Computation of Areal Reduction Factor and Its Regional Variability

Kim, Won*, and Yoon, Kang-Hoon**

Abstract/Areal Reduction Factor(ARF) has been developed and used to convert point Rainfall intensity-Duration-Frequency(I-D-F) to areal I-D-F in many countries. In Korea, though ARF was estimated in Han river basin by several researchers, it has some limitations to apply to other regions due to low density of rainfall gauging station and shortage of data. In this study ARF has been developed in areas of relatively high density of rainfall gauging station, i. e., Pyungchang river(Han river), Wi stream(Nakdong river), and Bochung stream(Guem river) basin by geographically fixed-area method. And coefficient of variation of mean annual precipitation was presented to use ARF in other areas and its applicability was analyzed.

1. Introduction

Considering general properties of rainfall, it has nonuniform distribution in space and its intensity is reduced gradually from the center to the edge of the storm. Areal averaged rainfall considering this spatial property of rainfall is very important to get design storm for minor hydraulic structures. In hydrologic design, engineers are more concerned with the averaged depth of rainfall over an area than with the depth at a particular point. But because we get only point rainfall data, we have to convert point rainfall data to areal data.

By this purpose ARF(Areal Reduction Factor)has been developed and used in many countries, but its procedure of derivation and application is different among the researchers. In Korea, though ARF was developed in Han river basin by several researchers, it has some limitations to apply to other regions due to low density of rainfall gauging station and shortage of data. And because geographical characteristics are very diverse by region, it may cause many problems to apply particular ARFs over whole country without geographical, hydrological, and meteorological considerations.

It is desirable that ARFs are developed in many regions as possible and then it is applied to other regions by considering regional characteristics. But because the relationships between ARF and geo-

* Researcher, Water Resources Engineering Division, Korea Institute of Construction Technology

** Senior Researcher, Water Resources Engineering Division, Korea Institute of Construction Technology

graphical, hydrological, and meteorological characteristics has not been identified yet, it is not easy to have the criteria to select ARFs appropriate to each region.

The main purpose of this paper are as follows ;

(1) To develop ARFs in three regions of high density of rainfall gauging station, Pyungchang river (Han river basin), Wi stream(Nakdong river basin), and Bochung stream(Guem river basin) basin by geographically fixed-area method.

(2) To develop the criteria to apply ARF to other regions where ARF has not been developed yet.

2. Derivation of ARFs

Generally there are two methods to derive ARFs, one is storm-centered method; the maximum rainfall occurs when the storm is centered on the area affected. And the other is geographically fixed-area method; the area is fixed and the storm is either centered over it or displaced , therefore only a portion of the storm affects the area. In this study, geographically fixed-area method has been used.

2.1 Selection of regions

Because high density of rainfall gauging station and long-term simultaneous rainfall data are necessary to derive ARFs, it is impossible to derive ARF over every regions. Therefore, we have to derive ARF in proper region, then it can be applied to other regions according to regional characteristics where the density of rainfall gauging station is low and rainfall data is not enough to derive ARFs.

In this study we select the mid-size basin (about 500㎢), Pyungchang(Han river basin), Wi stream(Nakdong river basin), and Bochung stream(Guem river basin) to derive ARFs because of relatively high density of rainfall gauging station(30～50㎢/rainfall gauging station) and enough simultaneous rainfall data. Because these regions have in respect to geographical, hydrological, and meteorological characteristics, it may be possible to analyze regional variability and cause of ARF.

2.2 Collection of rainfall data

As ARFs represent the spatial properties of rainfall, it is needed to use simultaneous rainfall data in deriving ARFs. In this study we use the simultaneous rainfall data of the representitive storm, 18 rainfall events('82～'89) in Pyungchang river bisin, 14 rainfall events('83～'89) in Wi stream basin, and 16 rainfall events('83～'89) in Bochung stream basin.

2.3 Derivation of point I-D-F curves

Point I-D-F curves can be obtained by analyzing point rainfall data. It can represent the characteristics of rainfall data in only one rainfall gauging station but not represent the characteristics of areal rainfall data. As frequency analysis to derive I-D-F curve is various, It has been used the frequency-coefficient method and Log-Pearson Type Ⅲ that is appropriate to data series of the maximum intensity as probability distribution type.[1]

2.4 Derivation of areal I-D-F curves

As areal I-D-F curves can be obtained by analyzing areal rainfall data, areal rainfall data have to be calculated by one of the various averaging method. Therefore areal I-D-F curves can be considered areal properties of rainfall.[5] First, deviding the whole regions into several small regions, second, calculating areal rainfall by appropriate averaging technique in small region, then we can obtain areal I-D-F curve by the same routine as point I-D-F curves.

