ANALYSIS OF FLOW RESPONSE CHANGE ON A DAM CATCHMENT DUE TO GLOBAL WARMING(*)

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1. INTRODUCTION

The effects by climate change are appearing in various forms and a prevention countermeasure of global warming is strongly required. The carbon dioxide density of all the world is increasing steadily by annual 1.0~1.5ppm degree, and the Korean Peninsula's carbon dioxide density is rising continuously. In last 1958, first measured value in Hawaii that carbon dioxide density measurement of air is begun by first was 315ppm, and 340.9ppm measured in 1982. Also, in 1995, because 360.9ppm is measured, this is that increase by 1.54ppm every year that 20ppm rise more correctly than 1982.

IPCC (The Intergovernmental Panel on Climate Change) was formed in 1988 by WMO and UNEP. IPCC was reported that the carbon dioxide density is reached in double of 1958 that observation is begun in 2030 if increase tendency of greenhouse effect is continued with present. In case, It is expected that temperature may rise 1.2~3.0℃ and global mean rainfall and evaporation may increase 2~9 % comparing with 1958.

The global warming has brought tremendous impacts on the hydrology and meteorological phenomena, but the effects act is very complex. In this point, analysis of water balance by global warming is thought that is important using assumable global warming scenario present.

This research wishes to grasp as quantitative water resources change of Andong Dam basin (Korea) by hydrological model. The simple and definite global warming scenarios are introduced for solution of problems of global warming in this study.

The water balance analysis is simulated using the typical runoff model and hydrological data so that interpreter's management may be excluded. Therefore, the method applied here is thought that is useful that achieve under the influence of comparative study of global warming about river flow because it can apply immediately in a river basin that is possessing hydrological data of long term in some degree.

(*)Analyses du changement du debit à la captation d'un barrage lié au rechauffement global.

2. STUDY BASIN AND HYDROLOGICAL DATA

2.1 Study basin

The target area of this study is the Andong Dam basin situated upper stream of the Nakdong river in Korea. The hydrological data during comparative long term is absolute to achieve this research. In the case of general river basin, the acquisition of runoff data during long term in a river mouse is difficult. And this as well as in correctness drawing often problems happen. In this situation, we can think that inflow of a dam is offering a comparative correct output about rainfall that is an input in a basin, although production method is indirect.

Specially, in case of the Andong Dam, inflow data for about 20 years could utilize possibility. Also, the propriety for Inflow of Andong Dam is confirmed by the annual runoff ratio and flood event analysis (KOWACO, 1997,1998,1999).

The Nakdong river is the large river secondarily that is situated in the Korean Peninsula's southeast department. The basin area of Nakdong river is 23,817.3㎢, and channel length is about 521.5㎞. The Andong Dam is situated in 340㎞ upper stream from Nakdong river mouse, and bed elevation is about 92m. The basin area of Andong Dam corresponds to whole Nakdong river basin's 6.7% as 1,584㎢. The annual mean rainfall of Andong Dam basin is about 1087.0㎜, and annual mean inflow that is flowed in after completion is $952.4 \times 10^6 m^3$.

2.2 Annual climate changes

The meteorological changes for Andong Dam basin are investigated using rainfall data of 23 years (1977 - 1999) and monthly temperature of 20 years (1977 - 1999). The changes of annual mean rainfall and temperature are shown in Figure 1 and 2. From the annual rainfall pattern, we can know that it was corresponding to rainy year for about 1990. On the contrary, there were serious drought damages about 1995. From the results of linear approximation, annual mean rainfall and annual mean temperature of Andong Dam basin are increasing very slowly.

