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Estimation of Baseflow based on Master Recession Curves (MRCs) Considering Seasonality and Flow Condition

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계절·유황특성을 고려한 주지하수감수곡선을 활용한 기저유출분리 평가

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Abstract

Baseflow which is one of the unmeasurable components of streamflow and slowly flows through underground is important for water resource management. Despite various separation methods from researches preceded, it is difficult to find a significant separation method for baseflow separation. This study applied the MRC method and developed the improved approach to separate baseflow from total streamflow hydrograph. Previous researchers utilized the whole streamflow data of study period at once to derive synthetic MRCs causing unreliable results. This study has been proceeded with total nine areas with gauging stations. Each three areas are selected from 3 domestic major watersheds. Tool for drawing MRC had been used to draw MRCs of each area. First, synthetic MRC for whole period and two other MRCs were drawn following two different criteria. Two criteria were set by different conditions, one is flow condition and the other is seasonality. The whole streamflow was classified according to seasonality and flow conditions, and MRCs had been drawn with a specialized program. The MRCs for flow conditions had low R2 and similar trend to recession segments. On the other hand, the seasonal MRCs were eligible for the baseflow separation that properly reflects the seasonal variability of baseflow. Comparing two methods of assuming MRC for baseflow separation, seasonal MRC was more effective for relieving overestimating tendency of synthetic MRC. Flow condition MRCs had a large distribution of the flow and this means accurate MRC could not be found. Baseflow separation using seasonal MRC is showing more reliability than the other one, however if certain technique added up to the flow condition MRC method to stabilize distribution of the streamflow, the flow conditions method could secure reliability as much as seasonal MRC method.

Key words : Baseflow separation, MRC, Recession analysis, MRC division, Seasonality, Flow conditions

요 약

기저유출은 지표하를 통하여 느리게 하천으로 유입되며 하천 관리에 있어서 중요한 요소이다. 기저유출의 정확한 파악을 위하여 본 연구에서 활용된 주지하수감수곡선(MRC) 방법을 포함한 다양한 방법들이 연구되었지만, 측정 불가능한 기저유출의 특성상 정량적인 평가는 어렵다. MRC를 활용한 선행 연구들은 연구 기간 내에 존재하는 모든 감수부를 활용하였으며 이는 국내환경에서 부정확한 MRC를 유도하였다. 본 연구는 기존에 행해지던 주지하수감수곡선(MRC) 분리방법을 국내 특성을 고려하여 계절과 유황특성으로 구분하고 기저유출 분리에 적용하였다. 연구대상지역은 한강, 낙동강 그리고 금강수계에서 각 3곳의 유량관측점을 선정하여 총 9 곳이며, 수리구조물의 영향이 없도록 상류지역에서 선정하였다. MRC를 도출하기 위하여 기존에 제작된 프로그램을 사용하였으며, 관측점 별로 총 세 개의 MRC를 도출하였다. 전체 기간에 대한 MRC와 본 연구에서 구분한 계절과 유황을 고려한 MRC 두 가지이다. 유황을 고려한 MRC는 낮은 R2값과 감수곡선과 비슷한 추세의 MRC를 도출하였다. 계절을 고려한 MRC의 경우 기저유출분리에 적합한 양상을 보여주었으며 계절별 특성이 뚜렷하게 반영된 MRC를 도출하였다. 두 가지 방법에 따라 도출된 MRC를 비교하였을 때, 계절을 고려한 MRC는 기존의 MRC를 사용한 분리과정에서 과산정 되었던 기저유출량이 감소되고 안정되게 분리되었다. 유황을 고려한 MRC의 경우 그래프 상의 감수부가 다양한 감수양상을 가지고 있었으며 이에 따라 낮은 R2값의 MRC가 도출되었다. 따라서 기저유출을 분리하기

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위해선 계절을 고려한 MRC가 더 높은 정확성을 보일 것으로 판단되며, 유황을 고려한 MRC의 경우, 추가적인 보정 작업을 통해서 신뢰도 높은 MRC의 도출이 필요할 것으로 판단된다.

핵심용어 : 기저유출분리, 주지하수감수곡선, 감수부분석, MRC분리방법, 계절성, 유황특성

1. Introduction

Streamflow is an important component of water resources and effective management considering precipitation is required (Chiew, 2006). Understanding about compositions of streamflow correctly is needed before studying streamflow. Streamflow can be separated into two components; direct runoff and baseflow. Direct runoff directly inflows into a stream over the land surface within the relatively short time over surface. Baseflow inflows into a stream through the ground slowly compared to the direct runoff (Arnold et al., 1999, Eckhardt 2005).