2.4.1 Division of the region

When we try to derive ARFs, it is general to divide the whole area into several elliptical or circle areas. In this study It is divided the whole area into several circle areas containing maximum number of rainfall gauging station as possible(50 ㎢, 100 ㎢, 200 ㎢, 300 ㎢).

2.4.2 Calculation of areal mean rainfall and derivation of areal I-D-F curves.

There are many techniques to calculate areal mean rainfall, and areal mean rainfall determined by techniques has some discrepancy to real mean rainfall. This discrepancy is directly affected by the density of rainfall gauging station.

In this study Kriging interpolation technique is used to calculate areal mean rainfall.(7) Areal I-D-F curves can be determined by the areal mean rainfall calculated by the interpolation techniques.

2.5 Derivation of ARFs

ARFs can be determined using the relationship between point and areal I-D-F curves as follows ;

(1) Calculating the point I-D-F curves in each subregion.

(2) Calculating the areal I-D-F curves in each subregion.

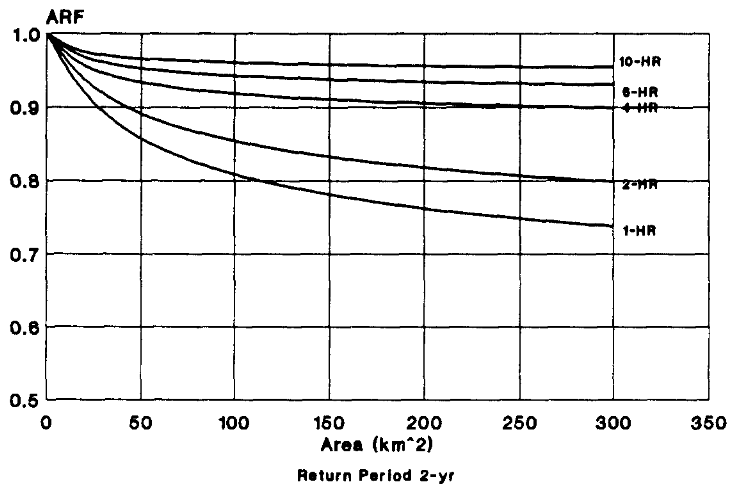

Fig. 1 ARF in Pyungchang river basin

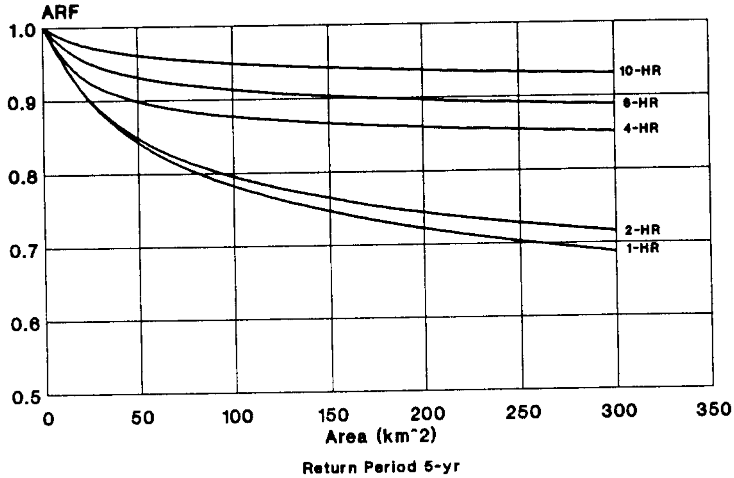

Fig. 2 ARF in Pyungchang river basin

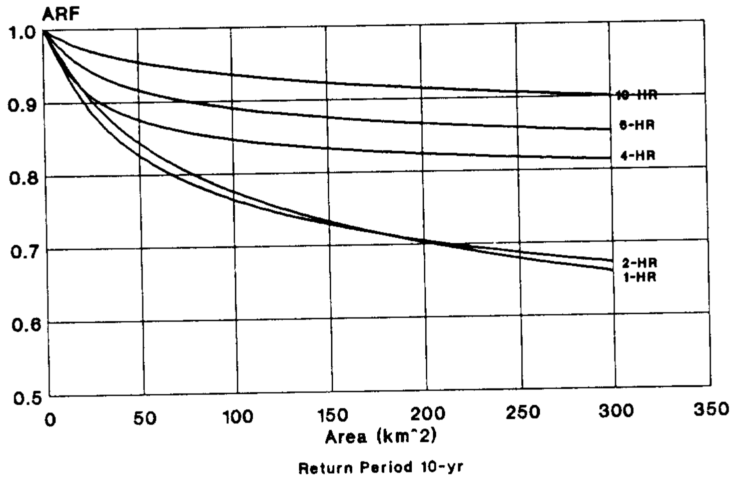