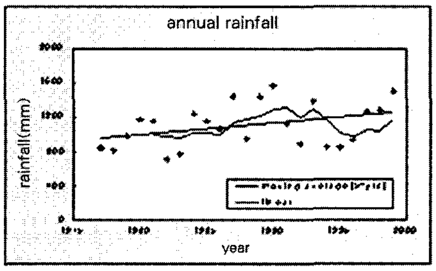

Fig. 1 Annual changes of rainfall
- Changements annuels des Précipitations

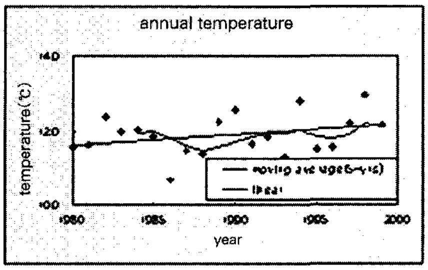

Fig. 2 Annual changes of temperature
- Changements annuels des températures

2.3 Estimation of evapotranspiration

In the hydrological studies, especially in water balance calculations, the information of evapotranspiration at the scale of a basin or a region is indispensable. The evapotranspiration is also fundamental to water resources planning, water supply management and irrigation, or drainage of agricultural lands. In spite of its importance, monthly, seasonal and annual fields of evapotranspiration data sets for large areas are even less well known. Because of difficulties in direct measurements, evapotranspiration is generally estimated using empirical or semi-empirical methods.

The general empirical methods are various to complicated method to need more various information from simple method required only mean air temperature. The methods required only mean air temperature have theoretical background that express evapotranspiration by function of temperature, that radiation and temperature have high interrelationship. These methods could use usefully when cannot get weather element except temperature.

Among these methods, representative methods are Thornthwaite and Hamon method. But, Thornthwaite method causes calculated result to be less in winter, is much in summer on the contrary. Therefore, Hamon method (Hamon, 1960) is adopted to calculate the monthly evapotranspration in this study.

$$PE = 0.14\ D_0^2 P_i$$

where, PE is potential evapotranspiration *(mm/d)*, D_0 is potential daylight *(12hrs=1)*, P_i is absolutely saturated humidity corresponding to mean temperature(g/m^3) The daily evapotranspiration is calculated by Hamon method using monthly temperature of 20 years (1980-1999). Also, monthly evapotranspiration is calculated by multiplying daily installment. The monthly evapotranspiration is calculated by each scenarios that rise lineally by mean air temperature 4℃ and 2℃ until 2050 that is last year of this research. The results are shown in TABLE 1 and Fig. 3.When the mean air temperature is increased by 2℃ until 2050,

TABLE 1 Changes of monthly evapotranspiration by temperature rise
- Changements de l'évaporation mensuelle en fonction de la hausse des températures.

	2℃(▲)				4℃(▲)			
month	2010	2020	2030	2050	2010	2020	2030	2050
1	1.027	1.081	1.108	1.162	1.081	1.135	1.189	1.324
2	1.037	1.057	1.094	1.151	1.056	1.113	1.189	1.321
3	1.032	1.053	1.084	1.147	1.053	1.116	1.179	1.305
4	1.022	1.050	1.078	1.134	1.050	1.106	1.162	1.284
5	1.025	1.050	1.075	1.128	1.049	1.099	1.152	1.266
6	1.023	1.047	1.070	1.120	1.047	1.096	1.146	1.253
7	1.020	1.045	1.070	1.114	1.045	1.089	1.139	1.234
8	1.022	1.044	1.069	1.116	1.044	1.091	1.138	1.239
9	1.027	1.051	1.075	1.126	1.051	1.098	1.149	1.260
10	1.029	1.058	1.080	1.138	1.058	1.108	1.167	1.289
11	1.027	1.055	1.082	1.151	1.027	1.123	1.178	1.315
12	1.023	1.047	1.069	1.139	1.046	1.116	1.163	1.302

annual evapotranspiration causes increase of 12.6% averagely with increase of maximum 16%. Also, for increasing 4℃ of mean air temperature, annual evapotranspiration was analyzed that annual evapotanspiration increase maximum 32% and average 26.2%. Finally, annual evapotranspiration is increased average 26% and this result means a difficulty in water use if increase 4℃ than present temperature in 2050 by effect of global warming.

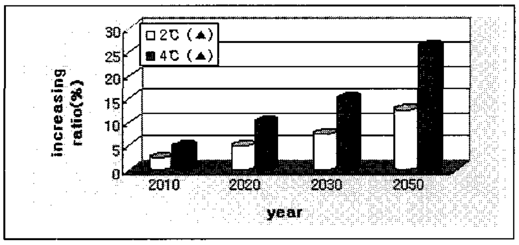

Fig. 3 Changes of annual evapootranspiration by some scenarios - Changements de l'évaporation annuelle selon 2 scénarios.

