Small Watershed Peak Flow Prediction

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ABSTRACT/ To estimate the peak discharge from the small rural watersheds, 53 storm events of seven small watersheds from 1972 to 1989 were selected and were analyzed by the multiple regression technique. The peak values by the new prediction method developed in this study were compared to the real data of Banwol Basins and the estimated peaks of the several watersheds which were analyzed by the Korean engineering companies. These values were also compared to the results from the other methods, i.e. the Rational Method, the Kajiyama Method, the Nakayasu Unit Hydrograph Method, the Area Routing Method, etc., which are favored by the Korean engineering companies. Through these comparisons, it is proved that the proposed method may be used for day-to-day use without any problem. However, there should be some modifications and improvements as more data are available in the future.

1. Introduction

Although the hydrologic design of the major structures has considerable interest and importance, the most of the man's effort in hydrologic design has been directed to the minor structures in the rural and urban areas. These minor structures are associated with relatively small watersheds which have been defined (AGU Committee on Runoff, 1957) as ones which are so small that their hydrographic sensitivity to high intensity rainfalls of short durations and to land use are not suppressed by the effect of channel or basin storage characteristics. Therefore, many engineering designs have been generated concerning runoffs from these small watersheds.[9]

Hydraulically, the runoff on overland surfaces and in channels may be described mathematically by the Saint Venant Equations. But, it is rather complicated and difficult to solve. Therefore, many simplified methods have been proposed to estimate the peak

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discharge from the watersheds because it is enough to know only the peak discharge in many design problems. In this sense, the purpose of this study is to develop a new peak discharge prediction method for small rural watersheds.

2. Peak Discharge Prediction Methods Used Frequently in Korea

There are various peak discharge prediction methods[6,7,8]; the empirical drainage area formulas, the rainfall intensity formulas, the frequency formulas, the monograph methods, the unit hydrograph method, the synthetic methods, and more advanced hydraulic simulation models. The frequency formulas are based on statistical analysis of flood data in the same way as the USGS method. The U. S. Bureau of Public Road (BPR) Method, the Chow's Method, the Cook Method, and the California Method belong to the monograph methods using graphs as a design aid.

Although there are many peak flow prediction methods as mentioned above, a few of them such as Rational Method, Kajiyama Method, Nakayasu Synthetic Method, and Area Routing Method have been used more frequently by Korean Engineering Companies. Table 1 reveals this situation clearly.

Table 1. Estimation Methods of Peak Discharge Used by Korean Engineering Companies.[2 3,4,5]

Basin	Company	Using Equations
Myoungjung – Urson	Namwon	Rational Method, Kajiyama Method, and Nakayasu Method * Selected Rational Method
Namdong – Inchon	Sunjin	Rational Method, Kajiyama Method, and Area Routing Method * Selected Area Routing Method
Chilkok – Taigu	Daeah	Rational Method, Nakayasu Method, and Area Routing Method * Selected mean value
Kwangjuchon – Kwangju City	Saman	Rational Method, Kajiyama Method, Nakayasu Method, and Area Routing Method * Selected lower value

3. Development of Peak Flow Prediction Model

In developing a peak flow prediction model for small watersheds, the following items were considered: a model based on major meteorological and geomorphological factors of catchment areas; a model with plain and objective input data; a model based on sound hydrological principles; and a model with logical schemes and consistent results.

3.1 Multiple Regression Analysis.

To obtain a simple peak flow prediction model, the multiple regression analysis technique was applied to rainfall-discharge records from the seven, steep, and upland catchments in Korea.

The factors included in the multiple regression analysis are the rainfall intensity (i), the catchment area (A), the channel length (L), the channel slope (S), the S. C. S. runoff curve number (CN), and the base flow (Q_b).

A weighting method[11] on rainfall intensities was also introduced to reflect varying contribution to peak discharges from different rainfall intensities.

3.2 Selection of Research Catchments.

The small catchments less than 55 km^2 in area were selected among the IHP catchments having rainfall-discharge records.[11] In particular, from the Pyoungchang River Basin, the Wi Stream Basin, and the Bochung Stream Basin, the smallest watershed in each basin was selected. The major geomorphological characteristics of these catchments are summarized in Table 2.

