Statistical Tests of the Flow Change after Dam Construction

Lee, Gwang Man[1] *Lee, Seung Yoon*[2] *Lee, Yo Sang*[3]

KIWE, Kwater, 462-1 Jeonmin-dong, Yuseung-gu, Daejeon, 305-730, Korea

1, E-mail: lkm@kwater.or.kr

2, E-mail: leesy@ kwater.or.kr

3, E-mail: yslee@kwater.or.kr

Abstract: An understanding of temporal trends of stream flows can help in the river management and the water resources planning for natural circumstances and human communities. Changes in temperature, precipitation, flow, and land use (agriculture, flood prevention activities, reservoir operation, interbasin diversion, etc.) are all eventually reflected in the flow pattern of the river. An assumption that the stationarity of the hydrologic series implying time-invariant characteristics of the time series accepted in water structure designs can no longer be valid if the flow changes as a result of the climate change or the stream flow use. Therefore, the identification and description of the characteristics of changes in hydrologic time series is a very important task in the river basin management. In this study, the statistical tests on the flow change forced by excess water diversions in the Sumjin River basin were performed by means of single variable and time series variable comparisons. The tests showed that currently the Sumjin River basin statistically keeps its homogeneity in annual streamflow series, but that the changed situation has appeared in dry season streamflow series.

keywords : statistical test, time series, flow change, water diversion

1. Introduction

Generally, historical hydrologic data are very important for planning and designing water resources projects. The design of most water structure projects assumes hydrologic characteristics as a time-invariant variable. However, this assumption is no longer valid because of numerous natural and artificial factors such as hydrologic changes associated with global warming and a reduction in the number of rivers due to water diversion outside the basin. These factors may lead to an occurrence of serious problems. Flood events, which have been long regarded by hydrologists as an invariable, independent and random phenomenon, are now changing their trends with significant evidences (Lins and Slack, 1999; Jain and Lall, 2000).

Regarding streamflow changes, diverse tests of special climate phenomena such as global warming and Elino have been conducted with the focus on determining hydrologic characteristics with the assumption of climate changes. For instance, Zhu and Day(2005), through the Mann-Kendall test, surveyed the flow change in 47 rivers that run through Pennsylvania. Also, for a nonparametric test method for flow changes, Kahya and Kalayci(2004) conducted Sen's T, Spearman's Rho, Mann-Kendall and Seasonal Kendall targeted at 26 basins in Turkey. As a similar method, Novotny and Stefan(2006) researched into climate change indicators targeted at five large rivers in Minnesota, using the basic statistical analysis and nonparametric test methods.

Korea has not yet been showing distinctive evidences on hydrologic changes, but torrential rain, a shortened period of precipitation, and a short spring and autumn are presumed to be attributable to global warming. Korea's research into hydrologic changes have mostly focused on the analysis of the impact associated with climate changes and hydrologic facilities. Kim Tae-gyu, et al. (2002) analyzed flow situation changes targeted at the Geum River basin in connection with the construction of Daecheong Dam, as well as determined the effects of the water usage and management through the analysis of an excess of the annual series. Kim Tae-ung, et al. (2004) analyzed the impact of climate changes on the water circulation in a basin, targeting the Daecheong Dam basin. An Jae-hyeon, et al. (2001) also researched into hydrologic changes associated with global warming, targeting the Daecheong Dam basin.

However, in nations like Korea with a high rate in river usage, more artificial changes than natural changes could cause streamflow changes, but in this regard there has not been much research conducted. In particular, the construction of large-scale water resources-related facilities in a river may have a great impact on changes in flow situations, and on natural situations before and after the construction. Generally, from a viewpoint of hydrologic statistics, a long-time hydrologic series does not cause a great change, while short-time large-scale artificial acts such as water diversion outside the basin may cause a greater change, probably leading to disputes over rights to use waterr. A sharp increase or reduction in streamflow will change the fish ecosystem, which may have direct or indirect impact on natural ecosystems and the human communities. Letcher, et al.(2001) analyzed social and economic impacts associated with a change in streamflow in connection with the use of land and agricultural dams.

Therefore, an accurate assessment of flow changes will be very useful for the use of river water, the conservation of river ecosystems and the management of rivers. A lowering of riverbed level and intrusion of salt water that are recently occurring at the downstream of Sumjin River are presumably attributable to the taking of aggregates from the area, the dredging in Gwangyang Bay, and other direct causes to the river, as well as to reduced flow associated with water diversion outside the basin. According to the three-stage environmental impact assessment report for Gwangyang (Kwater, 2004), in the case of the Sumjin River basin, a massive water diversion from the Bosung River Dam and the Sumjin River Dam outside the basin had long occurred, and the construction of Juam Dam in the early 1990s has caused flow changes. This paper examines flow changes using statistical methods in an effort to determine a reduced flow which in turn increases salt concentration and lowers the riverbed level as occurring at the downstream of Sumjin River. The test uses analysis methods such as single variables, group variables, and time-series comparison methods. The paper conducts parametric test and nonparametric test. Flow changes are compared before and after the construction of Juam Dam which is deemed to have reduced the flow.

2. Testing Methods for the Flow Variation

Historical hydrologic data could not be explained properly with physical laws, and the difficulty of explaining or forecasting hydrological variables is attributable mainly to the following reasons: inherent randomness of dominant variables such as precipitation; randomness of the hydrologic system involving topographical, underground water and soil state; errors of observed data such as observation errors in flow and other elements, and errors due to the limits of samples such as precipitation. Yet another error comes from an incorrect understanding of phenomena; although sampling surveys are not erroneous, human errors may always occur in the process of system analysis and during input and output.

