RAINFALL AND RUNOFF VARIATION ANALYSIS FOR WATER RESOURCES MANAGEMENT STRATEGIES

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Abstract: For the long-term strategic water resources planning, forecasting the future streamflow change is important to meet the demand of a growing society. The streamflow variation to the decade-long precipitation was investigated for the two major stage gauging stations in Korea.

Precipitation and runoff characteristics have been analyzed at Yongwol stream stage in the Han River as well as Sutong stream stage in the Kum River for the future water resources management strategies.

Monte Carlo method has been applied to estimate the future precipitation and runoff. Based on the trend line of 10-year moving average of runoff depth for the historical runoff records, the relation between runoff and the time variation was examined in more detail using regression analysis.

This study showed that the surface flows have been significantly decreased while precipitation has been stable in these basins. Decreasing in runoff reflects the regional watershed characteristics such as forest cover changes. The findings of this study could contribute to the planning and development for the efficient water resources utilization.

Keywords: precipitation, runoff depth, Monte Carlo method, runoff change

1. INTRODUCTION

Water is critical to the sustainable economic and social development and this is the common phenomenon throughout the world. It is accepted that the water resources are limited and are currently placing major constraints on a number of developmental proposals.

Gregory(1907) tried to find the relationship between the rainfall and runoff using the rational formula and other empirical formula and also Grunsky(1922) attempt to estimate the rainfall-runoff relationship using the climate characteristics and watershed characteristics. Eagleson(1970) used the linear model using the differential equations to analyze the rainfall-runoff relation and recently other researches which are related to rainfall-runoff relationship are focused on linear or non linear system analysis.

If the long term precipitation-runoff trend in specific region can be estimated, it can afford very effective and precious information in water resources planning and management practice. In this study, two major river basins in South Korea have been selected to evaluate the long term precipitation-runoff relationship for each basin. Based on the evaluated results from the historical precipitation-runoff record, future expected runoff trends are forecasted by regression analysis and random generation procedure.

2. THE STUDY WATERSHEDS

Two watersheds have been selected for this study, Yongwol watershed's basin area is 2,439 km^2 and located in upper reach of Han river basin. The second study area Sutong watershed's basin area is 1,563 km^2 and located also in upper reach of Kum river basin. Based on the general concepts that the runoff from the watersheds located in upstream region are sensitively affected by rainfall, both selected watersheds located in upstream region of each river basin.

3. DATA COLLECTTION AND CALIBRATION

The data were collected for each watershed included precipitation data and stream flow data. Precipitation data for each watersheds were obtained from raingage station which are operated by Korean Ministry of Construction & Transportation(MOCT) and Korean Meteorological Administration(KMA). Finally 13 raingage stations were selected for this study, 6 stations for Yongwol(Hwangji, Imgye, Daekwan-ryoung, Daehwa, Yeongchun, Jeongseon) and 7 stations for Sutong(Muju, Daebul, Jinan, Anseong, Jangsu, Seosang, Buhang). Also stream flow data at outlets of each watershed were obtained from MOCT in the form of daily stream flow.

In this study, yearly runoff is calculated using the daily average water level and rating curves for each stream gage stations which is located at the outlets of each watershed. Table 1 and Table 2 shows the rating curves used in this study to estimate the stream flow from water level.

