Regionalized Daily Streamflow Model using a Modified Retention Parameter in SCS Method

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Abstract □ A regionalized daily streamflow model using a modified retention parameter in the SCS method was developed to predict the daily streamflow of a natural series for Korean watersheds. Model verification showed that it is possible to use the model for extending short period records in a gaged watershed or for predicting daily streamflow in any ungaged watershed, with reasonable accuracy by simply inputing the name of the watershed boundary, the watershed size, the latitude and longitude of the watershed, and the daily areal rainfall.

Keywords □ Daily streamflow model, SCS method, Effective rainfall, Retention parameter, Recession constants, Daily distribution factor, Regionalization

I. INTRODUCTION

Estimation of the daily streamflow for ungaged watersheds is one of the most important elements for the planning, design, and management of water resource development. A daily water balance analysis based on daily streamflow is essential for comprehensive utilization of water resources such as the determination of reservoir storage capacity, multi-use of irrigation water, management of equilibrium storage in tendem reservoirs, and inter-basin transfer of water.

A model based on a modified retention parameter in the SCS method was developed to predict the daily streamflow of a natural series using the data during the period of 1965–1986 from 42 hydrologic watersheds with an area ranging from 33km^2 up to 20,310km^2 in the Republic of Korea. The model was designed to have general applicability, simple input requirements, and reasonable accuracy. The model might be useful to draw the flow duration curve for drought analysis, reservoir sedimentation, river planning for navigation and leisure complex, and water quality control in a lowflow river.

II. MODEL DEVELOPMENT

The model consists of four basic parts ; They are the estimation of effective rainfall, daily distribution factor, recession constants, and regionalization.

1. Estimation of effective rainfall

The most important part of the model for daily streamflow is the estimation of effective rainfall, because it is very difficult to understand the hydrologic responses in a watershed of infiltration, evapotranspiration, and percolation. The amount of infiltration varies widely with the season and the antecedent moisture condition. Both the seperation method of direct runoff and the SCS model were reviewed and modified to be a suitable way for daily streamflow, respectively.

1) Seperation of direct runoff : In a complex hydrograph resulting from closely spaced bursts of rainfall, usually in the summer season, it was assumed to be an isolated stormflow event if there were successive bursts of rainfall within the fixed time base. Otherwise, each burst of rainfall was treated as a different stormflow event. For the application of the unit hydrograph concept, the method of seperation should be such that the time base of direct runoff remains relatively constant in each stormflow event. This is usually provided by terminating the direct runoff at a fixed time after the peak of the hydrograph for flood analysis, but in a daily complex hydrograph, seperation was made by terminating the direct runoff after the last day of rainfall instead

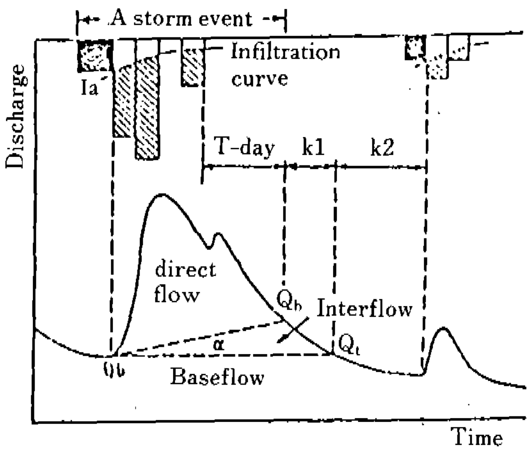

Fig. 1. Illustation of the seperation mothod, a stormflow event setting, and a recession curve

of the peak.

2) SCS model : The SCS model (1956) is a reliable procedure that has been used for many years in the United States. The SCS model was originally developed for predicting total volumes from watersheds where only total precipitation data was available. The time distribution of rainfall was not considered. However, the model was later extended for the determination of a flood hydrograph. The SCS model has some advantages, because it is computationally efficient, the required inputs are generally available, and it relates runoff to soil type, land use, and management practices.

$$Q=(P-0.2S)^2/(P+0.8S) \quad \cdots\cdots\cdots (1)$$

Where Q : Cumulative runoff (mm)
P : Cumulative precipitation (mm)
S : A retention parameter (mm)

The retention parameter S which represents the maximum available storage is transformed into another parameter called a curve number whose quantification is based on extensive field study and soil classification in the United States. The mean S value of the watershed was used in the equation that defines the curve number for the average watershed response in flood analysis. The S is limited by either the rate of infiltration at the soil surface or the amount of water storage available in the soil profile, whichever gives the lesser S value.

$$CN=25,400/(S+254) \quad \cdots\cdots\cdots (2)$$

The SCS model provides tables of curve numbers defined with respect to soil group, land use, land treatment, and antecedent moisture condition.

But, there are several weakpoints of the AMC procedure in the SCS model. First, the relationship between AMC and rainfall are shown as discrete classes, rather than being a continuum (Hawkins, 1978). Second, the use of 5 days' antecedent rainfall is not based on physical reality (Miller, 1979). Third, no consideration is given to the depletion of the catchment storage due to evapotranspiration and percolation which may vary from region to region within a season.