Direct runoff occurs during and after rain, while baseflow is consistent flow after rain and decays with time. According to a report for studying the ratio of baseflow to streamflow, the baseflow accounted for 56.2%, 58.4%, 55.5% and 51.3% for Han river basin, Nakdong river basin, Geum river basin and Youngsan·Seomjin river basin, respectively (Choi et al., 2014). In addition, the inflow of pollutant load through baseflow is significant to manage water quality in watersheds (Schilling et al., 2001; Choi et al., 2014).

There is no explicit method for separating baseflow from the streamflow (Blume et al., 2007). To overcome this limitation, various separation methods have been applied for the development of baseflow separation programs such as Web-based Hydrograph Analysis Tool(WHAT) (Lim, 2005), PART (Rutledge, 1998), HYSEP (Sloto et al., 1996) and BFLOW (Brodie et al., 2005). These are based on various graphical and numerical theories. The more researches proceed, the more hydrologic and hydraulic unknown variables are showing up, which means that new considerations and hypotheses are required.

The MRC method is based on graphical theory and prevailed for separating baseflow and direct runoff from hydrographs (Nathan et al., 1990, A.T. Rutledge, 1998). This method derives an MRC as the representative recession trend for a whole study period using the matching strip method. The matching strip method has a great advantage to understand the recession trend clearly since it has been derived based on the graphical method. A lot of previous researches using the MRC method (Chapman, 1999, Posavec et al., 2010) extracted multiple recession curves for a whole study period to derive a single MRC (expressed as synthetic MRC below) which is used to separate the baseflow from streamflow hydrograph. However, the MRC derived from whole study period could be inaccurate in the case of streams in South Korea because they have big quantitative differences of rainfalls seasonally that can significantly affect baseflow estimation (Cartwright and Morgenstern, 2015). Most of the previous studies have not considered temporal changes of MRC to estimate baseflow reflecting seasonality.

Thus the objective of this paper is to develop a new approach to separating baseflow from total stream hydrograph reasonably using various MRCs according to seasonality and flow conditions. To achieve this objective, the MRC deriving tool (Posavec et al., 2006) was applied and assessed applicability of MRCs following steps: (1) establishing criteria for MRC (seasonality and flow conditions); (2) deriving MRC with the criteria; (3) comparing the recession coefficient(k) of each MRCs; and (4) analyzing the applicability of the new approach. This research will significantly contribute to managing the streamflow fundamentally as well as calibrating and validating hydrologic models.

2. Material and Methods

2.1 Study area

Around 65% of South Korea's territory consists of the mountainous area (Ministry Consturction & Transportation, 2016). Under the influence of the monsoon climate, most of the precipitation is concentrated in the summer. Only a few stations were selected as study area among 644 stations nationwide considering the location of stations since quantity of streamflow could be easily influenced by hydraulic structures such as dam or reservoir located upstream (Bae et al., 2003). The spatial location of stations, stream networks, hydraulic structures, and streamflow data provided by WAMIS (Water Resources Management Information System) were considered. And nine stations were selected as study area, three gauging stations from three each major watershed, which have continuous five years(2011~2015) streamflow data (Han river basin - Panun, Yeojusi and Seoul station; Nakdong river basin - Macheon, Socheon and Sancheong station; Geum river basin - Guman, Yongchon and Hannaedari station) (Fig. 1).

For analyzing the seasonal proportion of streamflow depending on watershed scale, average 56% of streamflow happened in summer from Han river basin, average 47% from Nakdong and Geum river basins (Table 1). Generally, streamflow of winter season has the least portion and