2.4 Runoff calculation

Runoff characteristics differ depending on types of land utilization and conditions of water use. Tank model which is proposed by Sugawara(1972,1979) is basically composed of four tanks laid vertically in series. The model adopted in this study is well known as an excellent model because this model includes the mechanism of rainfall loss. However the decision of optimum parameters is a very difficult problem for the application of runoff analysis.

In this paper, the problem of searching for the parameters is substituted by the problem of function minimization, and analyzed, using Powell's conjugated direction method (Powell, 1964), which is well - known as a high efficient method for analyzing the problem of function minimization without constraint.

The four-cascade tank model adopted in this study is shown in Figure 4. The unknown parameters were identified by Powell's conjugated direction method. The tank parameters of the Andong Dam basin were obtained from Powell method using observed rainfall-runoff data and optimized parameters are shown in TABLE 2.

The purpose of the runoff analysis is to decide for model variables of tank model from rainfall - runoff data past in this research and calculate suitable runoff volume from future rainfall data calculated by rainfall fluctuation scenarios.

TABLE 2 Optimized tank parameters - Parameters de reservoir optimisés

1st tank	Ca0	0.0111	Ca1	0.0321
	Ca2	0.3127	Ha1	10.956
	Ha2	52.773	initial depth	4.7616
2nd tank	Cb0	0.2289	Cb1	0.0091
	Hb	49.666	initial depth	75.250
3rd tank	Cc0	0.0011	Cc1	0.0018
	Hc	42.561	initial depth	186.4
4th tank	Cd1	0.0002	initial depth	513.65

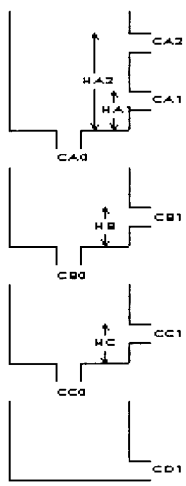

Fig. 4 Structure of four-cascade Tank model - Structure d'un modèle de réservoir à 4 cascades

3. GLOBAL WARMING SCENARIOS

3.1 Establishment of scenarios

If greenhouse effect gaseous increase tendency is continued with present, all globe mean air temperature rise amount is assumed by 1.2~3.0 ℃ at time that carbon dioxide density increases by double. Also, if greenhouse effect gas increases continuously by present augmentation, because carbon dioxide density of 2030 becomes double of density in 1958, temperature of that time can expect to multiply 1.2~3.0℃. Therefore, following assumptions are available.

① Carbon dioxide density change keeps a present augmentation.

② Temperature rise by greenhouse effect gas ignores to year to 1958-1990

because increasing is very little. Also, the temperature rise becomes T℃ in 2030 by increasing lineally since 1991. The mean temperature in the study basin will rise by T = 3.0℃ that is globe mean air temperature rise.

③ Basin characteristics of vegetation and land use etc. would not be changed, and runoff model's variables do that keep present state.

④ Runoff characteristics is reflected by change of evapotranspiration for the temperature change.

⑤ Rainfall in each scenarios increases linearly as P% by temperature T℃ rise at target time. The rainfall amount according to temperature rise of global average 1.2~3.0 ℃ is reported that increase about 2~9%, but case that decrease in some region happens.

With above states, the climate change scenarios in this research are established as following. The temperature change amount T℃ and rainfall change P% are fixed through an year. The climate change in the study basin is supposing the change amount such as whole earth average. Therefore, rainfall amounts change by P=-10~ +10%, when the temperature rise amount is T = 3.0℃ in 2030.

Because the carbon dioxide density is doubled ($2\times CO_2$) in 2030, we can establish as ($1.5\times CO_2$), ($1.75\times CO_2$), ($2.5\times CO_2$) in 2010, 2020, 2050, respectively. When the temperature rise amount is in T = 4.0℃ in 2050, rainfall change P = -15~15% in 2050 and 10 scenarios are established such as TABLE 3.

