (Wittenberg, 1994).

2.2 Parameters of a and b in recession curve

The start of the baseflow recessions had been flow assumed not earlier than two time intervals (days) after the inflection point of the total hydrograph recession. The skewed distribution of the exponent b is peaking between 0.3 and 0.4 with a mean value of b=0.49~0.5 and a standard deviation of 0.25. This empirically estimated mean value of 0.5 (i.e. discharge proportional to the square of storage) has also been obtained theoretically for the unconfined aquifers by other authors (Werner and Sundquist, 1951; Fukushima, 1988).

For most practical purposes, such as the regionalization of the relationship given by Eq.(1), it seems reasonable to fix the exponent b at a mean or dominant value, and to allow the coefficient a to vary between basins. A value of $b=0.5$ is suggested by Wittenberg and Sivapalan(1999) for this purpose, this is especially applicable to hillslope flow-strips(Kubota and Sivapalan, 1995) or to partial basin areas as these are less subject to spatial heterogeneities. It is believed that even if the "true" value of b is not exactly reproduced, the assumption $b=0.5$ would be more physically realistic and would provide a better match to observed streamflows in a majority of river basins, than the linear reservoir. When fitting the model function with a fixed value of $b=0.5$ to the German flow recessions an average variation coefficient of $CV=7.2\%$ was obtained instead of b (Wittenberg and Sivapalan, 1999).

Wittenberg and Sivapalan (1999) shows that the notional value of $b=0.5$ for the unconfined aquifers is independent of the number of flow strips which make up the basin. He also provides a discussion of the likely causes for the deviation of the field estimates of the exponent b from the theoretical value of $b=0.5$.

2.3 Derivation of evapotranspiration equation

The depletion of groundwater storage by evapotranspiration, or through fluxes other than baseflow, results in a biased streamflow recession curve which decreases at a faster rate than if would be expected with the "true" reservoir coefficient a_R. This is demonstrated in Figure 7 by two hypothetical recession curves for Pyungchang River, starting from an arbitrary value Q_0. The upper recession QR would occur under winter conditions(December) which is subject to minimum losses, and here assumed to be zero, and Q under summer conditions(June) with maximum losses.

For every time interval $\triangle t$ evapotranspiration loss can be determined as the difference between the theoretical (i.e. potential) storage $SR=a_R \times Q^b$ which would have occurred at the end of the time interval with minimum evapotranspiration loss, and corresponding to theoretical baseflow discharge QR, and the actual storage $S=a_R \times Q^b$ (subject to increased losses).

Note that a_R, being the "true" unbiased reservoir coefficient, determines the true storage corresponding to outflow in any season. That is, $S=a_R \times Q^b$ or $SR=a_R \times QR^b$ is hydraulic-volumetric hence physical relationships for the reservoir. Hence, if one wants to estimate this steeper recession curve, then a_1 must be used, as in Eq.(3).

In terms of a groundwater balance equation a preceding storage value S_{i-1} would become, after a time interval $\triangle t=1\,day$, at time i (i.e. on the ith day).

$$SR_i = S_{i-1} - \int_{i-1}^{i} Q\,dt \ \cdots \tag{3}$$

with only baseflow Q and

$$S_i = S_{i-1} - \int_{i-1}^{i} Q\,dt - \int_{i-1}^{i} ET\,dt \ \cdots \tag{4}$$

with baseflow Q and evapotranspiration ET (For simplicity, we define ET in terms of daily depth).

Note that both the terms on the right side related to real (physical) storage, not biased ones. QR is dischrage (during a recession) when ET is minimum, and Q is the discharge during recession which is influenced by evapotranspiration.