3) Modification of a retention parameter : Since such tables of curve numbers are not available in Korean watersheds and not suitable for daily streamflow, the S should be sought in a different way. The S value can be computed from eq. (1) for each observed streamflow event.

$$S=5\ [P+2Q-(4Q^2+5PQ)^{0.5}] \quad \cdots\cdots\cdots (3)$$

The new concept of a modified retention parameter S_a was defined. A modified retention parameter was newly introduced by replacing S into S_a. A regression equation for S_a could be set up from the observed streamflow events. Since S_a is the compound index of storage capacity of available water, it takes into account the antecedent moisture condition at a certain time and on a given watershed. The S_a value might be a function of the cumulative precipitation and the depth of baseflow which is an index of the antecedent moisture condition of a watershed. Other variables might be included to improve the relationship. The following general expression was proposed.

$$S_a=C_0+C_1\times P+C_2\times Q_b \quad \cdots\cdots\cdots (4)$$

where S_a : a modified retention parameter (mm)
C_0, C_1, C_2 : regression coefficients
P : cumulative precipitation (mm)
Q_b : baseflow just before stormflow event (mm)

Since there was some question on the adjustment of the coefficient of initial abstraction 0.2, it was reviewed.

$$I_a = k \times S_a \quad \cdots\cdots (5)$$

$$Q = (P - I_a)^2 / (P - I_a + S_a) \quad \cdots\cdots (6)$$

where k : coefficient of initial abstraction
I_a : initial abstraction (mm)

Kim (1989) has suggested a new concept of a modified retention parameter and applied it to 10 watersheds in Geum watershed boundary to estimate effective rainfall.

If we know the cumulative precipitation for a storm event and the depth of the baseflow which is simulated by the recession constants in a dry period, we could compute the S_a value from eq. (4) and then the total effective rainfall from eq. (6), from which the daily effetive rainfall can be obtained in accordance to the ratio between daily and total precipitation during a stormflow event. The S_a will be obtained not from the tables of curve numbers, but from a regression equation. The modified retention parameter for effective rainfall will not require soil groups, land use, land treatment, hydrologic condition, or antecedent moisture condition, but will only require the cumulative precipitation and depth of the baseflow simulated. The modified model overcame the shortcomings of the AMC procedure in the original SCS model by tracing the continuous variation of S_a on a daily basis.

2. Daily distribution factor

The distribution graph, first proposed by Bernard, represents the unitgraph in the form of the percentage of total flow occuring in particular unit periods. The relation between the effective rainfall and direct runoff can be expressed in matrix form.

$$PU = Q \quad \cdots\cdots (7)$$

where P : Matrix of effective rainfall
U : Unit hydrograph
Q : Matrix of direct runoff

There are several methods for determining the unit hydrograph from eq. (7). When the number of the equation exceeds the number of the unit hydrograph ordinates, an optimal determination of the unit hydrograph ordinates can be made using the least square method. Equation (7) can be written as

$$U = (P^t P)^{-1} P^t Q \quad \cdots\cdots (8)$$

where P^t : Transposed matrix of effective rainfall
P^{-1} : Inverse matrix of effective rainfall

This solution of linear simultaneous equations produces cumulative error, but error in U_i is less sensitive for daily streamflow than for flood analysis.

Daily streamflow during a stormflow event can be finally obtained by multiplying the unit hydrograph ordinates by the daily effective rainfall and superpositioning them and adding the interflow (α) and baseflow (Q_b) on a daily basis.

3. Interflow component

A straight line is drawn to a point at a fixed time base after the last day of rainfall from the rising point on the hydrograph. It makes the seperation slope of α which is defined to interflow in the structure of the model. This slope should be added to the direct flow along with base flow to simulate the total flow during a stormflow event (Fig. 1).

4. Recession constants

The falling part of the hydrograph can be subdivided into a number of recession curves. The hydrograph of interflow and baseflow is represented very closely by

$$Q = Q_0 \times k^t \quad \cdots\cdots (9)$$

where Q : discharge at t unit times later
Q_0 : discharge at a selected time
k : recession constant
t : unit time, taken as one day

We defined here, for convinience, the interflow recession curve (k_1) as the part from the end point of direct flow to the point where the depth is the same as the baseflow just before the stormflow event, and the baseflow recession curve (k_2) as the part from that point to the base flow just before next stormflow event (Fig. 1). Daily streamflow during a rainless period can be estimated by applying appropriate k_1 and k_2 values successively to the end point of direct flow.