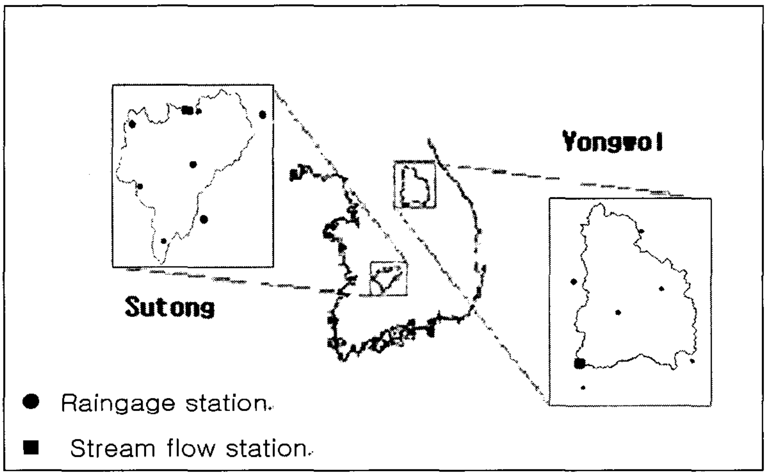

Figure 1. Location of study watersheds

Table 1. Rating curves at Yongwol

Water level range H(h):m	Rating Curve Q: m^3/sec H(h):m	References
$H=h+1$	$Q=20.8H^{2.94}$	Korea Hydrologic data survey 64
$h\geq0.70$ $h<0.70$	$Q=97.616(h+0.379)^2$ $Q=9.65+50.29h+128.09h^2$	Stream flow survey 82
$H=h+1$	$Q=21.274H^{2.797}$	Stream flow survey 83
$0.7<H<4.5$ $(H=h+1)$	$Q=35.36(H-0.235)^{2.38}$ $Q=35.36(H+0.37)^{2.38}$	Han river basin survey 90
$0.2<H<3.1$	$Q=76.88(H+0.261)^{2.0}$	Han river basin survey 90
$0.65<H<5.82$ $1.08<H<2.81$ $1.15<H<6.20$ $(H=h+1)$	$Q=38.396(H-0.235)^{2.31089}$ $Q=3.080H^{4.25628}$ $Q=10.556(H+0.261)^{3.16899}$	Water resources survey in Han river 96
$0.65<H<5.82$ $1.08<H<2.81$ $1.15<H<6.20$ $(H=h+1)$	$Q=38.396(H-0.235)^{2.31089}$ $Q=3.0796H^{4.25628}$ $Q=76.880(H+0.261)^{2.000}$	Dam operation study in Han river 97

Table 2. Rating curves at Sutong

Range of water level H(h) : m	Rating curves Q: m^3/sec H(h):m	References
	$Q=19.68-98.35h+122.89h^2$	HA64
$0.4<H<1.123$ $1.23<H<5.19$ $H=h+1$	$Q=0.243-6.3H+40.78H^2$ $Q=59.47-185.39H+144.48H^2$	HA65
	$Q=130.501(h+0.485)^2$	NG74
	$Q=88.26(h-0.155)^2$	F82
	$Q=125.530(h-0.283)^2$	F83
$1.0\leq h\leq6.0$ $0.4\leq h<1.0$	$Q=89.29(h-0.2888)^2$ $Q=44.06h^{2.308}$	WHA94
$1.0\leq h<4.88$ $0.6<h<1.0$	$Q=98.99(h-0.9187)^2$ $Q=64.88(h-0.493)^2$	WHA95
$1.33\leq h\leq4.88$ $0.60\leq h\leq1.29$	$Q=12.50h^{3.142}$ $Q=11.40h^{3.465}$	WHA96
$h\geq0.94$ $h<0.94$	$Q=4.23151(h+0.35)^{3.7454}$ $Q=0.50935(h+0.70)^{6.2111}$	WHA97
	$Q=5.54503(H+0.300)^{3.686}$	WHA98
	$Q=11.489(H+0.085)^{3.277}$	DAR99

Table 3. Runoff rate(% of rainfall)

Year	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84
Yongwol	Excluded										95	89	70	98	95
Sutong	87	40	93	93	86	86	36	39	79	86	33	71	56	71	72
Year	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99
Yongwol	86	75	84	91	98	91	82	67	61	66	62	67	81	67	66
Sutong	42	66	40	44	54	51	31	58	59	54	36	34	36	40	27

Based on the collected historical rainfall data, annual basin average precipitations of each watershed were calculated by Thiessen Method and annual runoff depth of each watersheds were obtained from the stream flow data divided by watershed area. Table 3 shows the Calculated runoff rate(%) for each watershed.