Starting from the preceeding baseflow Q_{i-1}, the value QR_i is obtained according to Eq.(2) using the constant a_R (minimum "no" losses, December), while Q_i is computed with a_1 (increased evaporation losses) thus becomes(see Wittenberg and Sivapalan, 1999):

$$ET_i = a_R Q_{i-1}{}^b (1+\frac{(1-b)Q_{i-1}{}^{1-b}}{a_R b})^{b/(b-1)} \cdots \quad (5)$$
$$-a_R Q_{i-1}{}^b (1+\frac{(1-b)Q_{i-1}{}^{1-b}}{a_1 b})^{b/(b-1)}$$

Replacing $Q_{i-1}{}^{0.5} = S_{i-1}/a_R$ yield Eq.(6) which shows clearly that evapotranspiration losses from the groundwater depend on season via the factor a_1 and groundwater volume S which is related to groundwater depth:

$$ET_i = S_{i-1}(\frac{1}{1+S_{i-1}/a_R{}^2} - \frac{1}{1+S_{i-1}/a_1 a_R}) \cdots \quad (6)$$

The relationships between evapotranspiration loss and storage depth of the groundwater can be computed by Eq.(6) using the average values of a_1 for each month of the year as given by the sinusoidal cruve.

2.4 Baseflow separation

There are many techniques for baseflow separation, though while most procedures are based on physical reasoning, the quantitative elements of the separation techniques are essentially arbitrary. Useful reviews of baseflow separation techniques are presented by Hall (1971). The nonlinear reservoir algorithm was also applied for the separation of baseflow from time series of total daily streamflow. The procedure and application has been amply described by Wittenberg and Sivapalan (1999). The computation starts at the last value of the time series and proceeds backwards along the time axis. A flow recession at the time $t-\triangle t$ is determined from the flow at the time t using Eq.(7), which has been derived by inverting Eq.(2). The time step $\triangle t$ is normally one day.

$$Q_{t-\triangle t} = (Q_t{}^{b-1} + \frac{\triangle t(b-1)}{ab})^{1/(b-1)} \cdots \quad (7)$$

As recharge is usually coincident with the rising and peaking of total flow, the following approach was adopted (Wittenberg and Sivapalan, 1999). When the reverse computed baseflow recession curve intersects the rising limb of the total hydrograph, a transition point which is at the next time step forward from the total flow is adopted as the peak of baseflow. Values of the rising limb of the baseflow hydrograph are then found as the computed recession curve for one time step forward for each given total flow value. This procedure is similar to the digital filter described by Chapman(1999) for baseflow separation for the linear reservoir.

2.5 Groundwater recharge response function to rainfall

Based on the obtained baseflow, the effective groundwater recharge is computed for every time step as follows:

$$GWR_i = S_i - S_{i-1} + \int_{t_i-1}^{t_i} Q\,dt + ET_i \cdots \quad (8)$$

Where S is the actual storage computed by Eq.(1) using the unbiased storage factor a_R. For practical computation, the baseflow volume during this time interval is determined by the trapezoidal formula, thus $\int Q\,dt \approx \triangle t(Q_{i-1}+Q_i)/2$. Evapotranspiration losses (ET) from the groundwater are computed using Eq.(6) with daily values of a_1.

As every rainfall impulse appears to produce a similar response, differing of course in magnitude, it appears reasonable to apply a linear unit response function of the unit hydrograph type. Linear response functions to estimate recharge have been derived. Recharge GWS from infiltrating rainfall $I(t)$ can be estimated by the application of the convolution integral:

$$GWR_i = \int_0^t (I_{t-\tau} \times h_\tau)\,d\tau \cdots \quad (9)$$

where h is the unit response function, which is defined as the theoretical recharge hydrograph which would occur for 1mm of effective rainfall percolation through the groundwater surface. For practical computations, with digital data of a time interval $\triangle t$, the convolution integral becomes:

$$GWR = \sum_{k=1}^{i} (I_{i-k+1} \times h_k)\triangle t \cdots \quad (10)$$

Where GWR and I are in mm. In this study effective rainfall I has been assumed proportional to measured rainfall throughout each recharge event. As the time interval for computations is $\triangle t = 1\,day$, the response function h in Eq.(10) represents a travel time distribution in d^{-1}. For every sequence of n_i values of effective rainfall I, there is a corresponding sequence of n value of recharge GWR, which could be computed by convolution, i.e. multiplication of the response function h with every value I and time shifted superposition of the estimated recharge hydrographs. The length of number n_h of value of the response function h is thus $n_h = n - n_i + 1$. Eq.(10) thus represents a system of n linear equations with $n_h (< n)$ unknowns h, which can be resolved by the least squares method(Snyder, 1955).