5. Regionalization of model

After the parameters for the daily streamflow estimation such as regression coefficients for effective rainfall, daily distribution factors, and recession constants were determined through previously discussed procedures, the daily

Table 1. Summary of hydrologic gauging station

Watershed boundary	Name of station	Code no.	Area (km²)	Period C.V.**	Watershed boundary	Name of station	Code no.	Area (km²)	Period C.V.**
Han	Yeoju	1	11,130	65−70	Geum	Whedeok	26	648	83−86
River	Chungju	2	6,657	65−70	River	Sange	27	476	83−86
	S.Y.dam	3	2,703	74−83		Gidae	28	347	83−85 86
	Yongwol	4	2,430	65−69		Ipeong	29	80	83−85
	Hupo	5	1,611	83−85					—
	Gwesan	6	671	76−83 84	Seomjin	Songjong	30	4,477	65−72
	Juchon	7	529	83−86	River	Abrok	31	2,448	65−73
				—		Bosung	32	275	76−81
Kakdong	Jindong	8	20,310	65−70					—
River	Waegwan	9	11,074	65−74 75	Yeongsan	Naju	33	2,060	65−71 72
	Jeongam	10	2,990	65−70	River	Mareuk	34	684	72−80
	A.D.dam	11	1,580	77−86		Nampeong	35	581	65−72
	Imha	12	1,360	67−76					—
	Weolpo	13	1,140	74−83	Anseong	Yucheon	36	492	70−72 73
	Changri	14	924	69−76	River	Yangrong	37	388	82−85
	Songriwon	15	475	80−85		Whewha	38	367	70−73
	Sanyang	16	212	70−76					—
	Yian	17	190	69−73	Taewha	Ulsan	39	439	70−72
	Gajang	18	149	69−75	River				—
	Donggok	19	33	83−85					—
				—	Suncheon	Yangyul	40	190	65−70
Geum	Gongju	20	7,126	67−74					—
River	D.C. dam	21	4,134	81−86	Geum	*Songpo	41	3,940	67−75 67
	Okcheon	22	2,943	67−71	River				—
	Seokwha	23	1,560	65−68					—
	Sutong	24	1,517	82−84	Anseong	*Songsan	42	242	70−73 70
	Yongdam	25	937	70−76	River				—

* : Station for verification of RDSM ** : C. ; Calibration V. : Verification

streamflow model can be constructed. Regionalization of the daily streamflow model should be made in order to apply the daily streamflow model to the ungaged watershed. Regionalization for general applicability could be statistically possible through multivariate analysis, but it will be undertaken in a hydrologic common sense in this study.

III. DATA SOURCES AND WATERSHED DESCRIPTION

Streamflow data is usually published in the form of mean daily streamflows. Since water level in a river was first recorded in 1904, there are about 250 gaging stations around the country. Daily streamflow data from 42 watersheds with sufficiently long peroids of record and accurate rating curves were chosen. Daily rainfall data from 104 stations mostly equipped with recording raingages were analysed to determine the areal daily rainfall by the Thiessen method.

The watershed of the Republic of Korea occupies 98,934km², and is divided into 5 major watersheds, i. e., the Han river, The Geum river, the Nakdong river, the Seomjin river, and the Yeongsan river watershed. The topography is mountainous. The highest mountains are in the eastern basin at 1,700 meters above sea level and western basin is lower and contains most of the

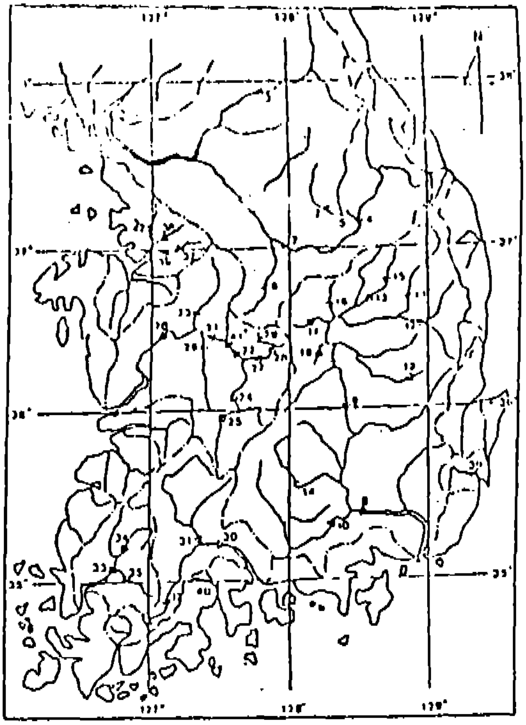

Fig. 2. Map of hydrologic gauging stations

flat land. The climate is humid-temperate and conditioned mainly by Asian monsoon. The temperature ranges from–20℃ to +35℃. Annual precipitation averages about 1,250mm with variation from 800mm to 1,600mm and about 70 percent falls during the summer rainy season.

IV. PARAMETER ESTIMATION

Data of daily streamflow and rainfall for the period 1965–1986 were used. It was assumed that the hydrologic systems of watersheds were time invarient and in a closed system. Parameters for daily streamflow such as estimation of effective rainfall, daily distribution factor, and recession constants were obtained from storm events of 2,000 or more selected from the observed daily hyeto-hydrograph.

1. Estimation of effective rainfall

Estimation of effective rainfall was estimated from a modified SCS model which considers the seperation slope, initial abstraction, and modified retention parameter S_a.