4. STOCHASTIC GENERATION OF RAINFALL AND STREAM FLOW DATA

The persistence of hydrologic data is examined for the purpose of understanding the characteristics of annual streamflow and rainfall data. Figure 2 and Figure 3 shows the correlogram for each watershed, which also indicate that the annual streamflow and rainfall of Yongwol and Sutong watershed has its stationarity and randomness.

Annual streamflow and rainfall data were generated by using Monte Carlo simulation model. Annual streamflow and rainfall of 20 years were generated by random number generator then the basic statistics such as mean, standard deviation, skewness and correlation coefficient etc between the historical and generated streamflows are computed and compared. The results are shown in Table 4.

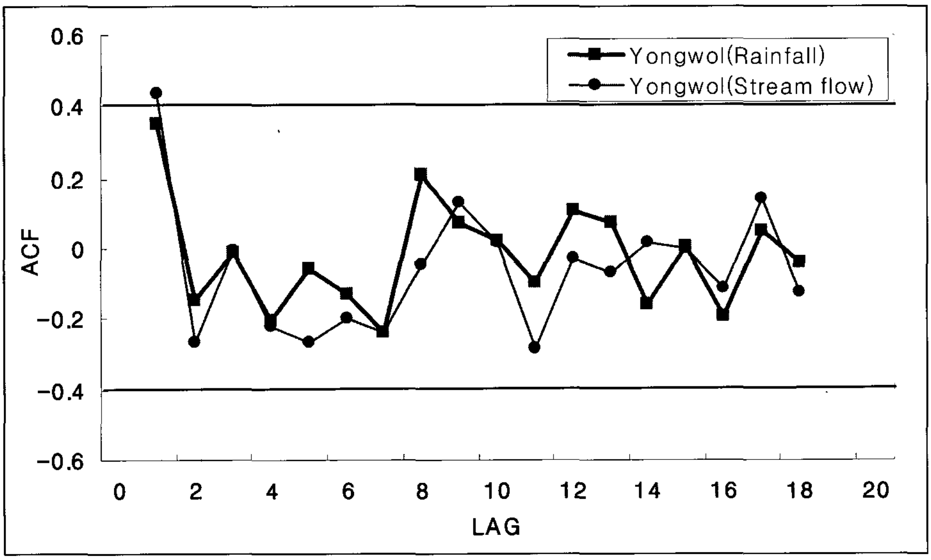

Figure 2. Correlogram (Yongwol)