3.2 Generation of daily rainfall and runoff

Because future rainfall amount (until K year) are generated using divided past rainfall data of N years. The rainfall does to be changed by P% at target time being extended by order by year. The rainfall amount (generated rainfall) $R_i=r_i(1),r_i(2),....,r_i(365)$ after i year ($1<i\leq K$) are given as $R_j=r_j(1),r_j(2),....,r_j(365)$ that these are obtained by random generation using rainfall data past.

$$\{R_j\} = \frac{\triangle P}{100} \times \frac{i}{K} \times \{R_j\}$$

TABLE 3 Established scenarios - Scénarios établis

	case 1	case 2	case 3	case 4	case 5	case 6	case 7	case 8	case 9	case 10	case 11
⊿T(℃)	4	4	4	4	4	2	2	2	0	0	0
⊿P(%)	+15	+10	0	-10	-15	+15	0	-15	15	-15	0

$$=\left\{\frac{\triangle P}{100}\times\frac{i}{K}\times r_j(1),\frac{\triangle P}{100}\times\frac{i}{K}\times r_j(2),\ldots,\right.$$

$$\left.\frac{\triangle P}{100}\times\frac{i}{K}\times r_j(365)\right\}$$

The daily rainfalls from 2000 to 2050 are generated from observed rainfall data by scenarios by ditto method. As we can know in Fig. 5, total rainfall is 11,674mm and about 55.3% of this is flowed in the dam from 1990 to 1999.

The total rainfall is generally consisted of volumes of runoff and evapotranspiration in long term water balance. If a potential evapotranspiration by Hamon method is used for actual evapotranspiration in the water balance, evapotranspiration is excessive more than about 2,000mm. Here, if evapotranspiration is 0(zero) in a rainy day, this is a decrease of 43.5% of rainfall. Also, the water balance of 10 years is satisfied when amount of loss suppose 143mm. Therefore, potential evapotranspiration by Hamon method is corrected and used by an input of a Tank model in this study.

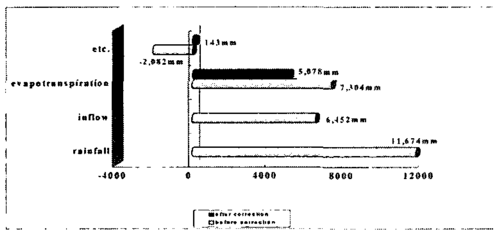

Fig. 5 Water balance for 10 years (1990-1999) of before and after correction
- Equilibre en eau depuis 10 ans avant et après correction

4. APPLICATIONS AND DISCUSSION

4.1 Investigations for mean value of runoff

The stream flow patterns could get from 1990 to 2050 by calculation of each year. The lists of discharge order $Q_1, Q_2, \ldots, Q_{365}$ are obtained by descending series order for each year. The changes of runoff are examined by change of hydrograph for each global warming scenario.

Figure 6 and TABLE 4 are shown the result of order statistic $Q_1, Q_2, \ldots, Q_{365}$ and their mean value $\overline{Q_1}, \overline{Q_2}, \ldots, \overline{Q_{365}}$ at 2010, 2020, 2030 and 2050 by global warming scenarios. These are relative value, when global warming is not gone ($\triangle T 0^\circ C$, $\triangle P=0\%$) about high position 3, 30th, 50th, wet, normal, low, and minimum flow.

When present condition of rainfall is kept and only temperature increases 4℃ (Case 3), wet season, normal, low and minimum flow are decreases of 11%, 10%, 14-19% in 2030, respectively. Also, wet season and normal discharge volumes are a decrease of 17%, and low flow is a decrease of 30% in 2050.

When global warming is gone and rainfall decreases (Case 4), stream flow of wet season is a decrease of 17% and low flow reduces 26~14 % in 2030 by increasing of evapotranspiration. Also, in 2050, wet flow and normal flow brings decrease of 25~26 %, low flow brings decrease of about 40%. For (Case 5), Stream flow of wet season is a decrease of 21% and normal flow reduces 30~14 % in 2030. Also, in 2050, wet season and normal flow are decreased to 30%, low flow brings decrease of about 40%.