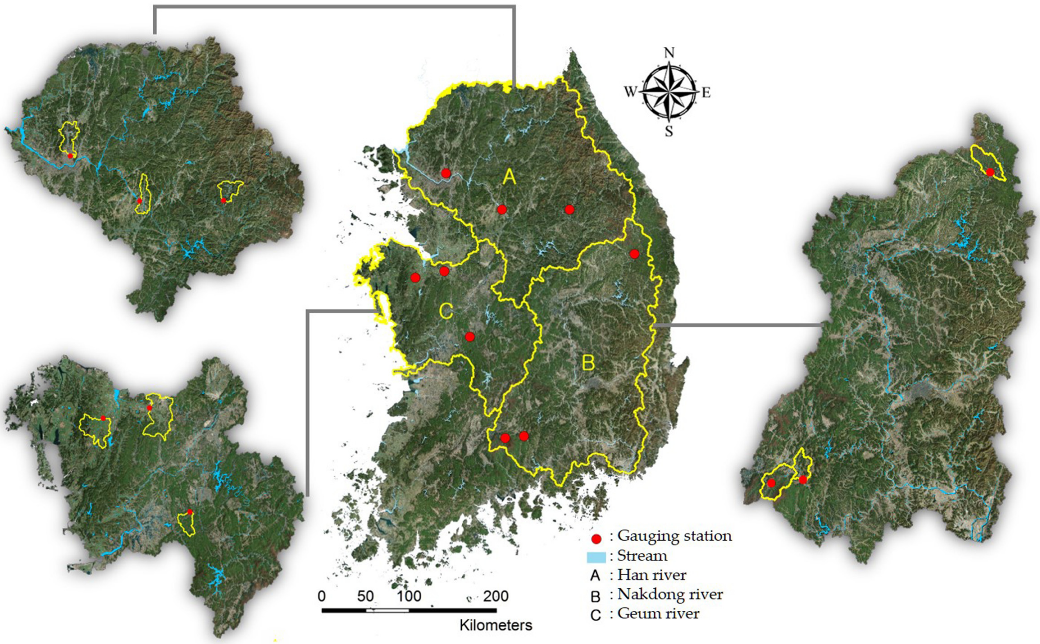


Fig. 1. Study areas: (A) Han river, (B) Nakdong river, (C) Geum river

Table 1. Portion(%) of streamflow for each season of all study area

Basin	Han river				Nakdong river basin				Geum river basin			
	Sp	Su	Au	Wi	Sp	Su	Au	Wi	Sp	Su	Au	Wi
Station	Panun				Socheon				Yongchon			
Portion	15.98	62.33	13.08	8.61	20.10	48.95	20.72	10.24	16.86	55.41	17.41	10.32
Station	Yeojusi				Macheon				Guman			
Portion	16.08	49.43	21.50	12.99	27.55	39.60	16.06	16.80	35.04	36.85	13.03	15.09
Station	Seoul				Sancheong				Hannaedari			
Portion	10.69	63.76	18.75	6.81	17.28	49.94	22.09	10.69	12.22	51.09	23.00	13.70

*Note: Sp for spring, Su for summer, Au for autumn, and Wi for winter.

considering domestic rainfall characteristic that rainfall is concentrated in the summer season. And it can be said that streamflow is reacting sensitively to the rainfall. The daily streamflow data were obtained from the gauging stations running by 'Ministry of Land, Infrastructure and Transport', 'water resources corporation' and 'Korea Hydro & Nuclear Power Co., LTD' from 2011 to 2015.

2.2 Description of Master Recession Curve (MRC)

Master recession curve(MRC) is a theory that helps analyzing recession coefficient 'k' (Eq. (1)) in the basin and can be used for separating hydrograph and groundwater recharge (Rutledge 2007, Sloto et al., 1996).

$$k = \frac{Q_t}{Q_{t-1}} \quad (1)$$

where k is recession coefficient, Q_t is streamflow for the day: t, Q_{t-1} is streamflow for the day: t−1.

k is ranging from 0 to 1 representing that high k value means gradually reducing streamflow and low k value means drastically reducing streamflow. The method of deriving a MRC from streamflow hydrographs for separating baseflow uses matching strip method for practical reasons and procedures are following; (1) array recession curves in order to the size of peak flow horizontally; (2) draw a trend line connecting the minimum values of each recession curve from past streamflow records (Berhail et al., 2012, Kim et al., 1999). From this process, graphically analyzed recession characteristic could be obtained and it is more realistic since embracing observed streamflow data.

The MRC method is a technique that derives a representative recession curve for a certain term and this can be applied to separate baseflow from streamflow hydrograph. Previous researches considered multiple recession curves synthetically to derive a MRC, which means there was no consideration about rainfall or any weather condition. However, when regarding rainfall affects streamflow, the synthetic MRC may not be applicable in watersheds of South Korea where rainfall tends to be concentrated on a certain period. The interseasonal hydrological characteristics involving large differences might not be considered in the synthetic MRC. When comparing the recession coefficient of synthetic MRC for the study period (from 2011 to 2015) to that of the summer season MRC, the difference is significant. For these reasons, separating baseflow with a synthetic MRC for an entire study period could not derive precise results, especially for watersheds showing large flow fluctuations seasonally. To overcome this limitation, multiple MRCs were derived differently for seasons and flow conditions in this study.