1) Seperation slope : It was found that seperation slope depends on the storm size, watershed size, and the season. Seperation slope as shown in Table 2 ranged from 0.18 to 0.01mm/day. This value is relatively small compared to the 1.1mm/day in the flood hydrograph reported by Hewlett (1977).

Table 2. Seperation slope for interflow

Watershed area	Dry	Semidry	Rainy
500km^2 or less	0.05	0.10	0.18
500−2,000km^2	0.03	0.07	0.13
2,000−8,000km^2	0.02	0.05	0.08
8,000km^2 or more	0.01	0.03	0.06

2) Coefficient of initial abstraction : Coefficient of 0.2 was available for the medium storm which is about 80mm to 200mm in this modified SCS model. The estimated effective rainfalls were generally underestimated for a large storm and overestimated for a small storm. This showed a similar trend to Kim's report (1984) and a reversed trend to Aron's paper (1977). The adjustment of coefficient was made according to the storm size. It was temporarilly adjusted to 0.25 for 30mm or less, 0.23 for 30−80mm, 0.20 for 80−200mm, and 0.1 for 200mm or more. It significantly improved the accuracy of effective rainfall estimation.

3) Modified retention parameter S_a : Computing procedure of regression coefficient for S_a in Gidae watershed was shown in Table 3. Cumulative effective rainfall can be predicted by inserting S_a value into eq. (6) considering the adjusted I_a.

Following the same procedure for Gidae watershed in Table 3, regression coefficients for S_a of 40 watersheds in Korea were obtained and a comparison between predicted (Q_c) and observed (Q_o) effective rainfall was made as shown in Table 4. In test with data from 40 watersheds regression equations beteen predicted (Q_c) and observed (Q_o) effective rainfall showed that slopes were 0.857 to 1.071 except 4 stations and coefficients of determination (R^2) were 0.9 to 1.0 for 28 watersheds as shown in Table 4.

2. Daily distribution factor

The time base was fixed to seperate base flow from direct flow and to find the unit hydrograph ordinates from the observed hydrograph. The

Table 3. Stormflow event setting and regression coefficient for Gidae watershed

No.	Event period	day	Se	Qb	P	Q	Qo	S	Qe
				--------	--------	-------- mm	--------	--------	-------- mm
1	1983/ 3/ 1~ 3/ 5	5	1	0.0	27.7	11.2	5.8	43.4	0.2
2	1983/ 6/ 19~ 6/ 23	5	2	0.2	102.7	17.7	14.0	207.0	27.2
3	1983/ 6/ 28~ 7/ 7	10	3	0.5	90.2	39.6	31.3	92.5	26.2
4	1983/ 7/ 14~ 7/ 18	5	3	0.8	59.9	24.7	18.6	68.5	16.3
5	1983/ 7/ 19~ 7/ 28	10	3	1.5	202.4	150.9	132.1	77.5	111.0
6	1983/ 8/ 9~88/ 12	4	3	0.4	16.4	3.5	0.9	47.1	0.0
7	1983/ 8/ 20~ 9/ 1	13	3	0.2	108.7	20.7	15.5	214.1	29.7
8	1983/ 9/ 2~ 9/ 8	7	3	0.6	59.5	20.2	10.8	102.2	13.3
9	1983/ 9/ 9~ 9/ 15	7	3	1.9	95.0	66.4	46.7	63.0	62.3
10	1984/ 4/ 17~ 4/ 22	6	2	0.0	77.3	27.0	23.2	91.2	13.0
11	1984/ 4/ 28~ 5/ 4	7	2	0.6	39.5	19.2	13.8	40.2	6.0
12	1984/ 5/ 12~ 5/ 17	6	2	0.3	44.9	8.0	5.9	92.2	5.2
13	1984/ 6/ 6~ 6/ 10	5	2	0.3	62.5	18.8	14.9	89.2	10.9
14	1984/ 6/ 19~ 6/ 24	9	2	0.3	80.1	13.5	7.3	193.5	19.2
15	1984/ 6/ 25~ 6/ 26	5	2	1.0	44.5	22.8	15.7	44.9	13.0
16	1984/ 7/ 3~ 7/ 16	14	3	0.8	183.7	99.3	71.6	165.9	74.4
17	1984/ 7/ 28~ 8/ 1	5	3	0.3	36.9	7.2	4.4	79.4	3.1
18	1984/ 8/ 2~ 8/ 6	5	3	0.8	31.5	7.7	3.4	70.9	5.3
19	1984/ 8/ 13~ 8/ 13	7	3	0.5	18.9	6.1	1.8	44.9	0.2
20	1984/ 8/ 30~ 9/ 7	9	3	0.6	152.3	61.8	38.0	209.9	55.7
21	1985/ 3/ 24~ 3/ 30	7	1	0.5	35.3	10.9	4.6	72.5	3.9
22	1985/ 5/ 4~ 5/ 10	7	2	0.2	67.5	29.9	24.1	67.2	11.6
23	1985/ 5/ 12~ 5/ 17	6	2	0.7	58.7	21.3	16.8	72.3	14.3
24	1985/ 7/ 3~ 7/ 21	19	3	0.3	382.0	231.3	204.6	222.3	181.2
25	1985/ 7/ 30~ 8/ 6	8	3	0.6	33.5	7.6	2.4	88.4	4.2
26	1985/ 8/ 9~ 8/ 23	14	3	0.5	227.1	104.1	86.6	210.3	103.5
27	1985/ 10/ 10~ 10/ 16	7	1	1.3	83.8	69.9	52.0	36.2	38.6

Se : 1 ; Dry(Oct. -Mar.) 2 ; Semi dry(Apr. -Jun.) d ; Rainy(Jul. -Sep.)