If only rainfall increases without temperature

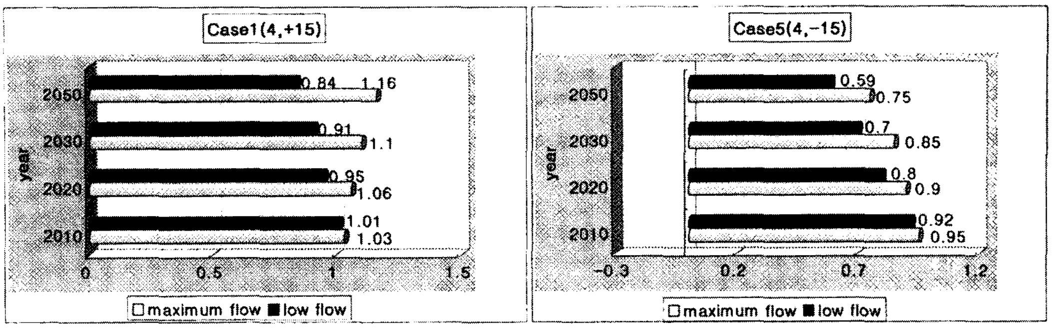

Fig. 6 *changes of maximum stream flow and low flow by warming scenarios*
- Changement des debits maximums et debits faible dans les scénarios de réchauffement

TABLE 4 Future stream flow changes for each global warming scenario
- Changements futurs de débit pour chaque scénario de réchauffement

	Case	1	2	3	4	5	6	7	8	9	10	11
	ΔT(℃)	4	4	4	4	4	2	2	2	0	0	0
	ΔP(%)	15	10	0	-10	-15	15	0	-15	15	-15	0
2010	1	1.03	1.02	0.99	0.96	0.95	1.04	1.00	0.96	1.04	0.96	1.00
	2	1.03	1.02	0.99	0.96	0.95	1.04	1.00	0.95	1.04	0.96	1.00
	3	1.03	1.01	0.98	0.95	0.94	1.04	0.99	0.95	1.04	0.95	1.00
	30	1.03	1.00	0.95	0.90	0.87	1.05	0.98	0.90	1.08	0.92	1.00
	50	1.01	1.00	0.97	0.95	0.93	1.02	0.99	0.96	1.03	0.97	1.00
wet	95	1.01	0.99	0.97	0.94	0.93	1.02	0.99	0.95	1.04	0.96	1.00
normal	185	1.01	1.00	0.97	0.95	0.95	1.02	0.99	0.97	1.02	0.97	1.00
low	275	1.01	0.99	0.96	0.93	0.92	1.01	1.00	0.96	1.03	0.97	1.00
minimum	355	1.00	0.99	0.99	0.99	0.99	1.00	1.00	0.99	1.06	1.00	1.00
2020	1	1.06	1.04	0.98	0.93	0.90	1.07	0.99	0.91	1.08	0.92	1.00
	2	1.06	1.04	0.98	0.92	0.89	1.08	0.99	0.90	1.09	0.91	1.00
	3	1.06	1.03	0.97	0.91	0.88	1.08	0.98	0.89	1.09	0.91	1.00
	30	1.06	1.01	0.90	0.78	0.74	1.11	0.95	0.78	1.17	0.84	1.00
	50	1.02	0.99	0.94	0.90	0.88	1.06	0.97	0.91	1.09	0.94	1.00
wet	95	1.00	0.98	0.93	0.88	0.86	1.04	0.97	0.90	1.07	0.94	1.00
normal	185	0.99	0.97	0.93	0.90	0.88	1.02	0.97	0.92	1.05	0.96	1.00
low	275	0.95	0.93	0.86	0.82	0.80	1.01	0.96	0.87	1.09	0.96	1.00
minimum	355	0.93	0.93	0.92	0.92	0.92	0.94	0.94	0.93	1.01	0.94	1.00
2030	1	1.10	1.06	0.97	0.89	0.85	1.11	0.99	0.87	1.12	0.88	1.00
	2	1.10	1.05	0.97	0.88	0.84	1.11	0.98	0.85	1.13	0.87	1.00
	3	1.09	1.04	0.95	0.86	0.81	1.11	0.98	0.84	1.13	0.86	1.00
	30	1.09	1.01	0.85	0.70	0.63	1.19	0.93	0.70	1.26	0.75	1.00
	50	1.02	0.98	0.92	0.86	0.83	1.09	0.96	0.87	1.17	0.91	1.00
wet	95	0.99	0.96	0.89	0.83	0.79	1.05	0.95	0.85	1.11	0.90	1.00
normal	185	0.97	0.94	0.90	0.85	0.82	1.02	0.95	0.88	1.07	0.93	1.00
low	275	0.91	0.87	0.81	0.74	0.70	1.00	0.92	0.80	1.15	0.91	1.00
minimum	355	0.86	0.86	0.86	0.86	0.86	0.88	0.88	0.88	1.01	0.89	1.00
2050	1	1.16	1.09	0.96	0.82	0.75	1.18	0.98	0.77	1.20	0.80	1.00
	2	1.16	1.09	0.94	0.80	0.72	1.19	0.97	0.75	1.22	0.78	1.00
	3	1.15	1.07	0.92	0.76	0.68	1.19	0.96	0.72	1.22	0.77	1.00
	30	1.14	1.01	0.74	0.53	0.45	1.30	0.87	0.51	1.42	0.62	1.00
	50	1.03	0.96	0.86	0.76	0.71	1.19	0.93	0.78	1.40	0.84	1.00
wet	95	0.98	0.93	0.83	0.74	0.69	1.08	0.91	0.75	1.18	0.83	1.00
normal	185	0.94	0.90	0.83	0.75	0.69	1.04	0.91	0.78	1.13	0.88	1.00
low	275	0.84	0.79	0.70	0.61	0.59	1.00	0.83	0.66	1.24	0.81	1.00
minimum	355	0.85	0.84	0.84	0.83	0.82	0.88	0.87	0.85	1.02	0.89	1.00