Table 2. Characteristics of Basins

Name of Basin	Basin Area $A(km^2)$	Channel Length L(km)	Length to Center L_c(km)	Channel Slope S	No. of Analyzed Storms
Pyoungchang Yimokjung	55.93	16.55	7.20	0.02037	14
Wichun Dongkok	33.63	8.00	4.00	0.04057	14
Bochungchun Samsung	53.70	13.01	5.52	0.01615	9
Kyounganchun	9.36	5.00	2.30	0.01786	2
Musimchun	19.86	4.60	2.10	0.01754	5
Banwol Sungpori	1.64	1.59	0.75	0.02600	5
Banwol Daeyamiri	2.70	3.83	1.90	0.01377	4

3.3 Data Analysis.

The rainfall-discharge records published from the Korea Ministry of Construction were used. 53 storm events between 1972 and 1989 were selected to examine storm characteristics and identify collinearity among variables. Without exception the observed major storms occurred during wet summer season in Korea between June and September.

The correlation between the logarithmic transforms of peak discharge rates and the weighted sum of rainfall is a function of the exponent n (Table 3 and Fig. 1). The highest simple correlation was achieved with the weighting value n=1.5. The p's in parentheses denote statistical significance levels.

Table 3. Simple Correlation between n and Peak Discharge

Classification	$\ln(P_{0.5})$	$\ln(P_{1.0})$	$\ln(P_{1.5})$	$\ln(P_{2.0})$	$\ln(P_{2.5})$	$\ln(P_{3.0})$
$\ln(Qp/A)$	.7762 (p=.000)	.8277 (p=.000)	.8459 (p=.000)	.8353 (p=.000)	.8225 (p=.000)	.8122 (p=.000)

*1n: Natural logarithm

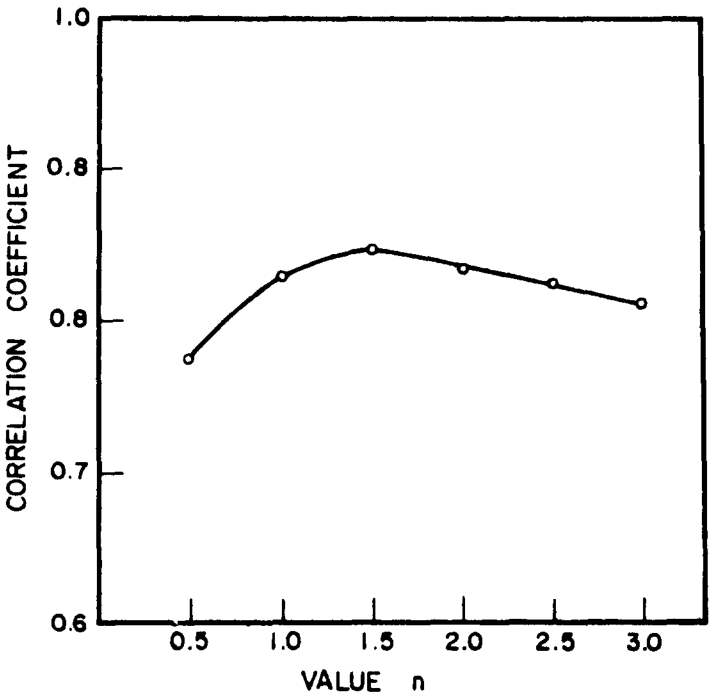

Fig. 1 Simple Correlation between n and Peak Discharge

The correlation matrices for the 53 data set were computed to examine any significant relations between variables (Table 4). No significant correlation between peak discharge rates and independent variables, except $P_{1.5}$, was obtained. A possible inference is that there exists collinearity between the variables, so multiple correlation equation should be used to describe the independent variable as a function of the dependent variables. Six multiple regression models with different combinations of the independent variables were derived from 53 storm data. The details of these models are summarized in Table 5.

There is no big difference in the multiple correlation coefficients among these models as indicated in Table 5. Because the estimation of runoff-curve numbers requires data on soil types, landuse, and antecedent precipitation of catchment areas, which may not be available for ungauged watersheds, M-5 was excluded from further consideration. In addition, M-1,

Table 4. Partial Correlation Coefficient between Independent Variables

Variable	$\ln(Q_p/A)$	$\ln(Q_b/A)$	$\ln(A)$	$\ln(L)$	$\ln(S)$	$\ln(P_{1.5})$
$\ln(Q_p/A)$	1.0000	.2803	.2361	.1839	−.0418	.8459
$\ln(Q_b/A)$	.2803	1.0000	.3767	.2351	.3120	.1842
$\ln(A)$	.2361	.3767	1.0000	.9196	.0948	.3052
$\ln(L)$	.1839	.2351	.9196	1.0000	−.1016	.2599
$\ln(S)$	−.0418	.3120	.0948	−.1016	1.0000	−.1173
$\ln(P_{1.5})$	.8459	.1842	.3052	.2599	−.1173	1.0000