Fig. 3 ARF in Pyungchang river basin

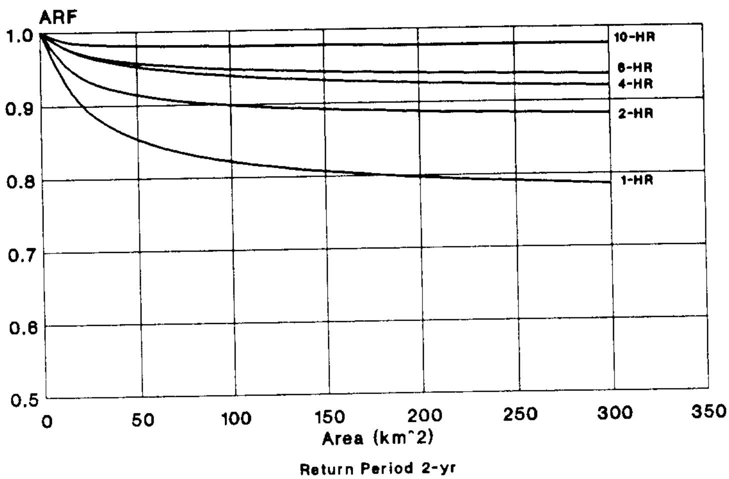

Fig. 4 ARF in Wi stream basin

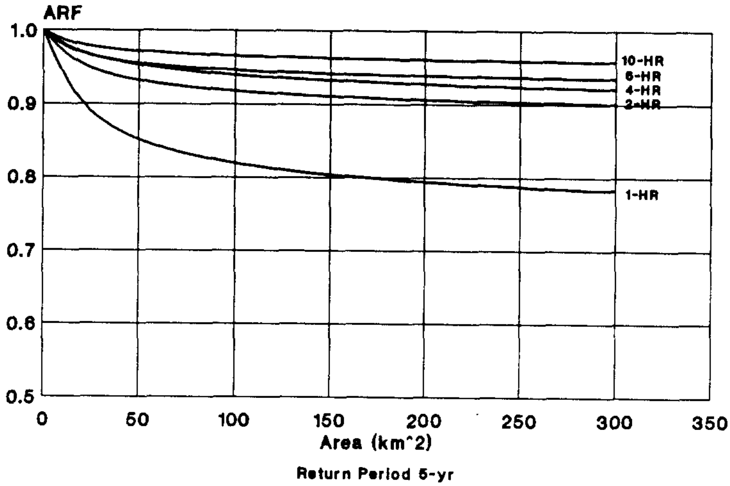

Fig. 5 ARF in Wi stream basin

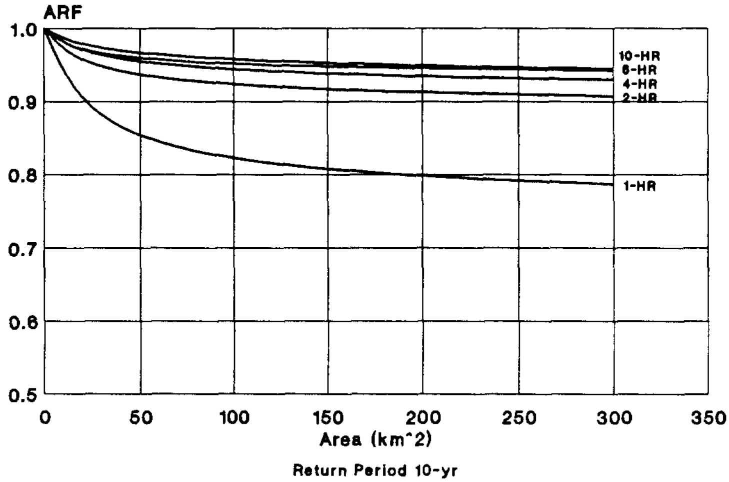

Fig. 6 ARF in Wi stream basin

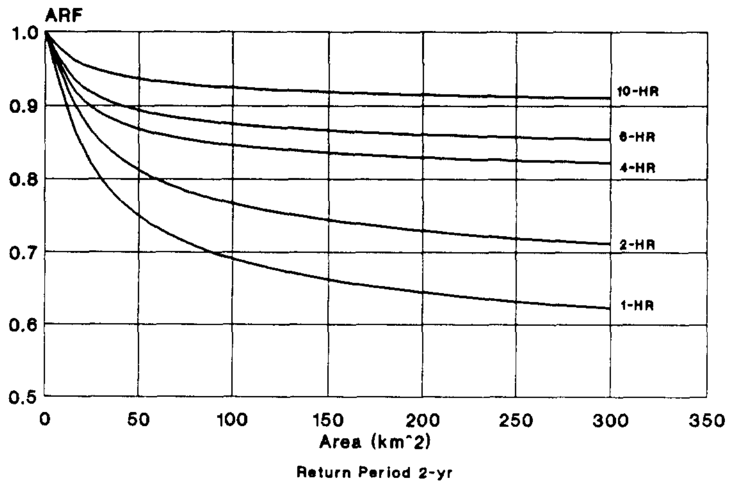

Fig. 7 ARF in Bochung stream basin

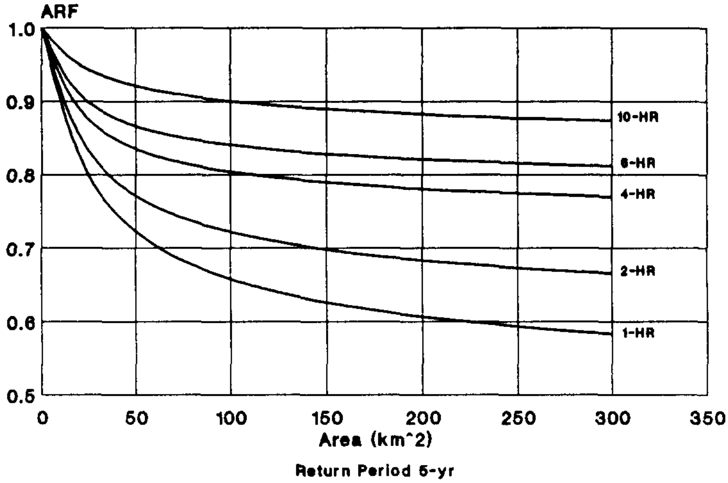

Fig. 8 ARF in Bochung stream basin

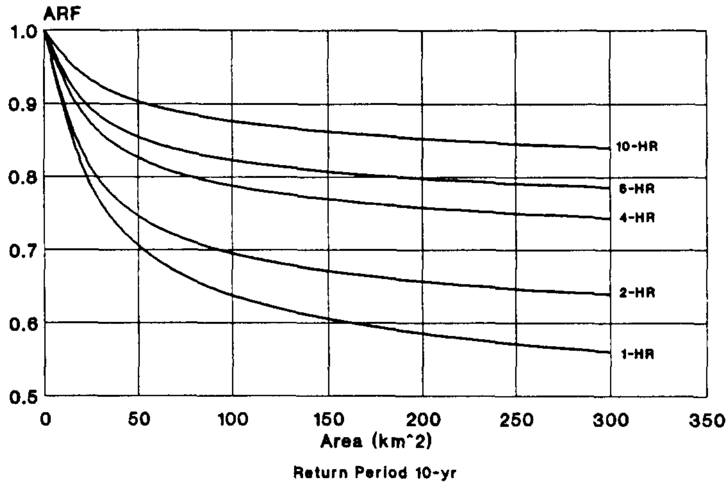

Fig. 9 ARF in Bochung stream basin

(3) Calculating the ratio between areal I-D-F curves in corresponding subregion and point I-D-F curves calculated in step (1).