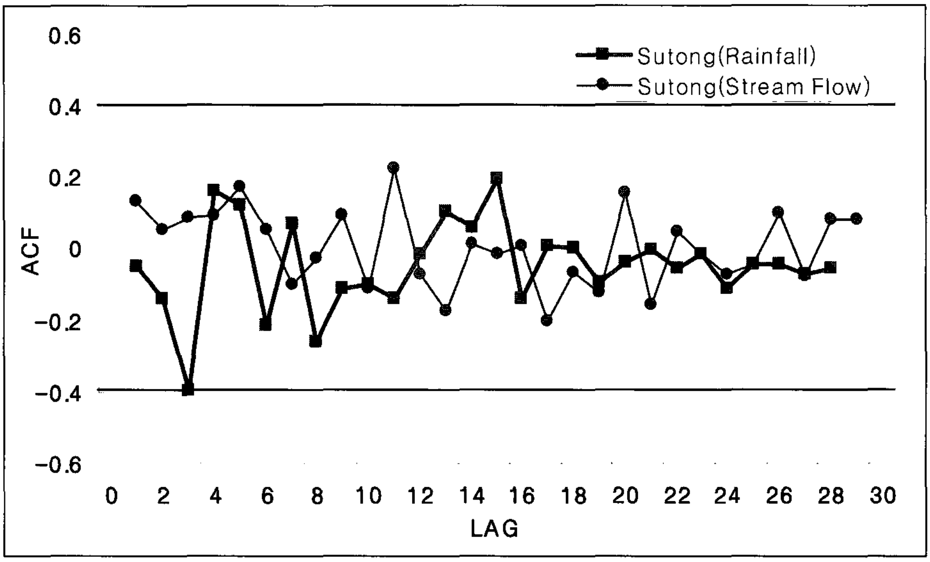

Figure 3. Correlogram (Sutong)

Table 4. The basic statistics of historical and synthetic annual data

Statistics			Mean (mm)	Standard Deviation(mm)	Skewness
Yongwol	Rainfall Depth	Historical	1150.5	227.2	0.5569
		Synthetic	1145.6	238.3	0.2699
	Runoff Depth	Historical	883.3	255.5	1.0301
		Synthetic	896.3	259.5	0.2164
Sutong	Rainfall Depth	Historical	1203.0	260.7	-0.2209
		Synthetic	1254.9	255.2	0.8785
	Runoff Depth	Historical	518.7	168.9	0.5068
		Synthetic	552.4	165.4	0.8785

5. RAINFALL AND RUNOFF VARIATION ANALYSIS

To evaluate the trends of historical data, 10 year moving average technique with regression analysis is applied to historical data as shown in Figure 4 and Figure 5.

From Figure 4 and Figure 5, it is apparent that the application results of 10 year moving average for precipitation data shows constant against the time variation for both Yongwol and Sutong watersheds. But the application results for run-

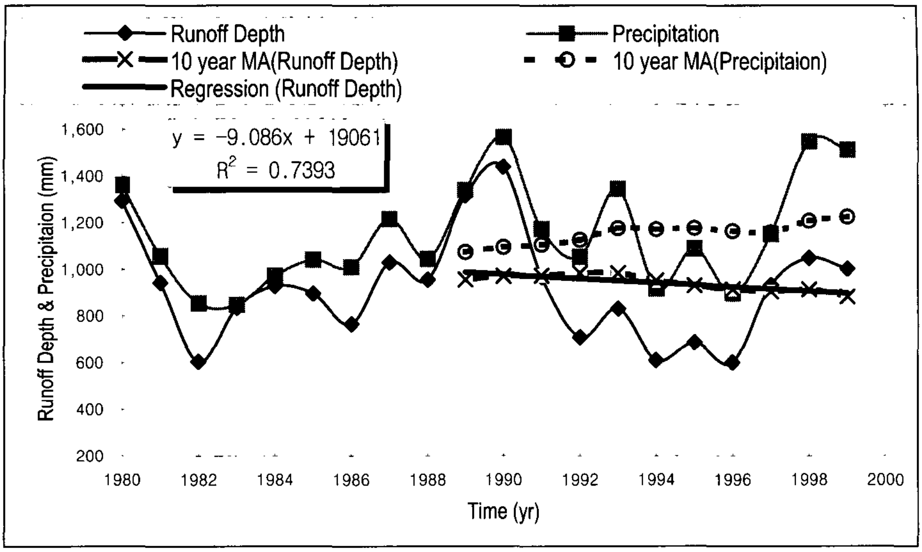

Figure 4. 10 year moving average and regression analysis (Yongwol)