It requires various investigation and tests to verify technically that a reduced streamflow as in Sumjin River has led to a lowering of the riverbed level and an increase in salt concentration at the downstream. Also to test whether there has been a change in streamflow from a viewpoint of hydrologic statistics could not exclude uncertainty in connection with the aforementioned reasons. However, it would be a practical alterative to put aside the possible error in defining the hydrologic circulation process, and thus to explore solutions using the data accumulated thus far, because the mobilization of all best possible solutions could not perfectly analyze the inherent characteristics of hydrologic variables for now.

Given the limit of information, it would also be impossible to conduct a quantitative analysis of whether the reduced streamflow associated with water diversion outside the basin due to water resources-related facilities in the Sumjin River basin led to the creation of completely new hydrologic series different from the series shown in the existing hydrologic data, how large such changes are, and how large the impact is due to such changes. However, despite such practical limitations, the variation of hydrological variables can be verified with theoretically valid statistical hypotheses (Maidment, 1993).

The variation of hydrologic variables can be tested using single variables and group variables; group variables are segmented into pair and multi-group. Single variable test uses mainly statistical values, variate graphs, parametric variables and nonparametric variables. Group variables can be compared using Rank-Sum Test or Two-sample t Test, if numerous independent data series are available or such data are independently distinguishable. Also, trends of single variables of hydrologic series can be assessed using t-Test or Mann-Whitney Test which tests mean shift.

This paper conducts an accurate and comprehensive assessment of the streamflow variation at the downstream of Sumjin River, using diverse analytic methods as shown in Table 1. Taking into account flow reduction problems in Sumjin River, a change in streamflow in time series is distinguished on the basis of the Songjeong's gauging station which is influenced by the flow of Bosung River where Juam Dam was constructed.

Table 1. Applied Methods for Testing the Flow Change in Sumjin River

Testing Objectives	Testing Methods	Contents of Analysis
1) Flow Duration Curve	Duration Curve	Daily Flow Probabilistic Analysis
2) Annual Flow Change	Moving Average	Trend Analysis of Annual Flow
3) Flow Homogeneity between After-Juam and Before-Juam	Two-Sample t Test	Homogeneity and Consistency Analysis of Hydrologic Time Series
3) Flow Homogeneity between After-Juam and Before-Juam	Rank-Sum Test	Homogeneity and Consistency Analysis of Hydrologic Time Series
4) Mean Shift(Jump) between After-Juam and Before-Juam	Mean Shift t-test	Mean Moving test of Separated Hydrologic Time Series by Using Means and Standard Deviations
	Mann-Whitney Test for Shift	Mean Moving of Two Hydrologic Time Series by Rank of Flow Magnitude

3. Basin Situation

3.1 Characteristics of the Basin

Sumjin River is one of Korea's five large rivers, is located in the central west part of the country's southern region, and runs from north to south. The river basin area covers 4,896.5㎢, and stretches 212.3㎞. The basin, in terms of an administrative district division, belongs to South Jeolla Province, North Jeolla Province, and North Gyeongsang Province. Of the total basin area, North Jeolla Province accounts for 44%, South Jeolla Province 47%, and North Gyeongsang Province 9%; the basin covers the administrative districts of three provinces, four cities, eleven counties, nine County and 93 Sub-county. The riverside and valley areas at the upstream encompass small-scale farms. The midstream areas, covering Namwon, Gurye, and Gokseong, offer a small number of plains; compared with other basins, the Sumjin River basin encompasses a small number of plains. Also, with the location of Sumjin River Dam, Juam Dam, Bosung River Dam and Dongbok Dam, the Sumjin River basin controls flood and supplies various kinds of water to areas outside the basin (Fig. 1)(MOCT/Kwater, 2006).

Since the Sumjin River basin is located at the central part of southern coastal areas, its weather has distinctive four seasons; in the July to September summer period, it is hot and humid due to a humid marine weather. In winter, it is cold and dry due to a continental weather; the downstream areas, adjacent to the southern costal areas, offer higher temperatures than the upstream areas. The average annual precipitation stands at 1,385.2㎜, which is 111.2㎜ greater than Korea's average annual precipitation of 1,274㎜. The seasonal distribution of precipitation is that during the period of June to September, 60～70% of the annual total of precipitation occurs. The record high temperature is 39.4℃ measured at Suncheon Gauging Station on July 24, 1994, and the record low temperature is -25.7℃ measured at Jangsu Gauging Station on February 23, 1991. The average annual temperature stands at 10.4℃ to 12.5℃, offering no big regional difference.