(4) Calculating the ARFs averging the ratio calculated in step (2) to the same size subregions.

Regression equation as follows is used to represent ARFs as a figure.

$$ARF(A) = 1 - Me^{-[aA^b]-1} \quad (1)$$

where, M, a, b are regression coefficients and A is a area of subregion.

ARFs derived in this paper are represented as Fig.1~Fig.9 and the coefficients M, a, b are shown in Table 2.

Table 1. Density of Rainfall Guaging Station

Basin	Pyungchang River		Wi Stream		Bochung Stream		Han River		Nakdong River		Guem River	
Station Type	Auto	T/MM	Auto	T/M	Auto	T/M	Auto	T/M	Auto	T/M	Auto	T/M
MOC[1]	11	0	11	0	12	0	53	32	54	35	42	0
KOWACO[2]	0	4**	0	0	0	1*	0	33	0	16	0	9
OOM[3]	0	0	0	0	1	0	11	0	14	0	7	0
Total	11	4**	11	0	13	1*	64	65	68	51	49	9
Number	15		11		14		129		119		58	
Area (㎢)	519.7		472.5		475.7		26,218.0		23,859.3		9,885.8	
Density (㎢/gauge)	35		43		34		203		200		170	

1) Ministry of Construction of Korea
2) Korea Water Resources Corporation
3) Office of Meteorology of Korea
*Not used in this paper

Table 2. Regression coefficients

$ARF(A) = 1 - M * EXP(-(aA^b)^{-1})$

Duration (HR)	Coefficient	Pyungchang River Return Period(yrs)			Wi Stream Return Period(yrs)			Bochung Stream Return Period(yrs)		
		2	5	10	2	5	10	2	5	10
1	M	0.441	0.591	0.784	0.265	0.269	0.263	0.472	0.516	0.539
	a	0.163	0.156	0.149	0.182	0.181	2.181	0.164	0.161	0.160
	b	0.433	0.404	0.365	0.570	0.571	0.572	0.579	0.590	0.598
2	M	0.353	0.489	0.560	0.140	0.127	0.120	0.372	0.408	0.426
	a	0.169	0.161	0.158	0.205	0.208	0.212	0.171	0.168	0.166
	b	0.413	0.427	0.432	0.589	0.520	0.508	0.549	0.596	0.628
4	M	0.136	0.185	0.236	0.132	0.130	0.103	0.206	0.271	0.315
	a	0.204	0.192	0.183	0.203	0.203	0.215	0.205	0.181	0.175
	b	0.490	0.555	0.551	0.403	0.401	0.439	0.610	0.615	0.580
6	M	0.091	0.166	0.240	0.089	0.084	0.074	0.172	0.226	0.265
	a	0.222	0.195	0.182	0.224	0.232	0.240	0.216	0.189	0.180
	b	0.491	0.450	0.424	0.460	0.490	0.491	0.579	0.590	0.570
10	M	0.055	0.141	0.345	0.024	0.061	0.096	0.112	0.180	0.235
	a	0.252	0.202	0.171	0.348	0.244	0.215	0.230	0.192	0.183
	b	0.533	0.343	0.271	0.631	0.420	0.373	0.519	0.472	0.465

3. Analysis of ARFs

As ARFs derived in this paper are shown in Fig.1~Fig.9, they have the general characteristics of the ARFs that ARFs increase as the durations increase and decrease as the return periods increase.[2] But ARFs derived in this paper represent the different values at each region.

3.1 Comparison of ARFs with other studies

To compare ARFs derived in this paper with other results, the results of MOC(Ministry of Construction)[8] and Lee[9] in Korea and the results of Myers[4] and Miller[3] from other countries have been used:

ARFs derived by MOC were calculated using data collected during 1975~1987 in Han river basin and ARFs derived by Lee were calculated using data collected during 1975~1986 in the same basin. Myers used data collected in Chicago and Miller used data collected in 11 states of western USA to derive ARFs.