3. Applications and Results

3.1 Study area

The case study is performed for the Pyungchang River basin which is the branch of Han River flows from north to south. The Pyunhchang River, also know as Seogang, is the first tributary of the Han River and is part of the Han River basin. It has a watershed of 1,774,32km^2 and a total channel length of 146.86km. The river is formed by the confluence of several streams including Soksa river, Hongcheon river, and Daehwa river, and eventually joins the Jucheon river before flowing into the Han River. The Pyungchang River is well-known for its winding course, traveling approximately 220km in length while covering only 60km in straight-line distance. In addition to the main stream classified as a local river, it includes 28 other local tributaries (Yi et al., 2012). Although the Pyungchang River basin is classified as a single mid-basin based on the standard basins, it corresponds to a mountainous basin. To utilize data from a water level gauging station, the outlet of the basin was redefined as the Banglim point and the basin was re-delineated accordingly. Therefore, the area of Pyungchang River basin is 519.69km^2 and the slope is 0.333 radian. The configuration of the basin is shown in Figure 1 and there are self-recording water stage, groundwater table, rainfall and pan evaporation gauges as the facilities for the measurements of hydrologic observations. Daily discharge data of Banglim and Sanganmi are used in 1990, 1994～1998 and daily basin rainfall data during the period are made by the Thiessen method. Banglim water stage gauge station is located at 128° 25´ of east longitude and 37° 26´ of north longitude. Datum of Banglim water stage gauge station is 357m.

3.2 Estimation of parameter a for recession curve

The Figure 2 shows an example of daily runoff and selected recession segment of hydrograph to analyze baseflow characteristics in Banglim. The analysis is performed in two ways. One is for two exponents (a and b) and the other is for one exponent(a with a fixed $b = 0.5$). The estimates of a_1 are represented in Table 1. From the calibrated curves in Figure 3, the fitted curve by two exponents is better than by one exponent but there are no large differences between the fitted curves. Therefore, one exponent is considered for practical purpose and simplicity of nonlinear reservoir modelling.