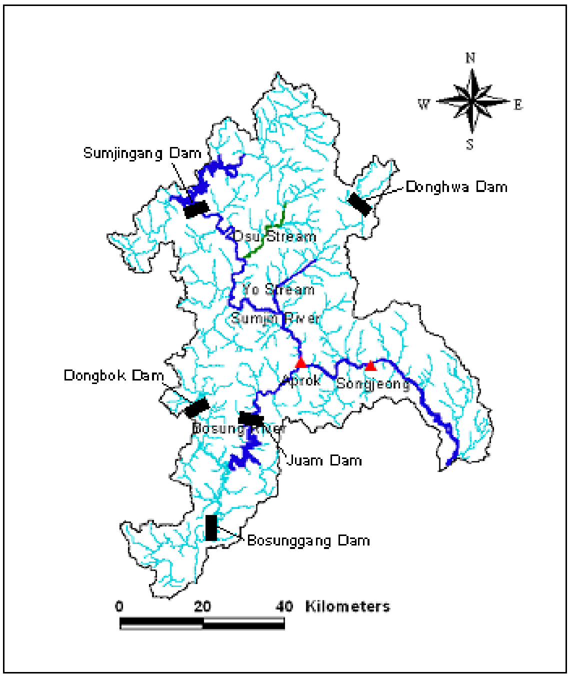

Fig. 1. Map of the Sumjin River Basin

3.2 Characteristics of Runoff

Available data on the Sumjin River runoff consist of the runoff data of Jeokseong, Aprok, and Songjeong gauging stations. This paper examines the gauging station of the Bosung River with the location of Juam Dam in order to assess the flow change in the whole basin. Aprok and Songjeong gauging stations are examined. The Aprok gauging station located at the upstream of the contact point of both Bosung River and Sumjin River mainstreams, thus avoiding the influence of Juam Dam. The Songjeong gauging station is located 40.3km downstream of the contact point with the Bosung River, thus avoiding the influence of Juam. As such, these points offer appropriate hydrologic information for the research into streamflow changes.

First, to assess the whole flow situation, Figs. 2 and 3 present the monthly flow of the gauging stations of Aprok and Songjeong. Available flow data are those between 1966 and 2001, and the finding for this period did not suggest a significant change in flow trends. Also, Table 2 presents the basic monthly flow statistics for the two stations. Compared with a normal distribution, the distribution is right-side leaning, which is similar to the characteristics of Korean river's runoff.

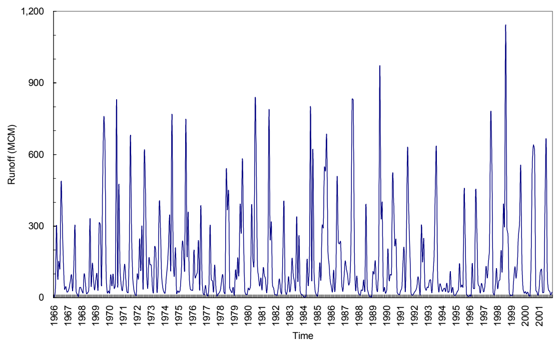

Fig. 2. Monthly Flow Series at Aprok

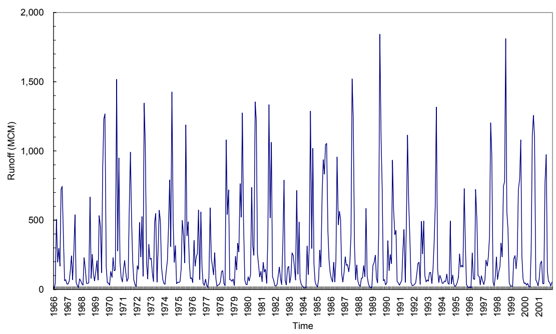

Fig. 3. Monthly Flow Series at Songjeong

Table 2. Statistical Characteristics of Monthly Flows at Aprok and Songjeong

Class	Aprok Gauging Station(10^6㎥)					Songjeong Gauging Station(10^6㎥)				
	Max.	Min.	Mean	S.D.	Skw.	Max.	Min.	Mean	S.D.	Skw.
Jan.	134.8	3.1	40.7	32.6	1.708	216.9	5.4	63.7	52.9	1.758
Feb.	200.1	4.7	61.9	47.7	1.145	354.9	7.9	100.2	83.7	1.344
Mar.	277.6	8.4	84.1	55.2	1.681	480.6	14.1	149.5	100.4	1.666
Apr.	370.2	13.9	109.0	85.8	1.304	717.1	24.7	216.1	167.1	1.133
May	319.8	10.8	93.8	83.3	1.473	763.5	20.4	199.6	173.4	1.660
Jun.	536.8	15.6	168.7	144.4	1.094	1085.6	33.6	339.8	289.7	1.088
Jul.	921.3	9.8	423.8	266.5	0.057	1792.3	21.4	789.5	482.7	0.255
Aug.	1127.2	35.5	341.9	246.8	1.081	1795.9	57.7	662.0	409.2	0.589
Sep.	690.1	17.1	230.1	198.6	0.946	1264.1	34.4	419.4	360.9	0.882
Oct.	277.0	11.5	74.1	64.2	1.599	451.2	21.0	120.9	103.3	1.817
Nov.	163.6	8.7	46.5	31.6	2.162	322.2	16.9	78.4	56.8	2.605
Dec.	136.1	4.1	40.0	27.7	1.710	214.9	9.7	64.7	46.5	1.950
Year	2986.9	311.5	1714.6	686.7	-0.037	5784.7	961.9	3204.0	1247.1	0.120

Table 3. Interbasin Water Diversions from Sumjin River Basin

Class	Period(year)				
	1937	1965	1971	1976	1991
Bosung River Dam	178 million ㎥/year				
Sumjin River Dam		460 million ㎥/year			
Dongbok Dam			92 million ㎥/year		
Daap Intake Station				21 million ㎥/year	
Juam Dam					381 million ㎥/year

Table 3 shows water usage information at the Sumjin River basin, which constitutes a major cause for a change in flow. With the construction of Bosung Dam as early as 1937, the Sumjin River basin supplies an annual water volume of 180 million ㎥ for hydroelectric power generation. Since 1966, an annual water volume of over 460 millionb㎥ has been diverted from Sumjin River Dam to Dongjin River for the purpose of hydroelectric power generation and agriculture. Since 1971, with the construction of Dongbok Dam in the Bosung River basin, water has been supplied to the Gwangju city area. Also, since 1991, with the incorporation of Juam Dam into the basin operation, water is diverted outside the basin to supply both domestic and industrial water to Gwangju, Suncheon, Yeosu and so on. At Daap, an water intake station - albeit a small amount - is conducted to supply water to POSCO. The total water supply volume of the Sumjin River basin stands at over 1.1 billion ㎥, and 20% of this total is diverted to areas outside the basin.