change (Case 9), justly stream flow is increased. But, if temperature goes up 2℃, stream flow is decreased even if rainfall rise 15% (Case 6) in the dry season. Also, if temperature goes up 4℃, stream flow decreases whatever rainfall rise 15% (Case 1). Therefore, because global warming is continued, if situation of happens, the flood runoff increases more than 10% at 2030 and 2050, and low flow is reduced to 15%.

4.2 Investigations of stream flow for each return period

The changes of stream flow about each return period are examined by calculated annual maximum flow. The statistical distributions (normal, 2 parameter log normals, 3 parameter log normals, pearson type Ⅲ, log pearson type Ⅲ, gumbel type Ⅰ extremal) are examined and satisfied all KS (Kolmogorov - Smirnov) test for frequency analysis.

But, main goal of this study is that yield relative difference compared with non- warming condition. Therefore, stream flow of each return period was used to examine relative change by Log Pearson Type Ⅲ that used most extensively for flood frequency analysis. The stream flow that is compared with non-warming condition and each climate scenario is shown in TABLE 5.

In case of only temperature changed (Case 3, Case 7), the change of stream flow is very little generally. But, the low flow is greatly influenced by temperature change. Finally, increase of evapotranspiration can cause much effect to low flow but seldom influence to flood runoff. While, in the case of most excessive Case 9 (rainfall rise 15%, without temperature rise), the stream flow for return period 200 years brought a increase of about 20%.

**TABLE 5 Changes of stream flow for each return period (2050)
- Changement des débits pour chaque période (2050)**

	return periods				
	10 yrs	25 yrs	50 yrs	100 yrs	200 yrs
(0, 0)	1.000	1.000	1.000	1.000	1.000
Case 1 (4,+15)	1.146	1.153	1.159	1.167	1.176
Case 2 (4,+10)	1.091	1.097	1.102	1.107	1.113
Case 3 (4, 0)	0.978	0.982	0.983	0.982	0.981
Case 4 (4,-10)	0.861	0.860	0.856	0.823	0.841
Case 5 (4,-15)	0.800	0.797	0.790	0.781	0.769
Case 6 (2,+15)	1.157	1.162	1.169	1.176	1.185
Case 7 (2, 0)	0.990	0.993	0.994	0.994	0.995
Case 8 (2,-15)	0.817	0.814	0.808	0.799	0.789
Case 9 (0,+15)	1.168	1.172	1.177	1.185	1.194
Case 10(0,-15)	0.831	0.829	0.824	0.817	0.808

4.3 Frequency and deficit volume for low flow

If the global warming is gone, frequency and duration for low flow may be changed. The low flow that indicate here defines as a discharge that "discharge Q is smaller than any threshold discharge Q*". Also, the one low flow is defined as "period that discharge Q is smaller than any threshold discharge Q*".