Table 5. Multiple Correlation Models

Symbol	Independent Variable	Model	Correlation Coef.
M-1	$P_{1.5}$	$\ln(Q_p/A)=-.58120+0.84697*\ln(P_{1.5})$	84593 (.5473)
M-2	$P_{1.5}$, Q_b/A	$\ln(Q_p/A)=-.58356+0.82322*\ln(P_{1.5})$ $+.07703*\ln(Q_b/A)$	.85536 (.5369)
M-3	$P_{1.5}$, Q_b/A, A	$\ln(Q_p/A)=-.49427+0.84256*\ln(P_{1.5})$ $+.09273*\ln(Q_b/A)-.06722*\ln(A)$	.85828 (.5373)
M-4	$P_{1.5}$, Qb/A, A, L, S	$\ln(Q_p/A)=-.26865+0.84779*\ln(P_{1.5})$ $+.05172*\ln(L)+.06771*\ln(S)$ $+.09062*\ln(Q_b/A)-.099968*\ln(A)$	.85855 (.5481)
M-5	$P_{1.5}$, L, S, CN	$\ln(Q_p/A)=-6.12617+0.78848*\ln(P_{1.5})$ $+.22592*\ln(L)-.08883*\ln(S)$ $+1.17240*\ln(CN)$	.82029 (.6499)
M-6	$P_{1.5}$, A, L, S	$\ln(Q_p/A)=1.0008-.0037586*\ln(A)$ $+0.86285*\ln(P_{1.5})-.04051*\ln(L)$ $+.15176*\ln(S)$	.84855 (.5597)

*Values in parentheses are standard errors.

M-2, and M-3 were excluded because determining base flow for ungauged catchments depend on the subjective estimation. There seems to be no big difference between M-1 and M-6. As considering geomorphological factors such as channel slope, channel length, and catchment area change in wide range, however, M-6 should provide more robust predictions than M-1 because M-6 considers those factors and is more reasonable in the hydrological sense as well. M-6 was considered to be the most proper model among the six models for the prediction of peak flow from small watersheds. Therefore, M-6 is selected to predict the peak discharge in this study.

The analysis on catchments with various channel slopes and areas was not possible because of the data limitation. The preponderance of the relatively large catchment areas and steep slopes of data sets caused consistent patterns of deviation between estimated flows and measured data depending on the slope and area of the catchments.

3.4 Verification of the Suggested Model.

To verify the suggested peak flow prediction model, it was applied to the data sets from the Banwol Changhari Basin and the new data from the Banwol Sungpori catchment. Except the storm event of Changhari in 1983. 7. 28., the predicted peak discharge rates were almost same or slightly bigger compared to the observed. The results of analysis are summarized in Table 6.

Table 6. Comparison between Observed and Predicted Peak Flows (Unit: m^3/sec)

Name of Basin	Date of Rainfall	Observed Peak Flow	Predicted Peak Flow
Sungpori (A = 1.64 km^2, L = 1.59 km, S = 0.026	82. 7. 26 82. 7. 28 82. 8. 20 83. 7. 19	2.03 5.98 1.66 1.12	2.06 6.83 1.72 2.31
Janghari (A = 1.442 km^2, L = 1.05 km, S = 0.036)	82. 7. 26 82. 7. 28 82. 8. 20 83. 7. 3 83. 7. 19	0.78 4.40 0.83 1.28 1.27	0.90 4.12 0.88 1.29 2.25

4. New Peak Discharge Prediction Method

New prediction method developed in this study is as follows;

4.1 Calculation of the time of concentration t_c (hr).

If the channel slope is less than 1/200, use Rizha Equation.

$$t_c = 0.833\ L\ /\ (60xS^{0.6}) \tag{1}$$

where L is the channel length in km, and S is the channel slope (dimensionless).

If the channel slope is larger than 1/200, use Kraven Equation.

$$t_c = 0.444\ L\ /\ (60xS^{0.515}) \tag{2}$$

4.2 Calculation of the weighted rainfall $P_{1.5}$.

(1) Decide one value of the rainfall intensity i (mm/hr), the total rainfall depth D (mm), or one-day maximum rainfall R_{24} (mm) for the rainfall duration same as the time of concentration.