The monthly flow correlation between both

Aprok and Songjeong gauging stations was high, and it was nearly 95% before the construction of Juam Dam. This suggests that the data after 1966 could be usable, and that the data already reflected the water diversion from Sumjin River Dam and Bosung River Dam into other basins, showing a high correlation since the data were based on those before the construction of Juam Dam. However, after the construction of Juam Dam, the correlation was somewhat lower at 83 ~ 90%, suggesting a reflection of the impact of Juam Dam.

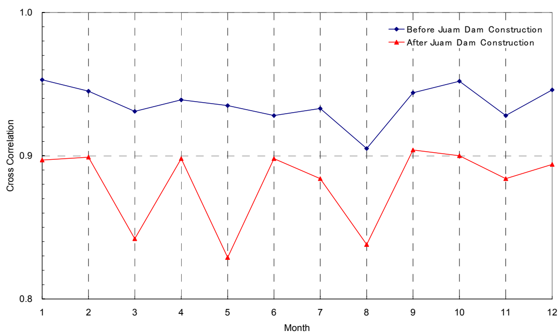

Fig. 4. Cross Correlation between Aprok and Songjeong

3.3 Estimation of the Streamflow Change Time

Cumulative deviation curves are used to estimate the point of time for flow change in the Sumjin River basin. A cumulative deviation curve can determine the point of time for a change in hydrologic data due to abnormal weather or artificial disturbances. To determine hydrologic inconsistency, mean deviation values during the given time series period are cumulated to assess the long-time trends of change through equations.

$$\phi = \frac{Q_{\max} - Q_{\min}}{\overline{Q}} \tag{1}$$

$$\phi' = \frac{\sum_{1}^{12} Q_i - \sum_{1}^{n} (Q_i - \overline{Q})}{\sum_{1}^{12} Q_i} \tag{2}$$

Where ϕ is a nonuniform parameter of annual runoff, ϕ' annual basic runoff parameter, $Q_{\max}$ annual maximum flow, $Q_{\min}$ annual minimum flow, $\overline{Q}$ average annual flow, Q_i average monthly flow, and n the number of months with $Q_i > \overline{Q}$ Thus, the annual nonuniform parameter of flow is arranged as follows.

$$1 - \phi' = 1 - \frac{\sum_{1}^{12} Q_i - \sum_{1}^{n} (Q_i - \overline{Q})}{\sum_{1}^{12} Q_i} \tag{3}$$

$$\sum \left(\frac{\phi_i}{\overline{\phi}} - 1 \right) = \sum (K_i - 1) = f(t) \tag{4}$$

$$\sum \left(\frac{\phi_i'}{\overline{\phi}'} - 1 \right) = \sum (K_i - 1) = f(t) \tag{5}$$

To estimate the point of time for flow change using the above equation, the nonuniform parameter is applied to the precipitation and flow data of the gauging stations of Songjeong and Aprok. First, to determine the correlation between the variation of precipitation and flow, Fig. 5 presents trends of such change based on the precipitation data of gauging stations within the Sumjin River basin. Fig. 6 presents the nonuniform parameter of flow. The findings indicate a sharp change in both precipitation and flow on the basis of 1991; precipitation increased from 1996, and recovered its original state after 2000, while the flow was at the level of 1991 slowing in recovery. Thus, with a possible coincidence, the base point of time for flow change in the Sumjin River basin is determined as 1991 when Juam Dam was constructed, and this criteria is applied to flow series data thereafter.

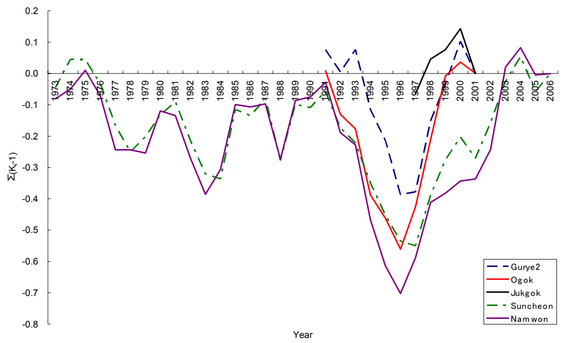

Fig. 5. Nonuniform Parameter of Rainfall

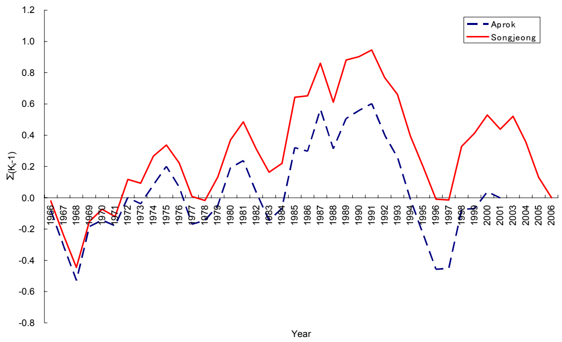

Fig. 6. Nonuniform Parameter of Runoff

4. Evaluation of Flow Variation

4.1 Statistical Test of Single Variables

To assess the flow variation associated with single variables, chiefly graphic methods are used. As the characteristics of the runoff of the Sumjin River basin are discussed in the previous Chapter, Figs. 7 and 8 show the analysis of flow situation of the gauging stations of Aprok and Songjeong. Compared with before the construction of Juam Dam, the period of after the construction showed a smaller amount of flood flow, average flow, low flow and dry flow, offering a 10 ~ 15% reduction. The flow situation curves of Aprok and Songjeong show a very similar distribution pattern, presumably because a reduced flow and some interbasin diversion occurred due to long-time drought spells in the early and medium 1990s. Likewise, a change in the basin which entails a vast flow into Dongbok Dam and Juam Dam is deemed to cause the low streamflow.