The low flow, $\overline{Q_{275}}$ when global warming is not happened is adopted as the threshold discharge Q*. Therefore, threshold discharge is $\overline{Q_{275}}=5.42m^3$ in this study. The low flow that it means here is smaller series discharge than threshold discharge. TABLE 6 is the result of comparison of low flow between non-warming condition and each global warming scenario. If present situation is continued, low flow is increased yearly by 8 times. Also, in case of $\triangle T=4°C$, $\triangle P=-15\%$ frequency of low flow was 1.88 times increases in 2050.

While, the total deficit and maximum deficit volume for the discharge that this is smaller than threshold discharge are calculated and this result is shown TABLE 7. The maximum deficit volume does not react sensitively about climate changes, but total deficiency is affected greatly.

TABLE 6 Occurrence frequency for each scenario - *Fréquence des occurrences pour chaque scénario.*

Scenario	2010	2020	1030	2050
(0, 0) (No./yr)	8.45	8.45	8.45	8.45
(4,+15) (No./yr)	8.55	8.92	9.03	9.48
(4,+10) (No./yr)	8.57	8.80	9.11	9.26
(4,0) (No./yr)	8.66	8.82	9.51	10.04
(4,-10) (No./yr)	8.59	9.17	9.58	10.14
(4,-15) (No./yr)	8.53	9.41	9.66	10.33
(2,+15) (No./yr)	8.43	8.23	8.46	8.57
(2,0) (No./yr)	8.53	8.66	8.69	9.20
(2,-15) (No./yr)	8.43	8.57	9.36	9.50
(0,+15) (No./yr)	8.23	7.93	7.45	7.34
(0,-15) (No./yr)	8.70	8.31	8.21	9.06

When temperature goes up 2℃ without change of rainfall, total deficit is an increase of 16%. This is the same effect that rainfall is a reduced of 15% without temperature change.

5. CONCLUSIONS

The study describes results of numerical simulations on river flow response due to global warming. Forecasts of changes in climatic conditions are required to estimate the hydrologic effects of increasing trace gas concentrations in the atmosphere. However, reliable forecasts of regional climate change are unavailable. Therefore various approaches to the development of scenarios of future climatic conditions are used. The approach in this study is to prescribe climatic changes for a dam basin in a simplified manner. As a rule, such scenarios specify air temperature increases from 0℃ to 4℃

TABLE 7 Comparisons between a total deficit and maximum deficit volume by each scenario - Comparaison entre le volume déficitaire total et le volume déficitaire maximun pour chaque scénario.

	2010		2020		2030		2050	
	total deficit volume	Max. deficit volume	total deficit volume	Max. deficit volume	total deficit volume	Max. deficit volume	total deficit volume	Max. deficit volume
(0,0) (m^3)	481,013.6	5,068.2	481,013.6	5,068.2	481,013.6	5,068.2	481,013.6	5,068.2
(4,+15)	1.01	1.02	1.06	1.01	1.10	0.99	1.19	0.94
(4,+10)	1.02	1.02	1.08	1.02	1.14	0.98	1.25	0.94
(4,0)	1.05	1.02	1.13	1.00	1.19	0.98	1.37	0.98
(4,-10)	1.07	1.03	1.17	1.00	1.28	0.98	1.49	1.03
(4,-15)	1.08	1.03	1.19	1.00	1.33	0.98	1.58	1.02
(2,+15)	0.94	1.03	0.99	1.01	1.00	1.00	1.01	0.98
(2,0)	1.01	1.03	1.05	1.03	1.09	1.02	1.16	0.99
(2,-15)	1.05	1.03	1.19	1.03	1.19	1.01	1.38	0.99
(0,+15)	0.97	1.01	0.93	1.03	0.89	1.03	0.84	1.05
(0,-15)	1.03	0.99	1.04	1.04	1.08	1.05	1.16	1.04

and precipitation change (increase or decrease) in the range of 0% to 15%. If the rainfall is no changed and temperature goes up 4℃ until 2050, wet season and normal flow bring decreases of about 17% but maximum decrease of low flow is about 30%. Also, if rainfall increases by global warming, flood runoff increases and low flow decreases. The total water resources and low flow are greatly influenced by evapotranspiration.