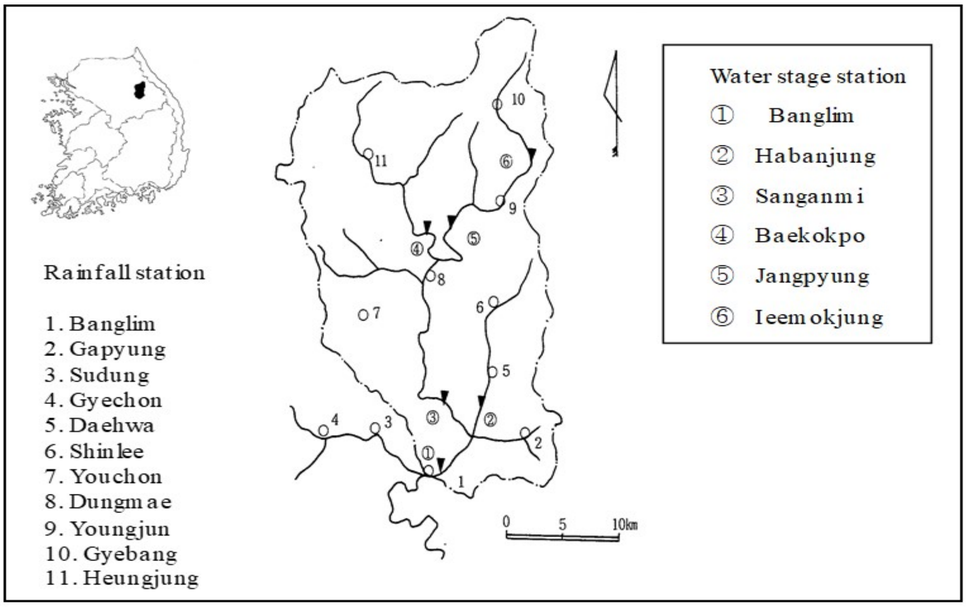

Fig. 1. Pyungchang River basin and gauge stations

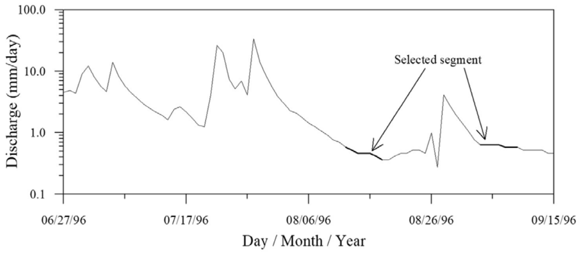

Fig. 2. Daily runoff hydrograph in Banglim (Pyungchang River)

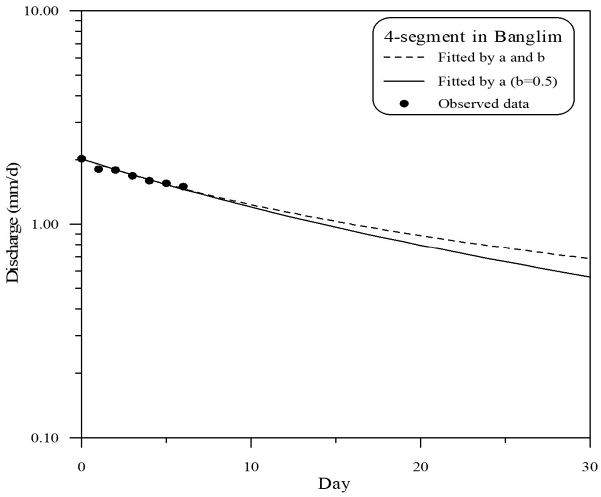

Fig. 3. Comparison of observed and modelled flow recessions

The mean seasonal variations of pan evaporation are shown in Figure 4. The data series shows seasonal monsoon climate which is high temperature and evaporation in summer and low temperature and evaporation in winter. Therefore, the variation of data series shows sinusoidal pattern.

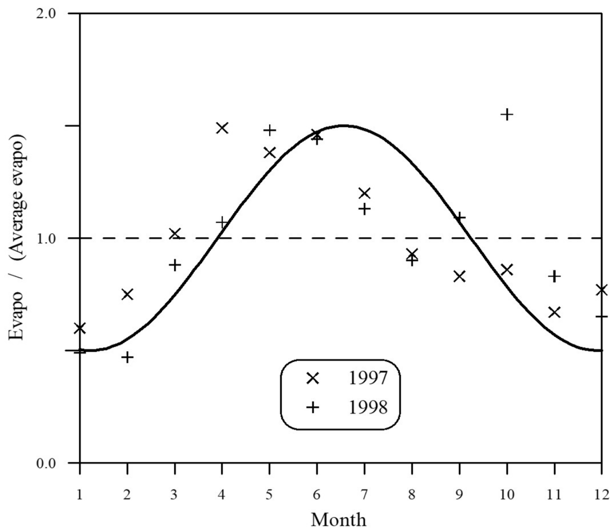

Fig. 4. Seasonal variation of pan evaporation (Pyungchang River basin)