2.3 Determination of flow condition and seasonal characteristics

In this study, hydrograph was divide following two characteristics (seasonality and flow conditions) shown in the table 2. And MRCs were derived by adapting the flow regime and seasonality for streamflow data collected from 2011 to 2015 using specialized tool. The MRC tool "Visual Basic Spreadsheet Macro for Recession Curve Analysis", developed based on Microsoft Excel, is a specialized program in deriving MRCs (Posavec et al. 2006). This program lets users input streamflow data and draw MRCs following the matching strip method. This program automatically suggests the best trend among five regression models (Linear, Power, Exponential, Logarithmic, and Polynomial). And the exponential trend (Eq. (2)) was used, which can express the MRC clearly had been

Table 2. Criteria detail for Flow regime and Seasonality

Criteria	#1	#2	#3	#4
Flow regime (Percentile)	High (100~75)	Moist (75~50)	Low (50~25)	Dry (25~0)
seasonality (Monthly)	Spring (3~5)	Summer (6~8)	Autumn (9~11)	Winter (12~2)

utilized in this study and R^2 (coefficient of determination) is referred for assessment. R^2 is an index established in classical regression analysis ranging from 0 to 1. This index is explaining whether this estimation made a useful and acceptable prediction of the dependent variable from the independent variable following Eq.(3) and it is considered that regression analysis is well conducted when value is closer to 1(Nagelkerke, 1991).

$$y = a \times e^{bx} \quad (2)$$

where a and b are constant for each MRCs, x is number of days after peak flow

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(y_i - f_i)^2}{\sum_{i=1}^{n}(y_i - \bar{y})} \quad (3)$$

where y_i means streamflow of regression curves on day: I, $\bar{y}$ means average streamflow of recession curve, and f_i means streamflow of MRC on day: i

3. Results and Discussion

3.1 Flow condition MRC

All of nine study areas showed a very steep MRC for the high flow condition. This flow condition had a small value of recession coefficient commonly for all study areas similar to that of synthetic MRC. However, other (moist, low, and dry) flow conditions had a comparatively big value of recession coefficients as shown in Table 2. Most study areas show big gap between high and moist flow conditions. However gap between moist, low, and dry flow conditions were relatively small. Comparing synthetic MRC and flow condition MRC, flow condition MRC was reflecting recession trends better despite low R^2 value (Table 3), since R^2 is focusing on the distribution of target values. And naturally low R^2 derived

Table 3. Recession coefficients (k) of the flow condition MRCs

Basin	Station	k value				
		Study period	High condition	Moist condition	Low condition	Dry condition
Han river	Panun	0.92	0.83	0.95	0.96	0.97
	Yeojusi	0.81	0.85	0.92	0.94	0.92
	Seoul	0.89	0.76	0.94	0.96	0.97
Nakdong river	Macheon	0.91	0.85	0.91	0.93	0.95
	Socheon	0.90	0.85	0.92	0.95	0.94
	Sancheong	0.86	0.81	0.88	0.88	0.91
Geum river	Guman	0.88	0.67	0.89	0.85	0.91
	Yongchon	0.89	0.82	0.86	0.89	0.91
	Hannaedari	0.88	0.83	0.90	0.96	0.97