Summary Table

VAR.	REG. COEF.	STE. ERR.	T VALUE	95% CONF. IN	99% CONF. IN
Const.	74.378	15.35	4.85	42.70~ 106.06	31.45~117.31
P	0.699	0.10	7.00	0.49~ 0.91	0.42~ 0.98
Qb	−55.190	18.28	−3.02	−92.92~−17.46	−106.32~−4.06

R^2 : 0.694 CRITICAL T0.01 : 2.797

STANDARD ERROR : 40.679 CRITICAL T0.05 : 2.064

Table 4. Regression coefficients for S_a and comparison between predicted (Q_e) and observed (Q_o) effective rainfall

Watershed boundary	Name of station	$Sa=C_0+C_1\times P+C_2\times Q_b$			$Q_e=a+b\times Q_o$		
		C_o	C_1	C_2	a	b	R^2
Han River	Yeoju	93.2**	0.560**	−41.4**	2.2	1.000	0.984
	Chungju	91.2**	0.248**	−32.1**	2.3	0.979	0.986
	S.Y. dam	52.5**	0.430**	−26.4**	1.2	0.979	0.967
	Yongwol	89.8**	0.345**	−27.6**	0.4	1.031	0.983
	Hupo	61.3**	0.785**	−20.0*	0.9	0.949	0.930
	Gwesan	67.4**	0.877**	−55.3**	1.4	0.886	0.883
	Juchon	67.9**	0.472**	−30.7*	0.8	0.953	0.977
Nakdong River	Jindong	67.9**	0.532**	−23.8**	−0.8	1.048	0.962
	Waegwan	60.3**	0.505**	−18.9**	0.3	0.962	0.951
	Jeongam	80.5**	0.414**	−40.2**	0.2	0.986	0.925
	A.D. dam	44.8**	1.476**	−48.7**	0.6	0.889	0.775
	Imha	60.1**	0.624**	−17.4**	−0.3	0.984	0.904
	Weolpo	88.1**	0.357**	25.9**	1.1	0.952	0.956
	Changri	49.4**	0.699**	−18.7*	1.1	0.935	0.936
	Songriwon	48.9**	1.223**	−28.9**	2.0	0.760	0.767
	Sanyang	49.7**	0.912**	−20.5*	0.9	0.882	0.897
	Yian	53.0**	0.581**	−20.7*	−0.9	0.963	0.910
	Gajang	61.4**	0.644**	−85.4**	2.2	0.809	0.872
	Donggok	76.0**	0.578**	−20.0*	−5.5	1.071	0.981
Geum River	Gongju	64.6**	0.711**	−32.5**	1.9	0.878	0.873
	D.C. dam	62.4**	0.563**	−28.9**	1.2	0.983	0.944
	Okcheon	48.5**	0.648**	−21.7**	0.7	0.990	0.904
	Seokwha	58.7**	0.330**	−20.3**	0.2	0.985	0.945
	Sutong	81.3**	0.378**	−50.0**	0.2	1.029	0.980
	Yongdam	59.6**	0.452**	−21.3**	2.5	0.857	0.907
	Whedeok	59.6**	1.099**	−29.9*	0.7	1.022	0.779
	Sange	61.3**	1.548**	−21.6*	0.8	0.926	0.800
	Gidae	74.4**	0.699**	−55.2**	2.4	*0.905	0.948
	Ipeong	64.4**	0.736**	−15.3*	1.1	0.994	0.916
Seomjin River	Songjong	78.8**	0.302**	−28.4**	0.7	0.976	0.965
	Abrok	56.2**	0.422**	−17.7**	3.8	0.877	0.872
	Busung	57.2**	0.610**	−26.7**	2.4	0.864	0.860
Yeongsan River	Naju	61.0**	0.445**	−25.3**	1.7	0.903	0.902
	Mareuk	66.7**	0.476**	−16.1**	1.3	0.931	0.926
	Nampeong	63.6**	0.565**	−26.6*	4.1	0.758	0.788
Anseong River	Yucheon	60.3**	0.705**	−30.0**	−0.6	1.028	0.967
	Yangrong	119.4**	0.990**	−66.5**	1.2	0.914	0.942
	Whewha	72.0**	0.637**	−26.3**	1.7	0.862	0.913
Taewha	Ulsan	61.4**	0.805**	−25.8*	−0.2	0.995	0.940
Suncheon	Yangyul	58.2**	1.409**	−27.8**	−2.5	1.329	0.906

time base (T–day) in Fig. 1 were determined through the empirical judgement of 2,000 or more stormflow events in observed hyeto-hydrograph and Beven's paper (1979). Daily distribution factor is not so sensitive in the daily streamflow that its seasonal variation was neglected. The time base was fixed to 3 days for 1,000km^2 or less, 4 days for 1,000–5,000km^2, 5 days for 5,000–15,000km^2, and 6 days for 15,000km^2 or more of watershed area. They were generally fitted well to the observed hydrograph. The daily distribution factor(U_i) was computed by the least square method and its sum was adjusted to be 1.0.