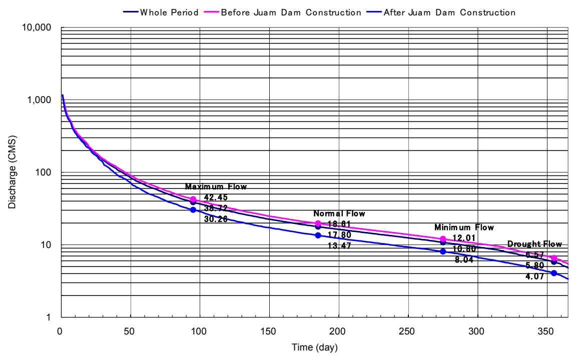

Fig. 7. Flow Duration Curve at Aprok

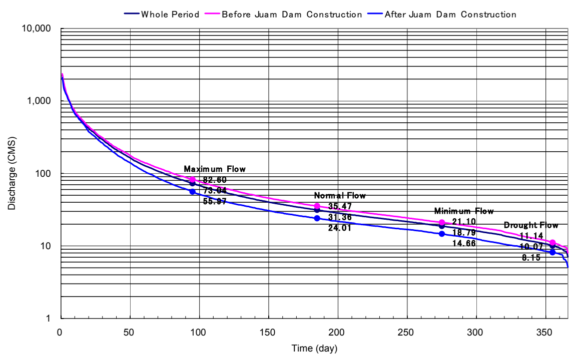

Fig. 8. Flow Duration Curve at Songjeong

To show the variation of flow visually, Figs. 9 and 10 present $Q_t / \overline{Q}$ (*t* year's flow/average annual flow) flow series.

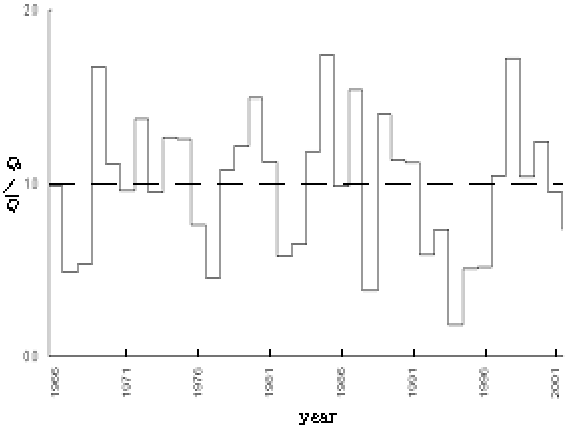

Fig. 9. $Q_t / \overline{Q}$ **Series at Aprok**

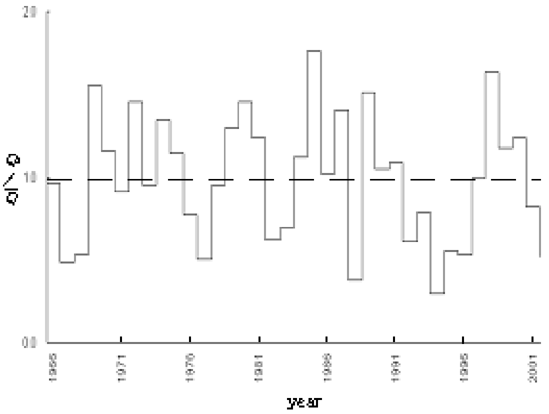

Fig. 10. $Q_t / \overline{Q}$ **Series at Songjeon**

Both points showed a similar $Q_t / \overline{Q}$ series trend before and after the construction of Juam Dam. The figures show a comparison of flow series between years with much rainfall and years with drought on the basis of an average year; the two figures present nearly the same number of events in both areas under and above 1, thus suggesting similar characteristics of flow situation between the two points.

4.2 Statistical Test of Group (independent) Variables

Homogeneity of flow series is analyzed to effectively test group (independent) variables. This method assesses a break in homogeneity of group (independent) variables series before and after an artificial impact, if any. Generally, the method of testing various parametric variables and nonparametric variables can evaluate and determine a change in characteristics of statistical time series, using the mean and variance. This method also conducts Two-Sample t Test of monthly flow series of the gauging stations of Aprok and Songjeong before and after 1991. The two group data's sampling average and standard deviation ($\overline{x}$ and s_x of the first group with the sample size of n; for y, $\overline{y}$ and s_y of the second group with the sample size of m) are calculated, and then the degree of freedom is determined (if the null hypothesis $s_x = s_y$ is not rejected, then $df = n + m - 2$, and if a big difference in standard deviation, the degree of freedom will be calculated using the following equation.). After calculating the test statistic t, if $|t| > t_{1-\alpha/2, df}$, H_0 will be rejected.

$$df = \frac{\left(\frac{s_x^2}{n} + \frac{s_y^2}{m} \right)^2}{\frac{\left(s_x^2 / n\right)^2}{n-1} + \frac{\left(s_y^2 / m\right)^2}{m-1}} \qquad (6)$$

$$t = \frac{\overline{x} - \overline{y}}{\sqrt{\frac{s_x^2}{n} + \frac{s_y^2}{m}}} \qquad (7)$$