As Fig.10 represents, the trend of ARFs derived in this paper is similar with ARFs derived by other researchers. But ARFs in this paper show different values at each region. From Fig.10, it is shown that ARFs in Pyungchang river basin are different from ARFs by Myers but close with ARFs by MOC or by Lee as the areas of the region increase. The fact that ARFs in Pyungchang river basin are similar with ARFs by MOC or by Lee has the cause that Pyungchang river basin locate in Han river basin and so has similar hydrological and meteorological characteristics. Because ARFs by MOC or by Lee cannot be considered the characteristics of the small regions(smaller than 300km²), ARFs in Pyungchang river basin are greater than ARFs by MOC or Lee in small regions.

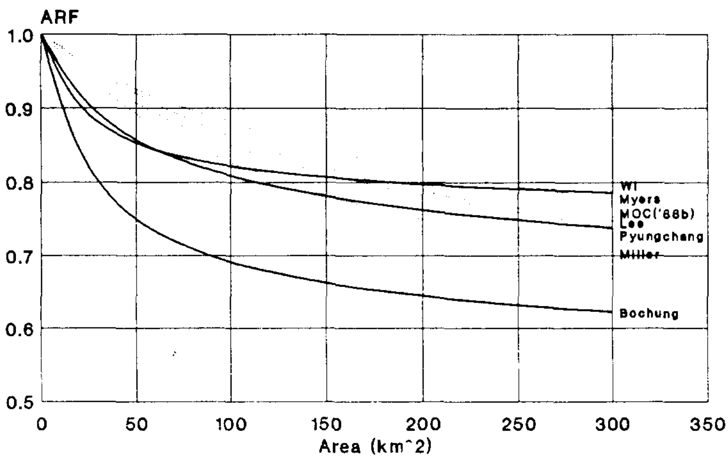

Fig. 10 Comparison of ARFs with other studies

3.2 Comparison of ARFs by the region

As shown in Fig.11, ARFs represent different values at each region by their regional characteristics. ARFs in Wi stream basin are always greater than ARFs in other two regions and represent small discrepancy with the return periods. But ARFs in Pyungchang river basin represent large discrepancy with the return periods and their values lie half between values of other two regions. And ARFs in Bochung stream basin have been changed with the return periods and their values are always smaller than ARFs in other two regions.

Because these properties of ARFs according to the regional variability are same in the case of 4 hrs, 10 hrs durations, it can be inferred that the same properties are sustained in the case of the longer duration than 10 hrs. Also, We can think that these properties stem from geographical and meteorological characteristics of the region. Though several ideas are introduced by some researchers, the relationships between ARFs and geographical, meteorological characteristics of region are not identified yet. For this purpose, the coefficient of regional variation is introduced to relate ARF and regional characteristics in this paper. Because the mean annual precipitation can be a variable to show the relationships between the meteorological characteristics of the rainfall and I-D-F relationship[6], it can be thought the spatial distribution of the rainfall can be explained to some degree by the coefficient of regional variation of the mean annual precipitation. Namely, that the coefficient of regional variation of the mean annual precipitation is large means the spatial distribution of rainfall is very irregular, and the value of ARFs are large. The coefficient of regional variation of the mean annual precipitation can be calculated by the following equation.

$$Cv = \frac{s}{m} \qquad (2)$$

where, Cv : coefficient of regional variation

s : standard deviation of the mean annual precipitation

m : average of the mean annual precipitation

As the coefficient of regional variation calculated by eq.(2) is 0.1513 to Bochung stream basin, 0.0872 to Pyungchang river basin, and 0.0359 to Wi stream basin, ARFs get large value according to increasing the coefficient of regional variation. As this trend can be identified by the Fig.12 and Fig.13, in Wi stream basin ARFs are always greater and the coefficient of regional variation is always smaller than other two regions in all return periods and durations. And in Bochung stream basin ARFs are always smaller and the coefficient of regional variation is always greater than other two regions.

Therefore the coefficient of regional variation can be used as criteria to select ARFs that are appropriate to the object regions and to presume ARFs to the region where data is not enough to calculate ARFs.