Table 5. Daily distribution factor according to watershed size

Area	〈1,000	〈5,000	〈15,000	〈15,000km^2
U_1	0.58	0.40	0.25	0.22
U_2	0.28	0.34	0.38	0.32
U_3	0.14	0.18	0.21	0.22
U_4		0.08	0.11	0.13
U_5			0.05	0.08
U_6				0.03

3. Recession constants

Recession constants are generally obtained from the hydrographs using the master recession curve method. It seems that k_1 value is related to storm size and k_2 value represents the seasonal evapotranspiration activity of the watershed. From the 1,470 recession events, the formulae are suggested to estimate the average monthly interflow and baseflow recession constants from the watershed area, which are essential parameters to develop the long term runoff model.

4. Regionalization

Regionalization of the model for general applicability was made in a hydrologic common sense under the following assumptions.

(1) Watershed boundaries in the Korean watershed were classified into 5 watersheds. i.e., the Han river, the Geum river, the Nakdong river, the Seomjin river, and Yeongsan river watersheds. It was assumed that each watershed boundary had its own topographic, hydrogeologic, and meteorologic characteristics.

(2) Characteristics of parameters for daily streamflow obtained from the gaged watershed can be applied to the proposed station if two stations are located at the same watershed boundary and have similar size of watershed area.

(3) In the case of a small ungaged watershed with an area less than 500km^2, characteristics of parameters of daily streamflow obtained from the most nearby gaged watershed can be applied, regardless of its watershed boundary.

V. TEST OF THE MODEL

1. Daily Streamflow Model (DSM)

In order to test the availability, DSM with parameters obtained from observed data was applied to the data of reserved periods in 6 watersheds for model verification. The results are shown in Table 7 and Fig. 3.

2. Regionalized Daily Streamflow Model (RDSM)

Structure of RDSM including Regionalization, Hydrologic Data Management System (HDMS), Thiessen method, and Daily Streamflow Model is shown in Fig. 4.

Table 6. Regression constants for interflow and baseflow

Mon.	$k=a+b\times\log_{10}A$ (km^2)				Mon.	$k=a+b\times\log_{10}A$ (km^2)			
	k_1		k_2			k_1		k_2	
	a	b	a	b		a	b	a	b
Jan.	0.793	0.027	0.921	0.014	Jul.	0.568	0.056	0.837	0.020
Feb.	0.809	0.021	0.933	0.011	Aug.	0.617	0.044	0.827	0.022
Apr.	0.802	0.019	0.937	0.008	Sep.	0.650	0.051	0.879	0.017
Mar.	0.676	0.041	0.872	0.018	Oct.	0.792	0.022	0.948	0.002
May	0.678	0.040	0.895	0.007	Nov.	0.743	0.036	0.937	0.009
Jun.	0.626	0.057	0.836	0.029	Dec.	0.776	0.031	0.897	0.019