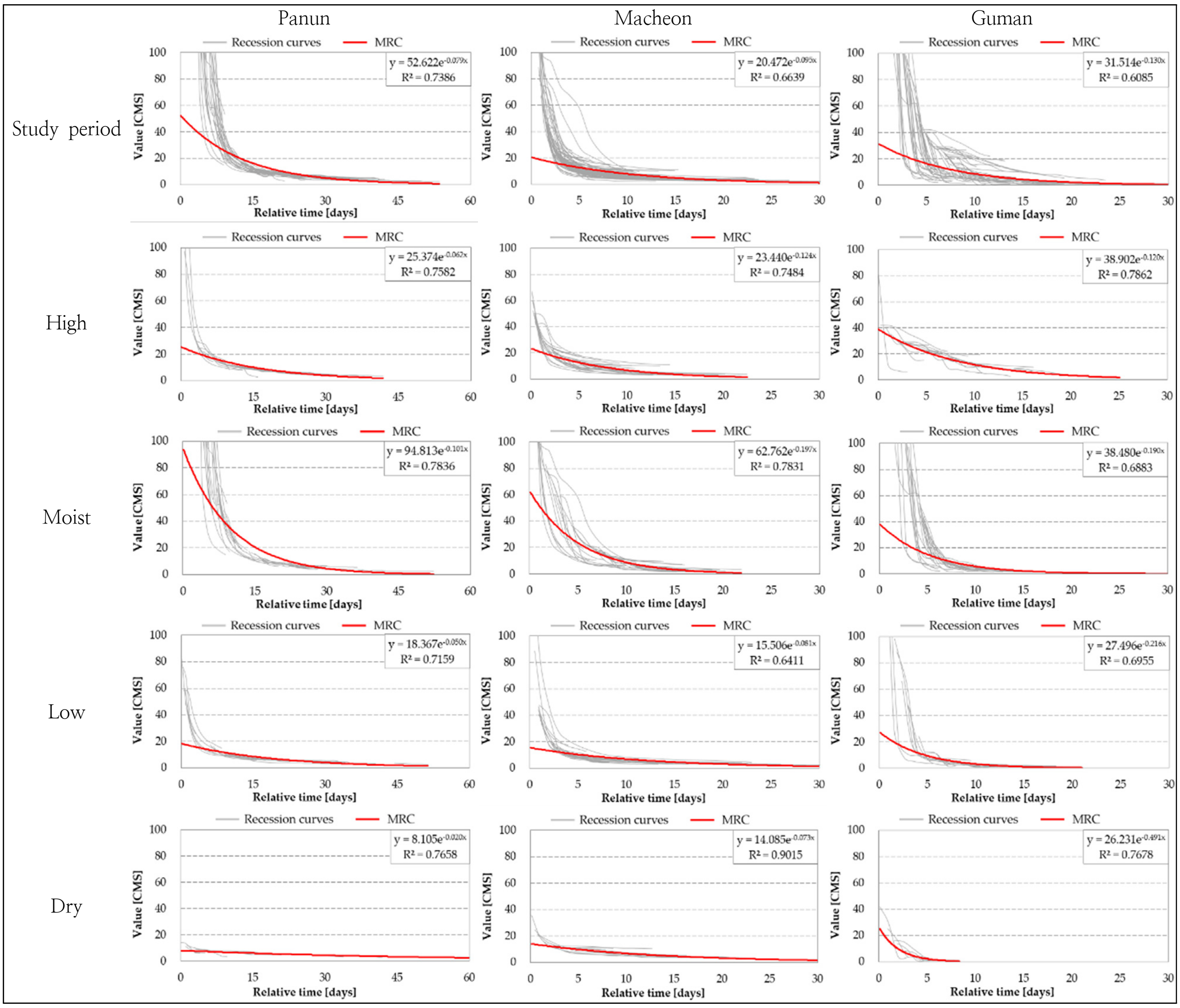


Fig. 2. Flow condition MRCs

from the wide distribution of segments (Nagelkerke 1991). Regarding this, it can be said that flow condition MRCs are graphically well representing each recession trends.

Fig. 2 shows the flow condition MRCs of the Panun, Macheon, Guman station from Han, Nakdong and Geum river basin, respectively. The MRC equations and R2s of all stations from Han, Nakdong, and Geum river basin. Low R2 values below 0.5 are recognizable because R2 is only considering peakflow not trend. For detailed, recession trends of each segment are different and it means that many segments have different recession trends from that of MRC. In addition, it can be inferred that the synthetic MRC could be biased due to the high condition flow for deriving the representative recession trend.

3.2 Seasonal MRC

In general, the extracted recession curves decrease gradually and dramatically during the spring and summer seasons, as shown in the MRCs during the study period. In autumn and winter, the trends showed a difference compared to those during summer. compared the recession coefficients (k) from the MRCs of summer and winter, which had a considerable difference, it showed minimum 0.05 to maximum 0.14. In most of the MRCs for the study areas were steeper in summer than winter (Table 4). Compared the MRCs of summer and winter, it was quite clear that this difference resulted from whether or not considered the precipitation. Thus, deriving the synthetic MRCs during the whole study period results significant uncertainty to configure baseflow from hydrographs.

Fig. 3 shows the seasonal MRCs of Panun, Macheon, Guman station from Han, Nakdong and Geum river basin, respectively. The MRC equations and R^2 of all station from Han, Nakdong, and Geum river basin. The synthetic MRC shows unreliable results considering four seasons' unique characteristics, but the four seasonal MRCs from each station show MRCs and

Table 4. MRC equations and R^2 of each station for four flow conditions of each gauging stations