Seasonal recession curve may vary with evapotranspiration as shown in Figure 5. Figure 5 shows the recession curves extracted from the observed daily flow for the different seasons and significant seasonal variations of a_1. The Figure 6 shows the seasonal variation of the coefficient a_1 and it shows a tentative sinusoidal curve as fitted. Hence, the observed seasonal variation of the coefficient a_1 suggests that the baseflow is not the only outgoing water flux from the groundwater reservoir. A seasonally varying rate of evapotranspiration loss from the groundwater aquifer appears as the most probable and plausible cause for the changing steepness of the streamflow recession. Baseflow recession studies in the

Table 1. Selected segments and estimated exponent for nonlinear reservoir modeling

Station	N	Segments	a_1	RMSE (a_1)
Banglim	1	May-1994	49.1	0.029
	2	Jul-1994	31.4	0.058
	3	Jul-1995	50.4	0.004
	4	Sep-1995	34.0	0.035
	5	Aug-1996	28.1	0.029
	6	Sep-1996	39.4	0.049
	7	Apr-1997	50.3	0.077
	8	May-1998	37.1	0.052
	9	Nov-1990	20.6	0.034
	10	Oct-1990	50.0	0.075
Sanganmi	1	May-1994	71.1	0.013
	2	Jul-1995	32.7	0.113
	3	Jun-1997	31.6	0.069
	4	Sep-1997	47.7	0.044
	5	May-1990	40.0	0.076

Pyungchang River, suggest a strong seasonal variation of the storage-discharge relationship of the aquifers, which can be attributed to biasing by seasonally varied evapotranspiration losses.

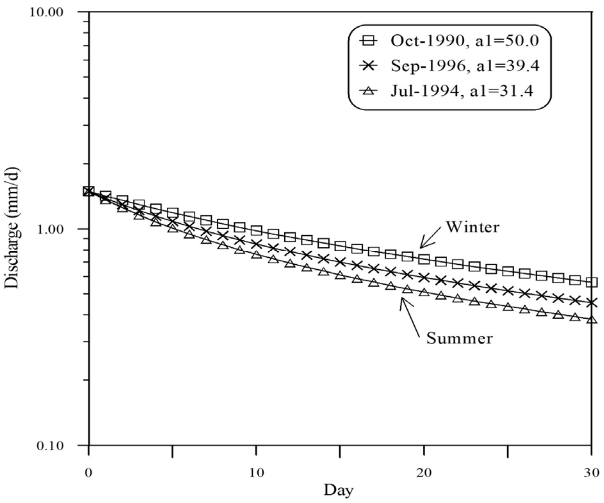

Fig. 5. Seasonal variations of recession curve (Pyungchang River)