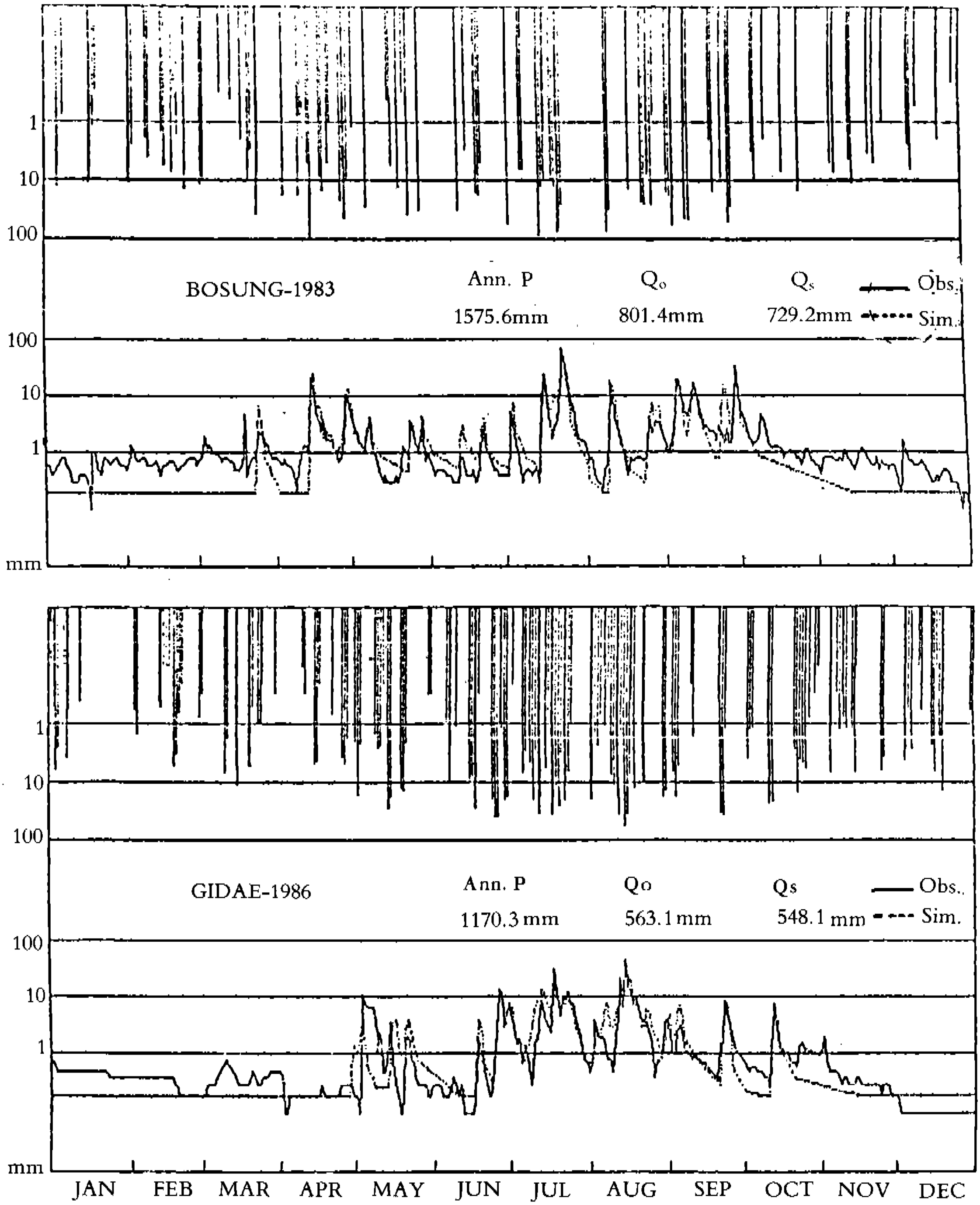

Fig. 3. Daily streamflow hydrograph simulated by DSM in Bosung and Gidae watershed

Table 7. Conparison between simulated (Q_s) and observed (Q_o) monthly streamflow for verification periods (in mm)

Watershed		Jan.	Feb.	Apr.	Mar.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Ann.	Ratio
Bosung	P	34.0	38.6	79.5	255.2	113.7	72.1	366.0	205.9	305.3	37.0	34.4	10.9	1575.6	–
1983	Q_o	17.3	19.4	34.0	92.0	41.9	17.9	226.4	67.1	202.3	47.0	22.0	14.1	801.4	50.9
	Q_s	6.2	5.6	20.2	107.6	43.5	33.3	206.6	76.2	192.2	24.8	6.8	6.2	729.2	46.3
Gidae	P	13.2	13.5	37.1	20.8	104.7	204.4	247.1	251.2	102.4	102.4	28.5	45.0	1170.3	–
1986	Q_o	14.7	8.8	13.2	6.4	60.9	51.2	150.9	164.4	43.5	35.8	10.2	0.0	563.1	47.9
	Q_s	6.2	5.6	6.2	8.3	36.7	60.8	162.2	180.7	47.1	21.6	6.5	6.2	548.1	46.8
Yucheon	P	36.3	3.7	3.5	92.5	53.5	129.0	26.0	127.5	47.5	13.0	8.5	0.0	541.0	–
1973	Q_o	41.3	31.2	15.6	13.3	21.9	43.4	33.0	24.3	34.1	16.1	7.1	6.4	287.7	53.2
	Q_s	7.8	5.6	6.2	28.6	21.5	33.2	28.2	55.6	52.6	14.4	6.8	6.2	266.7	49.3
Gwesan	P	9.0	5.6	21.9	117.7	80.2	192.9	159.9	178.3	215.2	29.9	69.0	16.4	1096.0	–
1984	Q_o	3.8	3.3	6.1	39.6	22.9	97.6	100.4	23.3	144.0	13.3	14.9	8.9	478.1	43.6
	Q_s	6.2	5.8	6.2	33.2	35.7	50.8	93.4	56.4	124.5	11.9	14.1	8.6	446.8	40.8
Gongju	P	14.6	11.0	79.4	136.5	106.3	89.4	362.8	166.7	199.0	60.2	46.9	33.6	1306.4	–
1975	Q_o	9.2	8.2	21.5	41.4	54.8	18.8	187.9	66.5	114.1	30.3	18.6	13.8	585.1	44.8
	Q_s	3.1	2.8	8.4	40.7	71.1	21.8	179.7	121.6	133.5	42.9	8.1	3.1	636.8	48.7
Waegwan	P	13.0	14.3	80.6	115.3	105.0	115.5	345.5	86.8	186.8	64.3	54.9	25.6	1207.6	–
1975	Q_o	4.9	3.5	22.4	36.1	66.5	17.1	216.2	58.3	92.3	28.5	30.2	15.2	591.2	49.0
	Q_s	3.1	2.8	11.3	34.9	57.3	35.2	220.3	86.0	112.8	57.2	13.6	5.9	640.4	53.0