Basin	Flow condition	Station name	MRC equation	R^2	Station name	MRC equation	R^2	Station name	MRC equation	R^2
Han river	Study period	Panun	$y = 52.622e^{0.079x}$	0.739	Yeojusi	$y = 2930.600e^{-0.205x}$	0.805	Seoul	$y = 22.368e^{-0.113x}$	0.638
	High		$y = 206.730e^{-0.190x}$	0.758		$y = 2407.100e^{-0.167x}$	0.642		$y = 186.650e^{-0.279x}$	0.763
	Moist		$y = 12.102e^{-0.050x}$	0.784		$y = 252.700e^{-0.086x}$	0.502		$y = 5.298e^{-0.061x}$	0.300
	Low		$y = 8.587e^{0.038x}$	0.716		$y = 154.640e^{-0.059x}$	0.470		$y = 3.882e^{-0.040x}$	0.425
	Dry		$y = 6.505e^{0.031x}$	0.766		$y = 146.080e^{-0.082x}$	0.895		$y = 2.771e^{-0.035x}$	0.802
Nakdong river	Study period	Macheon	$y = 20.472e^{-0.095x}$	0.664	Socheon	$y = 37.097e^{-0.101x}$	0.744	Sancheong	$y = 68.234e^{-0.149x}$	0.747
	High		$y = 38.334e^{-0.164x}$	0.635		$y = 68.504e^{-0.160x}$	0.662		$y = 128.710e^{-0.210x}$	0.686
	Moist		$y = 14.054e^{-0.901x}$	0.514		$y = 15.408e^{-0.087x}$	0.523		$y = 27.805e^{-0.132x}$	0.530
	Low		$y = 8.350e^{-0.070x}$	0.470		$y = 8.918e^{-0.049x}$	0.390		$y = 15.508e^{-0.129x}$	0.462
	Dry		$y = 5.101e^{-0.048x}$	0.880		$y = 6.265e^{-0.062x}$	0.721		$y = 7.145e^{-0.094x}$	0.430
Geum river	Study period	Guman	$y = 31.514e^{-0.130x}$	0.609	Yongchon	$y = 7.444e^{-0.117x}$	0.655	Hannaedari	$y = 20.372e^{-0.124x}$	0.623
	High		$y = 151.130e^{-0.403x}$	0.541		$y = 20.454e^{-0.201x}$	0.575		$y = 35.512e^{-0.184x}$	0.551
	Moist		$y = 22.246e^{-0.113x}$	0.301		$y = 3.930e^{-0.153x}$	0.522		$y = 8.955e^{-0.103x}$	0.463
	Low		$y = 7.234e^{-0.167x}$	0.509		$y = 2.351e^{-0.111x}$	0.413		$y = 5.429e^{-0.038x}$	0.218
	Dry		$y = 2.635e^{-0.093x}$	0.687		$y = 1.090e^{-0.089x}$	0.758		$y = 3.829e^{-0.032x}$	0.708