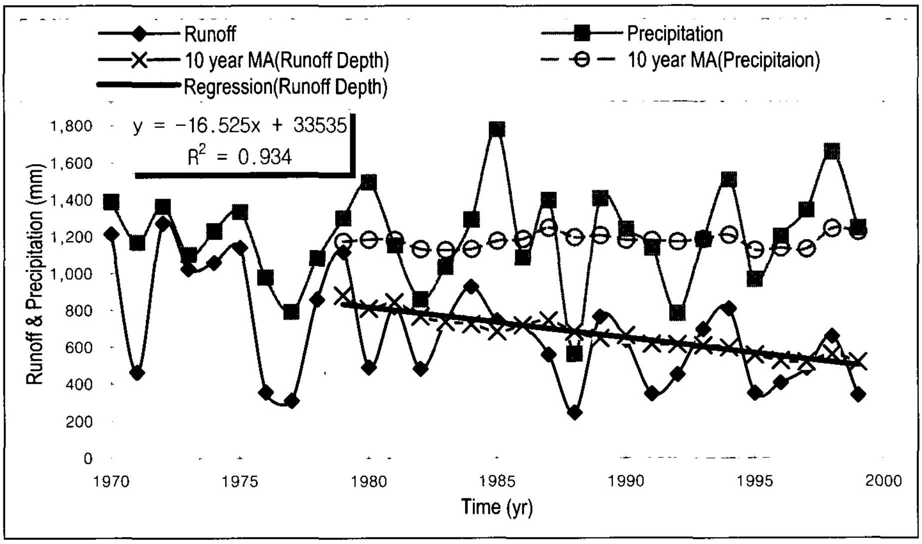

Figure 5. 10 year moving average and regression analysis (Sutong)

off data shows decreasing trends against time for both Yongwol and Sutong watersheds.

Further steps were needed to obtain the specific reasons of decreasing trends of runoff data. So the generated runoff data using Monte Carlo simulation model were examined by applying same techniques which were applied to historical data.

Both Figure 6 and Figure 7 show the change of trends for 10 year moving average between the historical and generated runoff data. It is apparent that the trends of historical runoff data were decreasing, while the trends of generated runoff data keep constant against time. So we can easily observe the decreasing trends are

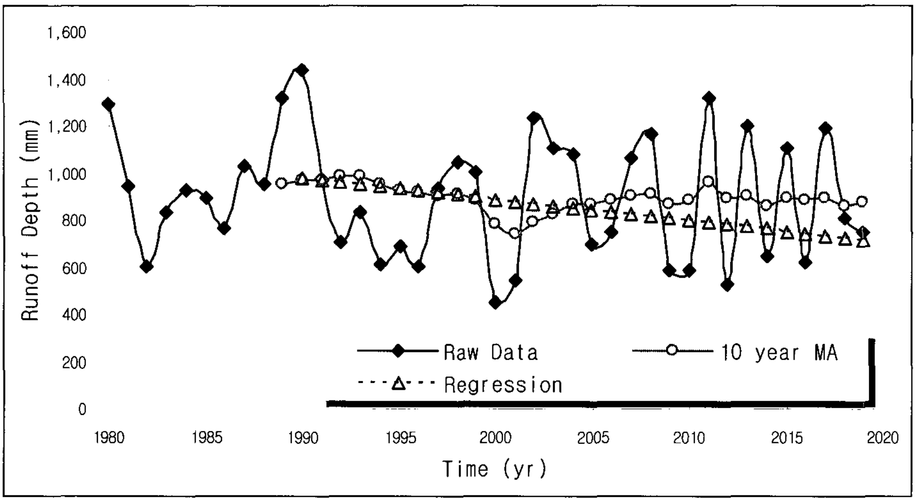

Figure 6. Moving average and regression analysis for runoff data (Yongwol)