(2) If the total rainfall or one-day maximum rainfall is decided, calculate the rainfall intensity (mm/hr).

(3) Calculate the weighted rainfall $P_{1.5}$.

$$P_{1.5} = \int i(t)^{1.5} dt \tag{3}$$

where i(t) is the rainfall intensity (mm/hr) at time t.

* If the block type for the rainfall pattern is adopted, the weighted rainfall $P_{1.5}$ is

calculated by the following equation.

$$P_{1.5} = \sum_{j=1}^{n} i_j^{1.5} \times \Delta t \qquad (4)$$

where i_j is the rainfall intensity (mm/hr) at the j-th time interval and Δt is a time span which is calculated by t_c/n. Specially for the uniform (or rectangular) type rainfall distribution, $P_{1.5}$ can be calculated by the following equation.

$$P_{1.5} = (i^{1.5}) x t_c \qquad (5)$$

4.3 Calculation of Flood Peak Discharge Q_P (m^3/sec).

$$Q_P = 0.0453\ A^{0.996}\ P_{1.5}^{0.86}\ L^{-0.04}\ S^{0.15} \times AF \times SF \qquad (6)$$

where A is a basin area (km^2), AF is a Area Factor and SF is a Slope Factor. These factors are selected in Table 7 and Table 8.

* In this method, the peak discharge for a triangular rainfall distribution is 1.11 times of that of a uniform rainfall distribution.

Table 7. Area Factor AF

Range of Area (km^2)	AF	Range of Area (km^2)	AF
$A \leq 3$	1.50	$10 < A \leq 30$	1.00
$3 < A \leq 5$	1.35	$30 < A \leq 55$	0.90
$5 < A \leq 10$	1.10	–	–

Table 8. Channel Slope Factor SF

Range of Slope	SF	Range of Slope	SF
$S \leq 0.005$	1.50	$0.05 < S$	1.00
$0.005 < S \leq 0.05$	1.20	–	–

A computerized version of this model can be used to provide an easy-to-use tool for the peak flow prediction. In this study, the model was programmed in Turbo-Pascal programming language which can be used in most IBM compatible PC's.

5. Test of New Peak Discharge Prediction Method

5.1 Characteristics of the Test Basins.

New prediction method in this study is applied to the three basins which are the

Changneung Stream Basin,[4] the Kwangju Stream Basin,[5] and the Myoungjung Stream Basin.[3] These basins are selected to test the applicability of new prediction method. The characteristics of these watersheds are listed in Table 9.

Table 9. Characteristics of the Test Basins

Symbol	Main Point	Basin Area $A(km^2)$	Channel Length L(km)	Channel Slope S
SU_2	Suohneung Cross Street	1.03	1.06	0.0172
B_2	before joining with Bookhanchun	1.69	1.57	0.1000
S_2	joining point with Angolchun	2.05	1.30	0.00787
H_2	joining point with Moomyoungchun	2.13	1.27	0.00714
SU_1	before joining with Gichun	2.25	2.36	0.0111
B_1	Sumoonan point	3.72	2.92	0.1051
S_1	joining point with Enmoosichun	3.89	2.45	0.00612
SU_0	mouth of Soonchangchun	4.30	3.50	0.0087
H_1	Dukeun bridge	4.78	2.90	0.00573
B_0	mouth of Bookhanchun	5.70	4.70	0.09445
S_0	mouth of Sungsachun	7.60	6.00	0.003466
H_0	mouth of Hyangdongchun	9.50	4.80	0.00411
C_8	before joining with Joonggolchun	21.71	8.70	0.0187
C_6	Gichook bridge	30.13	10.14	0.0167
C_3	before joining with Soonchangchun	47.18	16.74	0.0111
K_0-1	before joining with Jeungsimsachun	28.39	10.80	0.0702
K_0-3	Yangrim bridge	42.15	12.49	0.0614
K_0-5	after joining with DongKechun	52.95	14.54	0.0536
M_0	mouth of Myoungjungchun	3.24	3.6	1/62
M_1	Myoungjung bridge	2.91	3.1	1/49

*K: Kwangju Stream Basin; M: Myoungjung Stream Basin; Others: Changneung Stream Basin

5.2 Application of the Proposed New Method.

The peak discharges in these 20 small watersheds were calculated using the Rational Method, the Kajiyama Method, the Area Routing Method, and the Nakayasu Synthetic Unit Hydrograph Method by several Korean engineering companies. The peak discharges of these watersheds used in this study are the values which were calculated by the Korea Engineering Consultant Cooperation for the Changeung Stream Basin, by the Saman Engineering Consultant for the Kwangju Stream Basin and by the Namwon Keonseol Engineering Company Ltd. for Myoungjung Stream Basin.