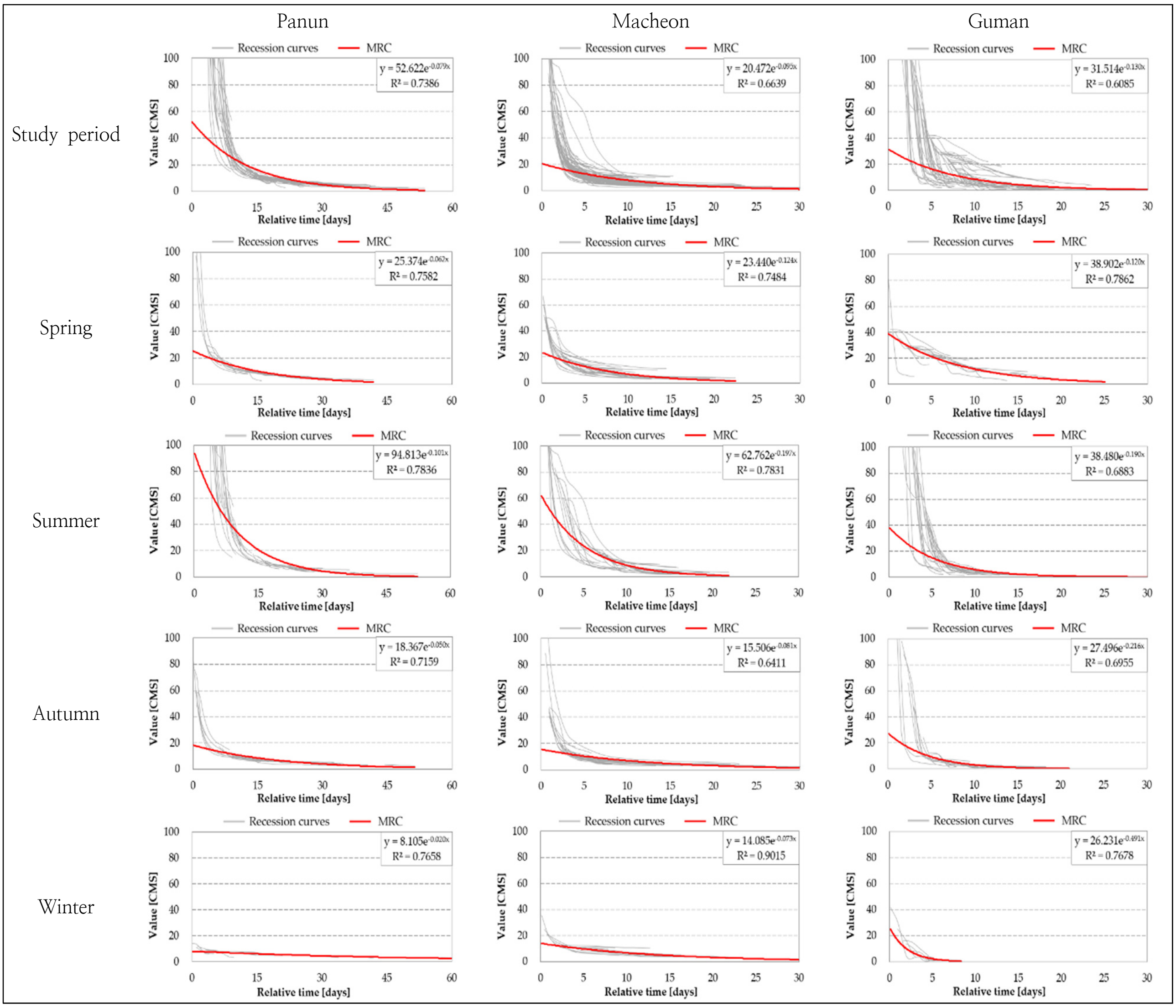


Fig. 3. Seasonal MRC

Table 5. Recession coefficients (k) of seasonal MRCs

Basin	Station	k value				
		Study period	Spring	Summer	Autumn	Winter
Han river	Panun	0.92	0.94	0.90	0.95	0.98
	Yeojusi	0.81	0.92	0.79	0.92	0.93
	Seoul	0.89	0.91	0.84	0.92	0.96
Nakdong river	Macheon	0.91	0.88	0.82	0.92	0.93
	Socheon	0.90	0.93	0.87	0.93	0.91
	Sancheong	0.86	0.84	0.75	0.89	0.89
Geum river	Guman	0.88	0.89	0.83	0.81	0.61
	Yongchon	0.89	0.82	0.76	0.85	0.87
	Hannaedari	0.88	0.93	0.84	0.89	0.93

Table 6. MRC equations and R^2 of each station for four seasons of each gauging stations

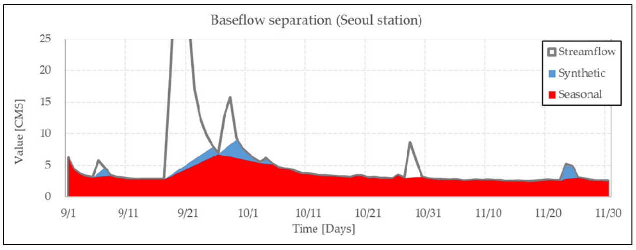
Basin	Season	Station name	MRC equation	R^2	Station name	MRC equation	R^2	Station name	MRC equation	R^2
Han river	Study period	Panun	$y = 52.622e^{0.079x}$	0.739	Yeojusi	$y = 2930.600e^{-0.205x}$	0.805	Seoul	$y = 22.368e^{-0.113x}$	0.638
	Spring		$y = 25.374e^{-0.062x}$	0.772		$y = 653.650e^{-0.084x}$	0.911		$y = 6.291e^{-0.091x}$	0.628
	Summer		$y = 94.813e^{-0.101x}$	0.575		$y = 3979.100e^{-0.230x}$	0.838		$y = 57.095e^{-0.177x}$	0.697
	Autumn		$y = 18.367e^{0.050x}$	0.691		$y = 318.400e^{-0.088x}$	0.891		$y = 8.194e^{-0.087x}$	0.509
	Winter		$y = 8.105e^{0.020x}$	0.870		$y = 247.770e^{-0.071x}$	0.930		$y = 4.460e^{-0.040x}$	0.685
Nakdong river	Study period	Macheon	$y = 20.472e^{-0.095x}$	0.664	Socheon	$y = 37.097e^{-0.101x}$	0.744	Sancheong	$y = 68.234e^{-0.149x}$	0.747
	Spring		$y = 23.440e^{-0.124x}$	0.748		$y = 25.477e^{-0.070x}$	0.756		$y = 61.062e^{-0.170x}$	0.816
	Summer		$y = 62.762e^{-0.197x}$	0.783		$y = 59.772e^{-0.145x}$	0.754		$y = 261.450e^{-0.282x}$	0.898
	Autumn		$y = 15.506e^{-0.081x}$	0.641		$y = 21.974e^{-0.069x}$	0.669		$y = 53.646e^{-0.121x}$	0.709
	Winter		$y = 14.085e^{-0.073x}$	0.902		$y = 28.566e^{-0.092x}$	0.883		$y = 50.715e^{-0.112x}$	0.832
Geum river	Study period	Guman	$y = 31.514e^{-0.130x}$	0.609	Yongchon	$y = 7.444e^{-0.117x}$	0.655	Hannaedari	$y = 20.372e^{-0.124x}$	0.623
	Spring		$y = 38.902e^{-0.120x}$	0.786		$y = 16.664e^{-0.197x}$	0.839		$y = 8.906e^{-0.068x}$	0.522
	Summer		$y = 38.480e^{-0.190x}$	0.688		$y = 41.189e^{-0.274x}$	0.861		$y = 37.662e^{-0.174x}$	0.654
	Autumn		$y = 27.496e^{-0.216x}$	0.696		$y = 12.790e^{-0.160x}$	0.754		$y = 16.940e^{-0.116x}$	0.597
	Winter		$y = 26.231e^{-0.491x}$	0.768		$y = 11.346e^{-0.143x}$	0.792		$y = 11.669e^{-0.076x}$	0.837

recession trends reflecting seasonal characteristics of stations. Compared all station's synthetic MRCs and seasonal MRCs show different results (Table 5). Considering rainfall characteristics of South Korea, summer season MRCs from all station show steep recession trend and other seasons show gradually descending recession trend. Thus, the seasonal characteristics need to be considered to separate baseflow accurately.