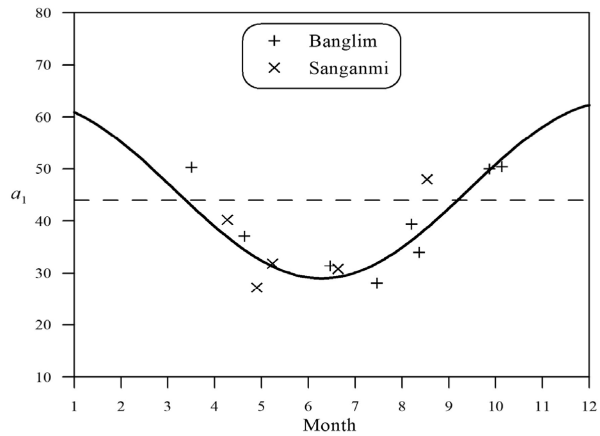

Fig. 5. Seasonal variation of parameter a_1

Table 2. The average values of a_1 for each month of the year

Month	a_1
1	61
2	56
3	47
4	39
5	33
6	29
7	30
8	35
9	43
10	51
11	58
12	62

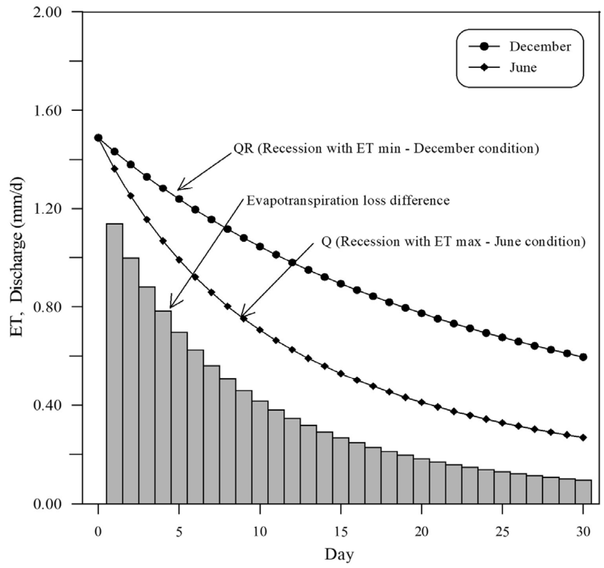

Fig. 7. Estimation of groundwater evapotranspiration (Pyungchang River)

When the Figure 5 and Figure 6 are compared, it is evident that pan evaporation and estimated variation of a_1 have the strong negative correlation. Table 2 represents the values of in each month obtained from the Figure 6.

3.3 Estimation of evapotranspiration

Two hypothetical recession curves starting from average Q_0 of selected segments for Pyungchang River are shown in Figure 7. It is also considered that upper recession curve would occur under winter conditions (December), which is subject to minimum losses (assumed to be zero in Wittenberg and Sivapalan(1999)), and the lower recession would occur under summer conditions (June) with maximum losses. Evapotranspiration is assumed by the difference of recession curve.

3.4 Baseflow separation by streamflow and groundwater stage

According to Wittenberg and Sivapalan (1999), the peak of baseflow is occurred at the peak point of runoff hydrograph. However, the method by Wittenberg and Sivapalan (1999) to separate baseflow from runoff hydrograph is not consistent with the hydrograph from the Pyungchang River basin.

Therefore, we propose a method here to separate the baseflow from the runoff hydrograph by considering the relationship between streamflow and groundwater stage. Eq.(11) proposed in this study can be used for the aim of the baseflow separation for obtaining the points from the starting of rising limb to the peak of the baseflow. If

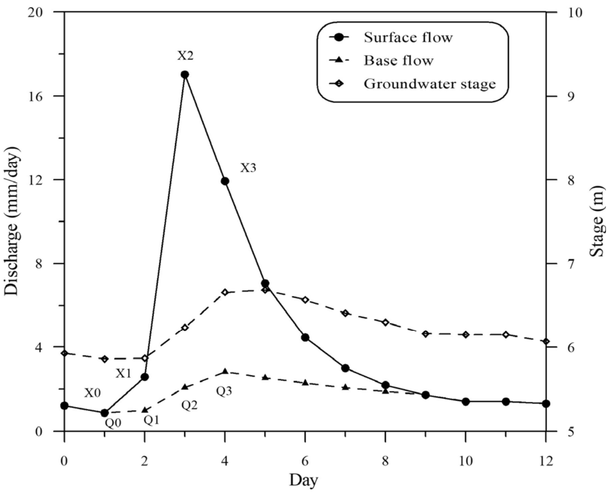

Fig. 8. Baseflow separation consdiering groundwater stage

the peak baseflow for peak day is know, the baseflow (Q_1, Q_2, ⋯) at each time step can be estimated using Eq.(11).

$$Q_i = Q_0 + (Q_n - Q_0) \times \frac{\sum_1^i (X_i - X_0)}{\sum_1^n (X_i - X_0)} \quad \cdots \qquad (11)$$

where, Q_0 is the start day of rising limb of runoff hydrograph which is considered as the start day of groundwater flow. Q_n is the peak baseflow for the peak day corresponding to the peak groundwater stage. X_i is the surface flow.