Table 4. Results of Two-Sample t Test for Aprok and Songjeong

Month	Aprok Gauging Station($10^6 m^3$)									Songjeong Gauging Station($10^6 m^3$)								
Month	Before-Juam			After-Juam			df	$\lvert t \rvert$	Remark	Before-Juam			After-Juam			df	$\lvert t \rvert$	Remark
Month	Mean	S.D.	Var.	Mean	S.D.	Var.	df		Remark	Mean	S.D.	Var.	Mean	S.D	Var.	df		Remark
Jan.	46.9	36.7	1345.2	26.5	13.2	174.3	33	2.4415	Reject	77.6	61.5	3789.3	42	18.9	359.6	31	2.6771	Reject
Feb.	71.5	50.9	2595	40	31.2	975	30	2.2643	Reject	124.3	91.4	8357.7	63.7	48.6	2369.8	37	2.7035	Reject
Mar.	90.7	60.5	3656.2	68.9	39.1	1530.9	29	1.2921	Pass	166.3	109.9	12082.4	127.7	76.3	5829.3	35	1.2873	Pass
Apr.	122.5	90.9	8261.3	78.3	66.7	4447.7	26	1.6312	Pass	260.2	177.3	31465.1	150.8	120.8	14597.5	35	2.2792	Reject
May	112.1	92.7	8586.5	52.3	31.1	966.5	33	2.8832	Reject	247.7	199.1	39641.7	123.9	69.9	4888.9	33	2.8138	Reject
Jun.	163.8	150.7	22708.7	179.9	135.1	18254.8	21	0.3162	Pass	364.7	317.5	100810.9	308.1	246.8	60922.6	33	0.6190	Pass
Jul.	457.7	276.7	76536.1	346.8	235.5	55463.2	22	1.2318	Pass	816.6	496.7	246718.4	771.1	477.7	228201.5	28	0.2812	Pass
Aug.	327.1	217.6	47349.3	375.6	312.7	97797.5	14	0.4670	Pass	648.9	383	146736.2	674.5	478.7	229168.4	22	0.1715	Pass
Sep.	240.4	200.1	40054.5	206.7	202.6	41035	19	0.4616	Pass	448.6	370.3	137131.9	364.3	364.1	132581.9	27	0.6894	Pass
Oct.	77.8	57.1	3266.1	65.8	80.4	6462.2	15	0.4467	Pass	133.4	98.4	9687.4	102.2	115	13229	24	0.8542	Pass
Nov.	52.1	35.4	1256	33.8	15	223.6	34	2.1764	Reject	92	66.3	4395.6	55.6	24.6	608.4	34	2.4537	Reject
Dec.	44.0	28.5	812.3	30.9	24.5	601.4	22	1.3959	Pass	71.7	46.2	2138.9	53.3	47.6	2268.9	26	1.1707	Pass

Table 4 shows the result of Two-Sample t Test. In the series for both gauging stations before and after 1991, the null hypothesis for part of the dry season period was rejected at the 95% confidence interval. This indicates that during the dry season accompanying a low flow, a great change was caused to the streamflow due to the construction of Juam Dam, thus suggesting that seasonal homogeneity in flow was not maintained.

The comparative test of the two independent groups is conducted to determine whether one group has greater values than those of the other group. One such method is Rank-Sum Test. In the Rank-Sum Test, the null hypothesis H_0 offers the same distribution for the two groups. The alternative hypothesis H_1 shows that one group has bigger observed values than the other group. The Rank-Sum Test calculation process first arranges all data from 1(minimum) to N (maximum), where $N = n + m$ (n is the number of the smaller one of the two samples, and m represents the number of the bigger sample; if the number of samples is the same, it is the average of the relevant ranking). Calculated is the test statistic W (the sum of the ranking of n , the number of observed values in the smaller group). Calculated as follows are the theoretical average and standard deviation of W under the hypothesis H_0 with regard to the standard size. Then the standard form of the test statistic Z_{rs} is calculated. If , $|Z_{rs}| > Z_{1-\alpha/2}$, H_0 will be rejected.

$$\mu = \frac{n(N+1)}{2} \tag{8}$$

$$\sigma = \sqrt{\frac{nm(N+1)}{12}} \tag{9}$$

$$Z_{rs} = \begin{cases} \dfrac{W - 1/2 - \mu}{\sigma} & if \;\; W > \mu \\ 0 & if \;\; W = \mu \\ \dfrac{W + 1/2 - \mu}{\sigma} & if \;\; W < \mu \end{cases} \tag{10}$$

where $Z_{1-\alpha/2}$ corresponds to the $1-\alpha/2$ point of the standard normal probability distribution. Table 5 shows the test results of the

Table 5. Results of Rank-Sum Test for Aprok and Songjeong

Month	Aprok Gauging Station			Songjeong Gauging Station		
	W	$\|Z_{rs}\|$	Remark	W	$\|Z_{rs}\|$	Remark
Jan.	159	1.511	Pass	227	2.235	Reject
Feb.	150	1.820	Pass	222	2.375	Reject
Mar.	174	0.996	Pass	258	1.369	Pass
Apr.	156	1.614	Pass	219	2.458	Reject
May	151	1.786	Pass	229	2.179	Reject
Jun.	218	0.481	Pass	290	0.475	Pass
Jul.	166	1.271	Pass	288	0.531	Pass
Aug.	215	0.378	Pass	310	0.056	Pass
Sep.	180	0.790	Pass	282	0.698	Pass
Oct.	162	1.408	Pass	246	1.704	Pass
Nov.	162	1.408	Pass	232	2.095	Reject
Dec.	151	1.786	Pass	233	2.067	Reject

gauging stationts of Aprok and Songjeong.