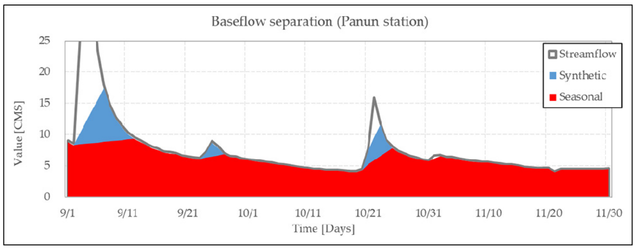
3.3 BFI calculation results

In the case of seasonality criteria, the MRCs were acceptable as representative adequate for the baseflow separation. On the other hand, in the case of flow condition criteria, those show representative recession trend per flow conditions. However, R^2 of MRCs were below 0.5 due to disregard of recession trend of segments and similar design to segments. Thus, separated baseflow from hydrographs only using the seasonal MRCs which has high R^2 values. Baseflow separated using the synthetic MRC occupied most of the whole streamflow except high streamflow due to extreme rainfall. On the other hand, the baseflow separation using seasonal MRCs estimated the bigger portion of direct runoff for high flow condition and bigger portion of baseflow for low flow condition. Figure 4 shows the comparison between the baseflow separation using synthetic MRCs and seasonal MRCs for the Seoul, Panun and Sancheong station representatively. For the Seoul station, the baseflow separated using the synthetic MRC tended to be overestimated during from 9/21 to 10/1, from 9/21 to 10/1 for Panun station and from 10/31 to 11/10 for Sancheong station.

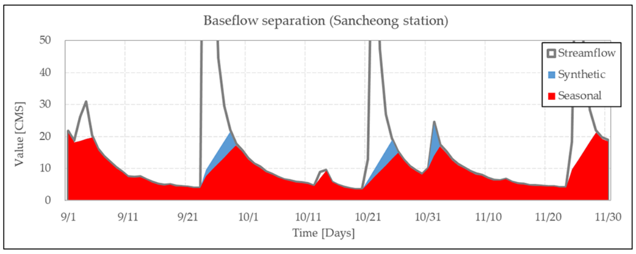
A flowage of baseflow happens underground and it takes a long time for baseflow to inflow into streamflow compared to direct runoff. Baseflow flows slowly passing through soil particles, which has a high fraction in streamflow (Willems 2009). Considering this, the immediate reaction of baseflow to change of streamflow is unnatural as it can be seen in the separation graphs using the synthetic MRC. The separations using seasonal MRCs considering the characteristics of baseflow mentioned above well.



(a)



(b)



(c)

Fig. 4. Baseflow separation of (a)Seoul, (b)Panun, and (c)Sancheong station using seasonal MRC (Autumn) and synthetic MRC

4. Conclusion

This study attempt to decrease the uncertainty of baseflow separation from the use of MRC containing whole recession curves of the study period. It was able to reflect rainfall characteristic by making MRC criteria considering seasonality and flow condition. The derived MRCs were used for separating baseflow, which reflects seasonal characteristics and variability.

As the results, the seasonal MRCs were helpful for conducting detailed separation of the baseflow reflecting seasonal rainfall trends which affect considerably to streamflow at most areas. Throughout the study period, some parts separated as direct runoff when using synthetic MRC was baseflow when it comes to using the seasonal MRC. This means seasonal MRC, considering conditions (e.g. concentrated rainfall in particular seasons), is more effective for baseflow separation. And synthetic MRC method is available only for areas do not have huge precipitation variability and have certain geographical features. As the improvement for baseflow separation using MRC, this study suggests MRCs separated according to the seasons. Seasonal MRC will be more helpful as a reference for separating baseflow than synthetic MRC and also for preparing measurements of drought on low and dry condition flow periods.

In addition, MRC draws representative recession trend from multiple recession curves of the study period, and this means that securing streamflow and precipitation etc. data as much as possible is important. And those with several flow regime MRCs with R^2 value below 0.5 will needs a follow-up study for calibration with more streamflow data so more reliable result could be derived.

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