On the basis of acceptable supposition of warming scenarios, future daily stream flow is simulated. The numerical experiments have quantitatively revealed the change of discharge at 2010, 2020, 2030 and 2050 for each warming scenarios and compared it with the results for a non-warming scenario. The method to apply here is useful to carry out a comparative study of global warming on river flow because this method would be applied in a river basin that is possessing hydrological data of long term in some degree.

Cette étude présente les résultats de simulations numériques des conséquences sur les cours d'eau du réchauffement global de la planéte. Les prévisions de changement des conditions climatiques sont utilisées pour évaluer les effets hydrauliques de l'augmentation de la concentration de gaz dans l'atmosphère.

Toutefois les prévisions sûres sur le changement climatique local ne sont pas disponibles. En l'absence de ces données, différentes approches sont utilisées pour développer des scénarios possibles des conditions climatiques futures.

L'approche choisie pour cette etude est de prévoir les changements climatiques d'un bassin de fleuve d'une manière simplifiee.

En règle générale, de tels scénarios prévoient que la température de l'air augmentera de 0° à 4°C et que les changements de précipitations (augmentation ou diminution) seront de l'ordre de 0% à 15%.

Sur la base de suppositions acceptables de scénarios de rechauffement, le futur debit quotidien du fleuve est simulé en utilisant le modèle de précipitations et d'écoulement dans le bassin du barrage Andong.

Les expériences numériques ont révélé quantitativement le changement de débit en 2010, 2020, 2030 et 2050 pour chaque scénario de réchauffement et l'ont comparé avec les résultats d'un scénario de non-réchauffement.

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Summary

This study describes results of numerical simulations on river flow response due to global warming. Forecasts of changes in climatic conditions are required to estimate the hydrologic effects of increasing trace gas concentratrions in the atmosphere. However, reliable forecasts of regional climate change are unavailable. In there absense, various approaches to the development of scenarios of furture climatic conditions are used. The approach in this study is to prescribe climatic changes for a river basin in a simplified manner. As a rule, such scenarios apecify air temperature increases from 0℃ to 4.0℃ and precipitation change (increase or decrease) in the range of 0% to 15%. On the basis of acceptable supposition of warming scenarios, furute daily streamflow is simulated using rainfall-runoff model in the Andong Dam basin. The numerical experiments have quantitatively revealed the change of discharge at 2010, 2020, 2030 and 1050 for each warming scenarios and compared it with the results for a non-worming scenario.

요 약

본 연구에서는 온난화에 의한 하천유역의 수문응답(강우유출, 특히 일단위의 유황)의 변화양상을 수치실험을 통해 정량적으로 평가하였다. 이산화탄소 농도의 증가에 따른 온난화의 진행으로 야기되는 수문학적 평가는 많은 관측자료를 필요로 하며 이를 정량적으로 평가한다는 것은 대단히 어려운 일이다. 따라서 장래의 기후를 예측하는 수단으로서 적정한 시나리오를 상정하여 평하는 방법을 생각할 수 있다. 본 연구에서는 여러 가지 상정할 수 있는 시나리오 중 기온은 0℃에서 4.0℃까지 변화하며 강수량은 15%까지 증감할 수 있다는 시나리오를 상정하여 불확실성이 큰 지구온난화의 문제에 대하여 간단하면서 명확한 가정을 도입하였다. 따라서, 대상유역인 안동댐 유역에 대한 장래의 하천유량은 기후변화 시나리오에서 야기되는 강수량을 발생시켜 탱크모형에 의하여 일 유량을 모의 발생하게 된다. 본 연구에서는 2030년을 이산화탄소 농도가 배증되는 시점(2×CO2), 2010년, 2020년 및 2050년을 각각 (1.5×CO2),(1.75×CO2) 및 (2.5×CO2)로 설정하였으며, 이 시기에 대한 하천유황의 해석 및 온난화가 발생되지 않았을 때와의 비교 검토를 실시하였다.