In the case of Songjeong, the test statistic $|Z_{rs}|$ rejected the null hypothesis for a part of the dry season period at the confidence interval of 95%($Z_{0.05}$=1.96). This suggests that with the impact of Juam Dam, the flow series distribution was not identical between before and after the construction.

4.3 Test of Time Series Mean Shift

Mean shift can be analyzed by Mean Shift t-Test and Mann-Whitney Test. Under the Mean Shift t-Test, as in Fig. 11, if the hydrologic variable y_t, $t = 1,....,N$ is non-correlational, and the mean μ and the standard deviation σ are continuous hydrologic series of the normal distribution sample size N, and series are divided into the two sub-series of N_1 and N_2 with the size of $N_1 + N_2 = N$ (herein, before and after the construction of Juam Dam); then it is assumed that the first sub-series y_t, $t = 1,....,N_1$ has the mean μ_1 and the standard deviation σ, and that the second sub-series y_t, $t = N_1 + 1, N_1 + 2,....,N$ has the mean μ_2 and the standard deviation σ. Likewise, if the hypothesis of $\mu_1 = \mu_2$ that the two data series is identical is rejected, there is a mean shift in the original data series, and the mean shift is calculated as follows.

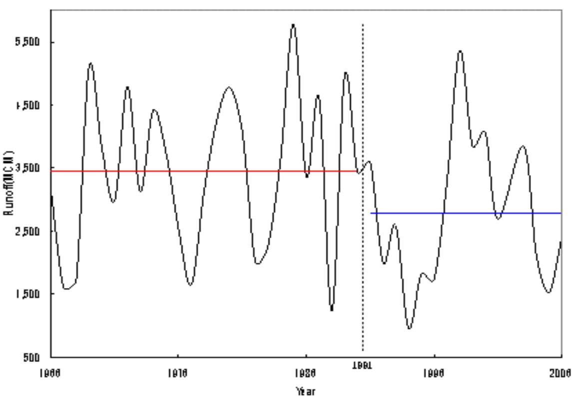

Fig. 11. Conception of Mean Shift(jump) Test

Table 6. Results of Mean Shift t Test for Aprok and Songjeong

Case		Annual Average Flow(10^6 m³)	S.D	Var.	df	T_c	$T_{0.05}$
Aprok	Before-Juam	1806.608	660.323	436026	34	0.0018	1.697
Aprok	After-Juam	1505.539	731.374	534909	34	0.0018	1.697
Songjeong	Before-Juam	3452.452	1240.537	1538931	38	0.0014	1.684
Songjeong	After-Juam	2789.892	1183.333	1400276	38	0.0014	1.684

$$T_c = \frac{\left|\overline{y_2} - \overline{y_1}\right|}{S\sqrt{\frac{1}{N_1} + \frac{1}{N_2}}} \quad (11)$$

$$S = \sqrt{\frac{(N_1 - 1)s_1^2 + (N_2 - 1)s_2^2}{N - 2}} \quad (12)$$

where $\overline{y_1}$ and $\overline{y_2}$, and s_1^2 and s_2^2 are the estimated mean and variance of the first and second sub-series, respectively. The hypothesis is rejected if $T_c > T_{1-\alpha/2,v}$. The test result of mean shift is shown as in Table 6, and satisfies the hypothesis, suggesting that there was no mean shift in flow series between before and after the construction of Juam Dam.

Also, under the Mann-Whitney Test, as in Fig. 11, it is assumed that the data series y_t, $t = 1,....,N$ is divided into two continuous sub-series of $y_1,....,y_{N1}$ and $y_{N1+1},....,y_N$ with the size of N_1 and N_2, respectively, with $N_1 + N_2 = N$. New series z_t, $t = 1,....,N$ is the result of the re-sorting of original data y_t by ascending order. This can be verified with the hypothesis that the average of the first sub-series is the same as that of the second sub-series, with the following equation.

$$u_c = \frac{\sum_{t=1}^{N_1} R(y_t) - N_1(N_1 + N_2 + 1)/2}{[N_1 N_2 (N_1 + N_2 + 1)/12]^{1/2}} \quad (13)$$

where $R(y_t)$ is the ranking of actual measured y_t by series z_t. The hypothesis that the average of the two sub-series is identical is rejected if $|u_c| > u_{1-\alpha/2}$. The test result is shown in Table 7, and the Mann-Whitney Test also shows that there was no mean shift in data series before and after the construction of Juam Dam.

4.4 Comprehensive Evaluation of Test

In connection with the use of water from the Sumjin River basin, this paper conducted statistical examination to assess the trend and variation of streamflow. Early on, the Sumjin River began a diversion of significant quantity of water into other basins. This offers a predicted reduction in flow at the downstream. To test

Table 7. Results of Mann-Whitney Test for Aprok and Songjeong

Case		Annual Average Flow	S.D.	Var.	df	u_c	$u_{0.05}$
Aprok	Before-Juam	1806.608	660.323	436026	34	1.2535	1.96
Aprok	After-Juam	1505.539	731.374	534909	34	1.2535	1.96
Songjeong	Before-Juam	3452.452	1240.537	1538931	38	1.4667	1.96
Songjeong	After-Juam	2789.892	1183.333	1400276	38	1.4667	1.96

Table 8. Comprehensive Evaluation on Tests of the Flow Change in Sumjin River

Testing Methods	Interpretations of Results
1) Duration Curve	Recession of Duration Curve after Juam Dam
2) Moving Average	No Significant Variation in Annual Flow Moving Average
3) Two-Sample t Test	Seasonally Non-homogeneity and Non-consistency
4) Rank-Sum Test	Seasonally Non-homogeneity and Non-consistency
5) Mean Shift t-test	No Jump of Mean
6) Mann-Whitney Test for Shift	No Jump of Mean

whether or not this situation has caused the variation of hydrologic variables in the long term or whether the homogeneity and consistency of data series are maintained will provide the criteria for future river management or use of water resources. In this regard, a comprehensive assessment of the variation of the Sumjin River basin is outlined in Table 8.