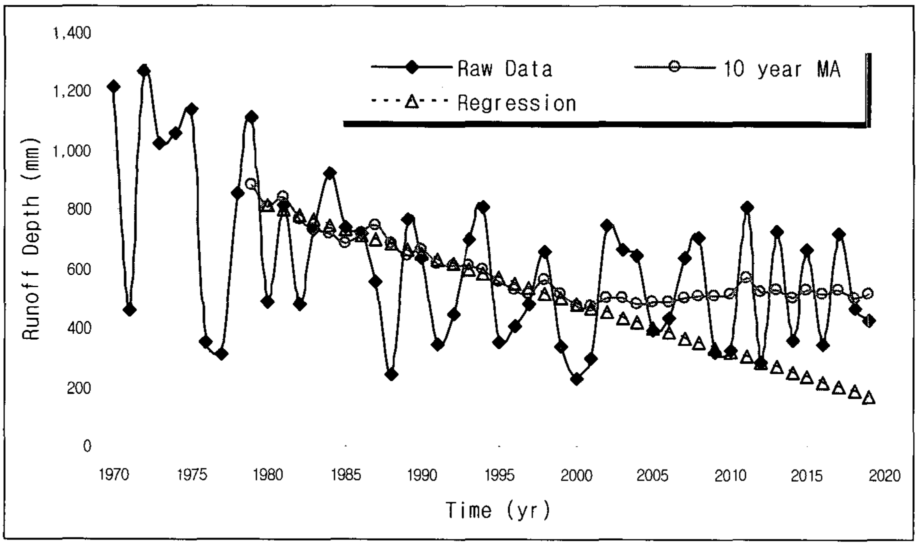

Figure 7. Moving average and regression analysis for runoff data (Sutong)

converted to constant at 2001 which is the starting year of generated data.

The statistical parameters of generated data reflect well the statistical parameters of historical data. On the contrary, the generated data were unable to reflect the decreasing trend of historical runoff data because the random generation technique was used in this study. Accordingly, forecast of future runoff by regression analysis and random generation technique might result in great differences as shown in Figure 6 and Figure 7.

6. REASONS OF DECREASING RUNOFF RATE

Generally there are plenty of reasons which can affect the change of runoff rate. For this analysis, 10 year moving average of annual precipitation for each watershed was constant against time variation. So we can assume that the change of runoff rate might be resulted from change of land use and land cover classes over the forest region in watershed.

In Korea, usually 65% of total precipitation reaches at forest region and 45% of forest region precipitation was lost by evaporation from the earth surface or evapotranspiration from the vegetation (Jeong, 1999). Basically the major precipitation losses caused by forest vegetation are Canopy Interception Loss and Evapotranspiration.

As a different approach to verify the relationship between the land cover and runoff rate, the forest land area and forest growing stock of each watershed were investigated using the historical data of Korea National Statistical Office (KNSO).

Figure 8 illustrate the forest growing stock change of each watershed from 1972 to 2000 and Figure 9 show the change of forest are of both watershed. From Figure 8 it is apparent that forest growing stock for both watersheds is increasing constantly. For Yongwol watershed, forest growing stock of 2000 is 275 % greater than that of 1972 and also forest growing stock of 2000 at Sutong watershed increased 561% than that of 1972.

On the contrary, Figure 9 shows that forest area of 2000 at Yongwol watershed is 1.016 times greater than that of 1972 and forest area of 2000 at Sutong watershed is 0.96 times greater than that of 1972. As a result, Figure 9 shows that the forest area for both watersheds is quite constant during past few decades.

Because of these forest growing stock changes, we can easily assume that the amount of evapotranspiration of each watershed also increased very much and these phenomena can cause the decrease of runoff rate in watershed.