Each hydrograph for eleven single storm events is selected to separate the components of hydrograph in Banglim water stage as shown in Table 3 and the groundwater recharge is estimated. The Figure 8 shows an example of hydrograph separation.

It is assumed that groundwater stage has a relationship with baseflow quantity as demonstrated. We consider the surface runoff and groundwater stage to separate the baseflow from the surface runoff. Say, the baseflow is separated from the surface runoff by considering the same pattern as groundwater stage. The increment of the baseflow, $\triangle Q_i$, may be proportional to the increment of surface runoff, $(X_i - X_0)$, as shown in Figure 8.

It is known that the fluctuation of runoff rate is large from the Table 3 and it is due to the small peak time of Pyungchang River basin. Daily discharge measurement cannot express storm event characteristic by rainfall exactly. That is, as difference of discharge measurement time of water stage and dropped rainfall time is larger, as variation of runoff rate is smaller in the contrary.

3.5 Estimation of effective rainfall and groundwater recharge hydrograph

The effective rainfall is needed to estimate the groundwater recharge response function and this study uses Φ-index method. As shown in Table 4, the fluctuations of Φ-index are large.

Generally groundwater recharge is affected by infiltrating rainfall $I(t)$ of Eq.(9), but the baseflow is separated from surface runoff by considering the pattern of groundwater stage. Also, groundwater recharge may be more related to effective rainfall than infiltrating rainfall because groundwater recharge is proportional to the increase of baseflow which is related to the surface runoff and the surface runoff is related to the effective rainfall. Therefore, the groundwater recharge equations of Eq.(9) and Eq.(10) representing infiltrating rainfall should be changed as the function of effective rainfall.

Table 3. Total rainfall, effective rainfall, runoff rate and Φ-index

N	Month	Total rainfall (mm)	Effective rainfall (mm)	Runoff rate	Φ-index (mm)
1	Nov-1989	108.0	30.8	0.286	26.1
2	Sep-1990	99.4	33.6	0.338	20.8
3	Jul-1994	273.3	39.4	0.144	97.2
4	Oct-1994	48.5	12.3	0.253	21.5
5	Aug-1995	109.0	75.0	0.688	22.7
6	Aug-1995	144.2	67.1	0.466	55.8
7	Jul-1997	103.2	39.2	0.380	45.5
8	Aug-1997	182.2	60.9	0.334	34.0
9	May-1998	26.8	18.6	0.693	3.9
10	Oct-1998	100.4	13.5	0.134	41.9
11	Oct-1998	43.9	5.6	0.129	20.4
Average				0.350	35.4

The Figure 9 shows the groundwater recharge response function for 1mm-effective rainfall of 1 day and the function can be computed from rainfall and recharge events for each month of the year in Pyungchang River basin. Then, hydrographs of groundwater recharge are recomputed by convolution of the response function with measured rainfall in the following section.

The shape of the determined functions is very similar. The travel time distribution thus appears rather time invariant not only within the events but also over all seasons. Peak recharge is reached at the first day after the rainfall event and recharge ends after 2∼3 days.

Concerning the recharge functions obtained in this study, the shape will be influenced by baseflow modeling during the recharge phase. The length is restricted by the basic assumption of baseflow separation that there is no further recharge when typical recession starts.

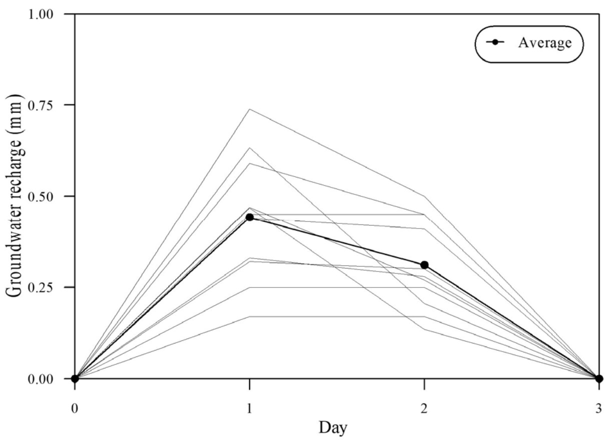

Fig. 9. Response function of groundwater recharge for 1mm effective rainfall of 1day (Pyungchang River)