The findings indicate a trend of reduced streamflow after the construction of Juam Dam. Two Sample t Test and Rank-Sum Test showed a difference in the distribution of flow series in some dry season period. However, the mean shift test (Mean Shift t-test and Mann-Whitney Test for Shift) showed no mean shift, suggesting that consistency in series was maintained. Therefore, the flow series for the Sumjin River basin showed that a reduction in streamflow began to appear in 1991 when Juam Dam started operation. In particular, with a greater variation of streamflow, the dry season did not maintain the consistency and homogeneity of hydrologic series. The Sumjin River basin showed variation of streamflow by season, but maintained homogeneity in annual series.

5. Conclusion

This paper conducted time-series and statistical analysis of streamflow data to assess flow change situations at the downstream of the basin in connection with the construction of Juam Dam within the Sumjin River basin. The findings indicate that a change in streamflow began in 1991, which coincided with the commencement of the operation of Juam Dam. The analysis of flow variation indicates that the streamflow was smaller for several years since the early 1990s than during usual years. This was deemed to affect the streamflow, causing it to fall. However, given that the streamflow was slow in recovery compared with the precipitation, water diversion into Juam Dam presumably contributed to the reduced streamflow. Statistical test results indicate that the streamflow variation was greater during the dry season, suggesting that there was variation before and after 1991; however, there was no mean shift in long-term flow series. Therefore, with regard to the Sumjin River basin, measures are needed to address the problem of reduced streamflow during the dry season. Also, a continued analysis of long-term flow series is needed in order to rationalize the use of water resources including intrabasin diversion of water.

References

An Jae-hyeon, Yoo Cheol-sang and Yoon Yong-nam (2001). "In Connection with Global Warming, Analysis of Hydrologic Environment Change in the Daecheong Dam Basin Using GCM Results." KWRA's Collection of Symposium Papers, KWARA, Vol. 34, No. 4, pp. 335-345.

Choe Seong-uk, Yoon Byeong-man, Woo Hyo-seop and Cho Gang-hyeon (2004). "In Connection with Flow Situation Change Associated with Dam Construction, River Topographical Change and Vegetation Cover Change at Downstream River Courses : a case of Hwang River Hapcheon Dam." KWRA's Collection of Symposium Papers, KWARA, Vol. 37, No. 1, pp. 55-66.

Maidment, D.R. (1993). *Handbook of Hydrology*. pp. 17.11.

Kahya, E. and Kalayci, S. (2004). "Trend analysis of streamflow in Turkey." *Journal of Hydrology*, Vol. 289, pp. 128-144.

Eric V. Novotny and Heinz G. Stefan. (2006). "Stream flow in Minnesota : Indocator of climate change." *Journal of Hydrology*, Vol. 334, Issues 3-4, February, pp. 319-333.

Jain, S. and Lall, U. (2000). "Magnitude and timing of annual maximum floods : trends and large-scale climatic associations for the Blacksmith Fork River, Utah." *Water Resources Research* 36, 12, pp. 3641-3651.

Kim Byeong-sik, Kim Hyeong-su, Seo Byeong-ha and Kim Nam-won (2005). "In Connection with Climate Change, Assessment of Hydrologic Factors in the Basin and Impact on Water Resources." KWRA's Collection of Symposium Papers, KWARA, pp. 143-148.

Kim Gwang-cheon, Bae Doeok-hyo, Choe Byeong-gyu and Shin Hui-beom (2006). "Analysis of Variation of Hydrologic Factors for Plan for Water Resources." Korea Water Resources Association' (KWRA) Collection of Symposium Papers, KWARA, pp. 1231-1235.

Kim Tae-gyun, Yoon Yong-nam and An Jae-hyeon (2002). "In Connection with Dam Construction, Analysis of Downstream Flow Situation Change." KWRA's Collection of Symposium Papers, KWARA, Vol. 35, No.6, pp. 807-816.

Kim Tae-ung, Lee Dong-ryul and Yoo Cheol-sang (2004). "In Connection with Climate Change, Analysis of Runoff Impact in the Decheong River Basin." KWRA's Collection of Symposium Papers, KWARA, Vol. 37, No. 4, pp. 305-314.

Kwater (2006) Environmental Impact Assessment Report for Three-stage Gwangyang Industrial Water Supply.

Lettenmaier, D. P. (1976). "Detection of Trends in Water Quality Data from Records with Dependent Observations." *Water Resources Research*, vol. 12, pp. 1037-1046.

Lins, H.F. and Slack, J.R. (1999). "Streamflow trends in the United States." *Geophysical Research Letters* 26, 2, pp. 227-230.

MOST/Kwater (2006). Sumjin River Basin Survey Report

Letcher, R.A., S. Yu. Schreider, A. j. Jakeman, B.P. Neal and R.J. Nathan (2001). "Methods for the analysis of trends in streamflow response due to changes in catchment condition." *Environmetrics*, Vol. 12, Issue. 7, pp. 613-630.

Snedecor, G.W., and W.G. Cochran (1980). *Statistical Methods*. The Iowa State University Press, Ames, Iowa.

Y. Zhu and R.L. Day (2005). “Analysis of Streamflow Trends and The effects of Climate in Pennsylvania, 1971 to 2001.” *Journal of the American Water Resources Association*, Vol. 41, Issue 4, pp. 1393-1405.