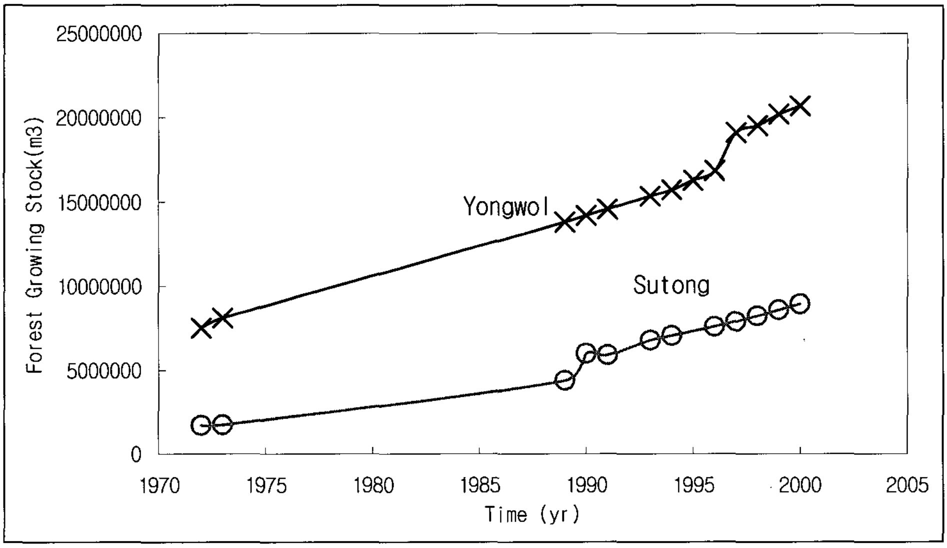

Figure 8. Forest growing stock change

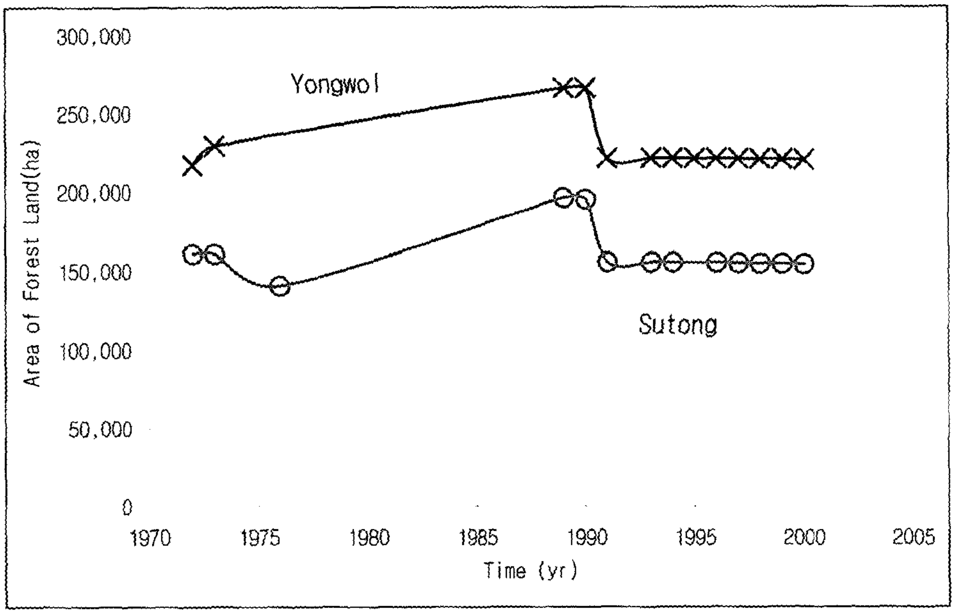

Figure 9. Change of area of forest

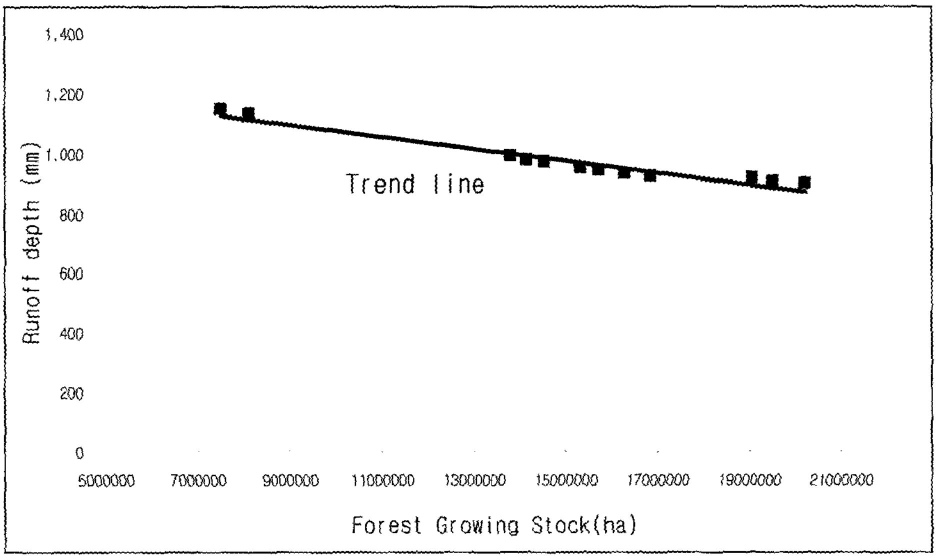

Figure 10. Runoff depth-forest growing stock relation of Yongwol

Finally, Figure 10 and Figure 11 illustrate the relationship between the forest growing stock and runoff depth using the historical data. Both graph show that the runoff depth of watershed is constantly decreasing as forest growing stock is increasing while the annual precipitation is constant condition.

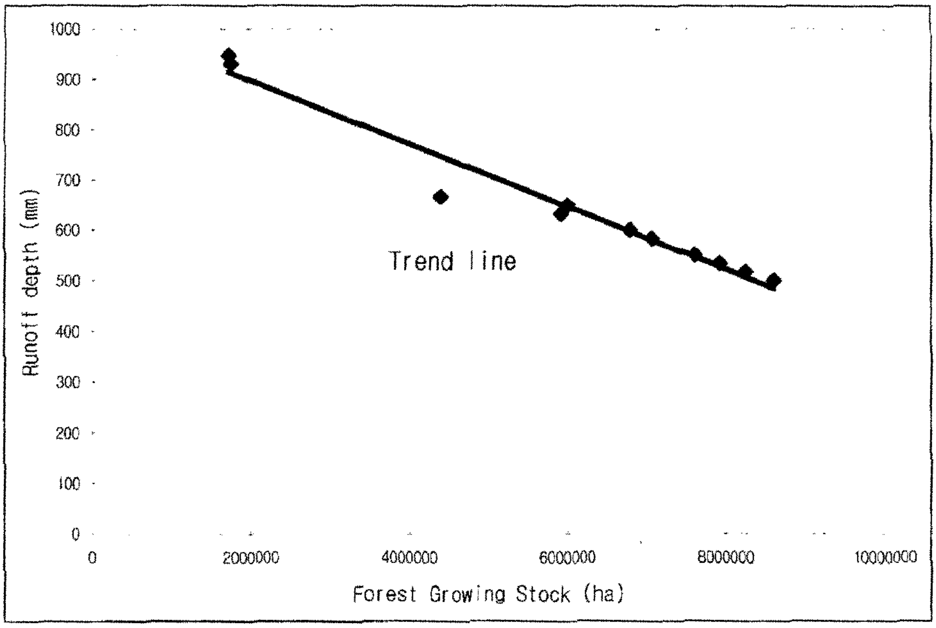

Figure 11. Runoff depth-forest growing stock relation of Sutong

7. SUMMARY AND CONCLUSION

Long term rainfall-runoff variation analysis has been implemented for two major river basins in Korea. As a result of these analyses, we can reach the conclusions that the runoff rate is constantly decreasing ever since after 1970 while annual precipitation has been kept constant.

Because of dominant land cover class of studied watersheds is forest, the forest growing stock change has been examined by historical data and finally runoff depth-forest growing stock change relationship was provided.

The research documented in this paper has clearly shown that increasing forest growing stock contribute the increasing evapotranspiration of vegetation in watershed and also we can conclude that this process is direct reason of decreasing runoff rate under the constant annual precipitation condition.

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