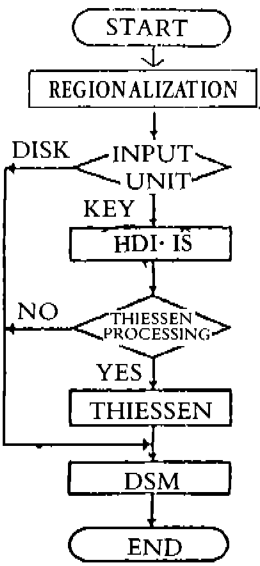

Fig. 4. Structure of RDSM

The depth of the initial streamflow (Q_b) of the starting date should be assumed, normally 0.2mm is taken, to run RDSM for an ungaged watershed. The daily streamflow by RDSM with parameters obtained from regionalization were simulated by inputing the name of watershed boudary, the watershed size, the latitude and longitude of the watershed, and the daily areal rainfall in two reserved watersheds of Songsan and Songpo for model verification. Scattergrams of simulated, by RDSM, and observed monthly streamflow depths were shown in Fig. 5. It is natural that the result of RDSM is less accurate than that of DSM. Kim (1988) in a practical manner applied RDSM to develop the daily water balance model and to simulate the daily water level of Sapkyo-Sambong reservoirs, and to evaluate the possibility of multi-use of irrigation water. It showed excellent applicability.

VI. SUMMARY AND CONCLUSION

The basic time periods for water yield assessment is usually in daily streamflow volume. Since evaluation of spatial and temporal distribu-

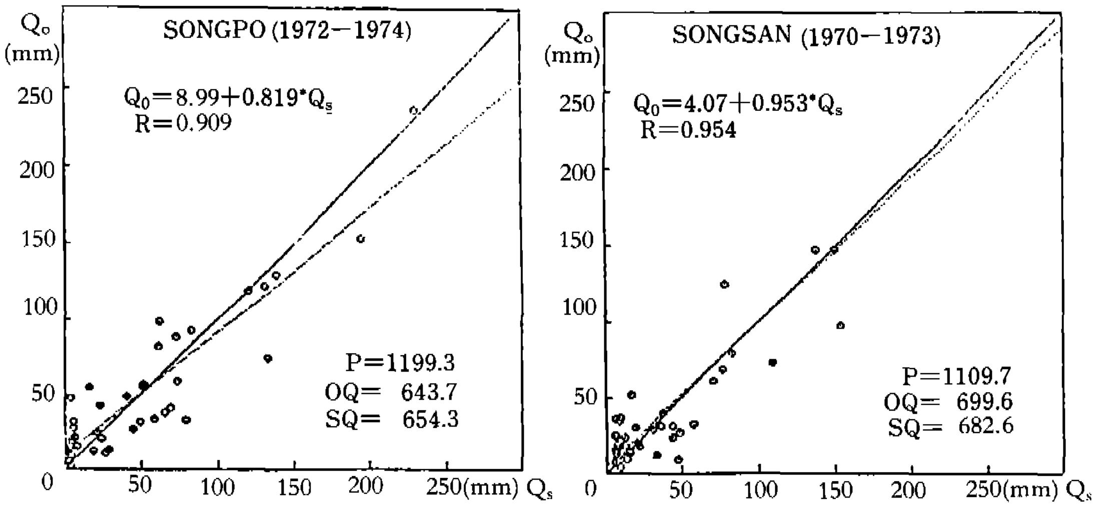

Fig. 5. Scattergram of simulated and observed monthly streamflow in Songsan and Songpo of verification watershed

tion of streamflow is very important for water resource development, a model was developed to predict daily streamflow of a natural series using daily streamflow data from 42 hydrologic watersheds with an area ranging from 33km² up to 20,310km². It is possible with the model to draw a flow duration curve for drought analysis, reservoir sedimentation, river planning for navigation and leisure complex, and water quality control in lowflow river. And it will be possible afterwards to develop the daily water balance model to determine the reservoir storage capacity, multi-use of irrigation, and inter-basin transfer of water.

Modeling processes were summarized as follows :

1. From the observed hyeto-hydrograph, baseflow was seperated directly by the base time method, which terminates the direct flow at a fixed time base after the last day of rainfall.
2. The SCS equation was revised for daily streamflow. Modified retention parameter S_a was newly introduced and obtained not from the curve number, but from a regression equation.
3. The time base was determined according to watershed size. Daily distribution factor was determined by the least square method.
4. Daily streamflow during rainless periods were determined by recession constants of interflow and baseflow. The relationships between recession constants and watershed area on a monthly basis were derived.
5. The results of evaluating the performance of RDSM requiring the simple input of data of rainfall, the name of watershed boundary, the watershed area, and the longitude and latitude of the watershed were generally satisfactory.

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