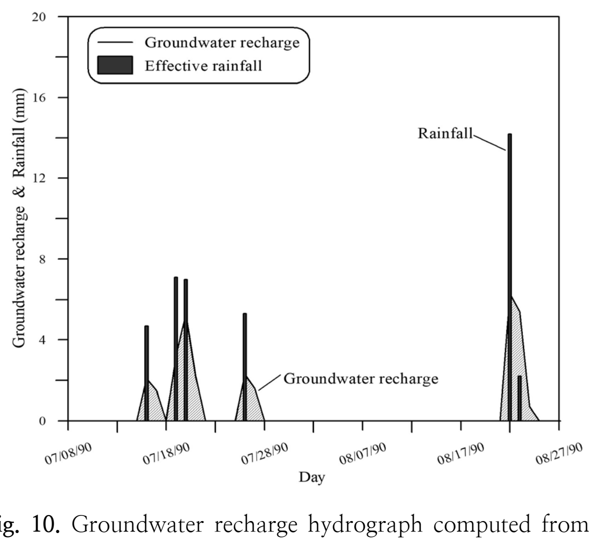

Fig. 10. Groundwater recharge hydrograph computed from effective rainfall for Pyungchang River basin in July, 1990

Table 4. Groundwater recharge for each year

Year	Groundwater recharge (mm)
1990	573.9
1994	323.6
1995	555.5
1996	122.3
1997	341.1
1998	455.2
Average	395.3

Figure 10 shows groundwater recharge in summer by the response function of effective rainfall. The Φ-index to calculate effective rainfall uses the average value in Table 3. This method can estimate groundwater recharge by knowing effective rainfall which is calculated by a Φ-index. Monthly or seasonal groundwater recharge quantity will be taken by this method corresponding to this duration. Yearly groundwater recharge is shown in Table 4 by this method.

4. Conclusion

The groundwater balance of a basin and the processes of recharge, storage, evapotranspiration loss and discharge can be described by simple but physically based conceptual model components. The properties of these components can be identified and obtained from streamflow data. Observed streamflow data especially for flow recessions are considered as a very authentic database for a basin, carrying a wealth of information about the foregoing hydrological processes. Decoding some of this information is the main purpose of this work.

The nonlinearity of the storage-discharge relationships has been found in the literature. Depletion of the groundwater aquifer by evapotranspiration losses, however, biases the observed flow recession curves depending on the storage, vegetation and potential evapotranspiration. Although these losses are known and acknowledged in the past literature(Tallaksen, 1995), they have been rarely considered in the recession analysis ; as shown in this study, baseflow recession analysis also permits their quantification. Evapotranspiration loss in winter period is assumed zero in this study, which generally is not correct. Pan evaporation during winter in Pyungchang River basin is almost 1.5~2.0mmdaily. The Eq.(5) must be changed to consider winter evapotranspiration.

The complexities of basin processes are such that the applications described in this study are not expected to accurately reflect baseflow or recession performance. In this study, baseflow quantity is assumed that concerned with groundwater stage and baseflow separation is performed roughly by the shape of groundwater stage. However, a precise quantitative analysis is required about relationship between surface flow and groundwater stage in many other basins.

If the relationship between surface flow and groundwater stage according to basin geologic characteristics can be identified clearly, groundwater recharge will be estimated easily by the method proposed in this study. By including evapotranspiration flux in baseflow separation techniques, hydrographs of recharge to the aquifer were computed by inverse nonlinear flow routing. Linear time-invariant unit response functions were identified between the measured rainfall and the recharge hydrographs estimated by the baseflow separation.

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