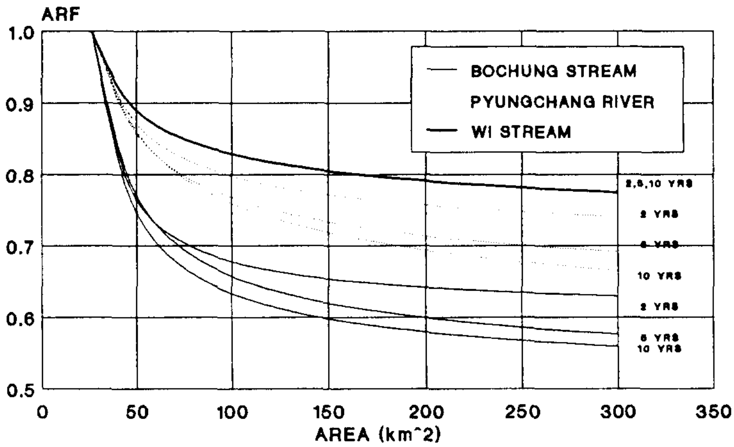

Fig. 11 Comparison of ARFs with river basing and return period

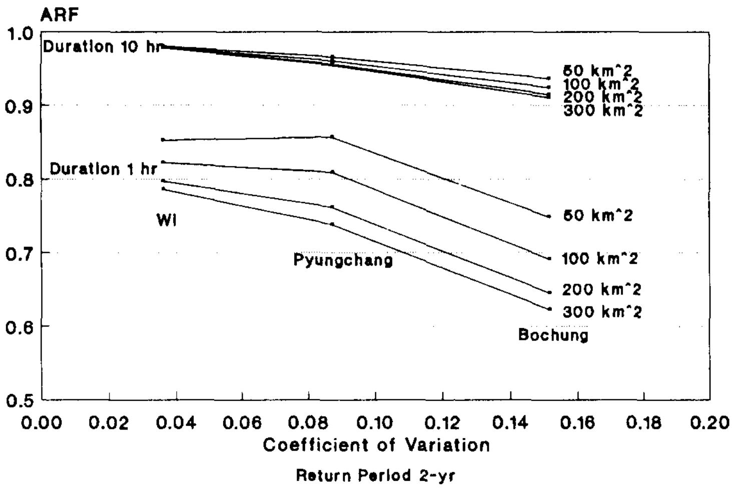

Fig. 12 ARFs vs. Cv at Wi, Pyungchang, Bochung stream basin

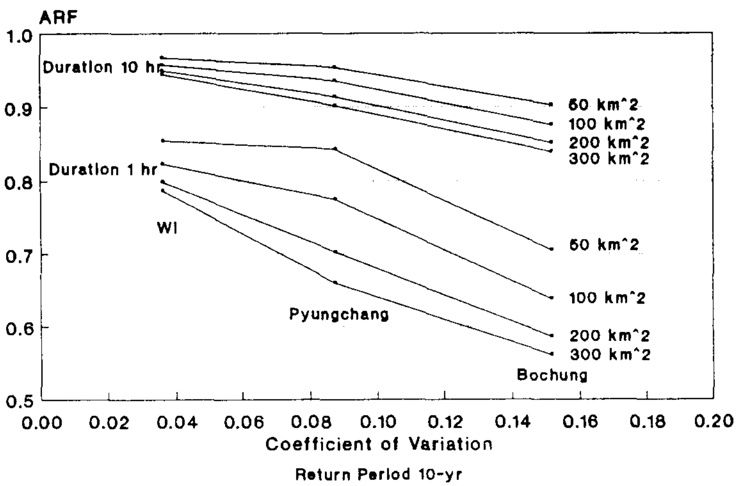

Fig. 13 ARFs vs. Cv at Wi, Pyungchang, Bochung stream basin

4. Conclusions

In this paper, ARFs have been estimated in Pyungchang river basin, Wi stream basin, and Bochung stream basin where the density of rainfall gauging station is relatively high and investigate the regional variation of ARFs and finally represent the criteria to select and to presume appropriate ARFs.

Conclusions are as follows.

(1) ARFs calculated in this paper represent a general characteristics of ARFs.

(2) But ARFs calculated in this paper represent different values according to selected regions, namely, ARFs in Wi stream basin are always greater and ARFs in Bochung stream basin are always smaller than other two regions in all return periods and durations.

(3) The coefficient of regional variation of mean annual precipitation proposed in this paper has relationships with ARFs, so the coefficient of regional variation has large value as ARFs become large and vice versa.

(4) Therefore the coefficient of regional variation of mean annual precipitation can be used as criteria to select appropriate ARFs and to presume ARFs.

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