The peak discharges of these 20 small watersheds for 20-year return period and 30-year return period are illustrated in Fig. 2 and Fig. 3. REF means the calculated values by the proposed new prediction method.

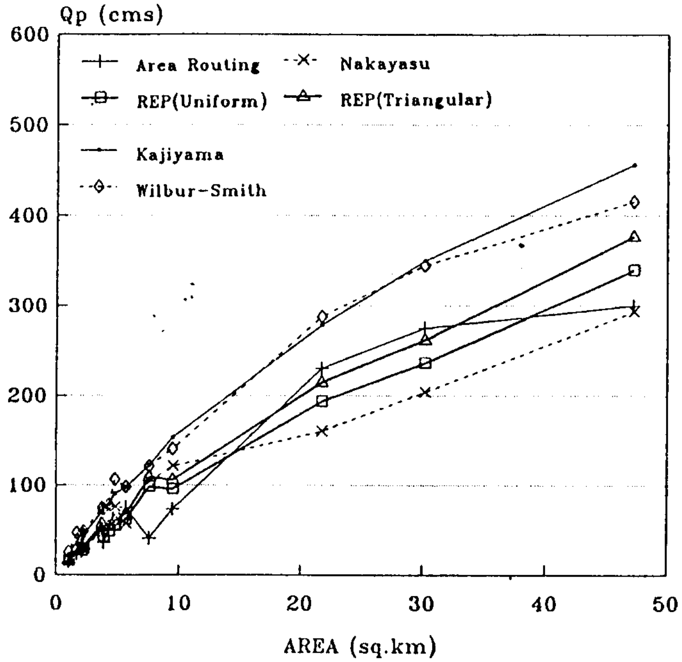

Fig. 2 Comparison of Proposed New Method with Other Frequently Used Methods
(20-year return period)

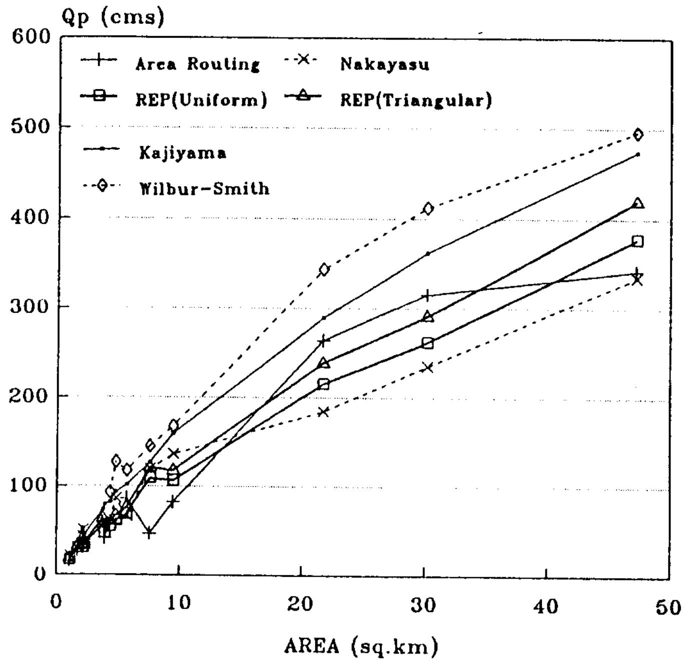

Fig. 3 Comparison of Proposed New Method with Other Frequently Used Methods
(30-year return period)

These figures reveal that the Wilbur Smith Method[10] and the Kajiyama Method give high values for all return periods. The values of peak discharges calculated by the Area Routing Method are higher than those by the Kajiyama Method which generally gives high values. The peak discharges calculated by the proposed new prediction method are between the values of Nakayasu Synthetic Method and Area Routing Method in less than 30-year return period, and are slightly lower than those of Nakayasu Method in more than 50-year return period.

It is proved that the proposed new prediction method may be used for the hydrologic design without any significant problem through the verification and testing processes in this study. This method, however, needs further improvements because of the limitation of data for the small watersheds in Korea. The hydrologic observation in the small watersheds should be made under following conditions; different size, channel length, channel slope, basin slope, rainfall pattern, etc.

6. Conclusions

Through the derivation and the verification processes of the multiple regression model based on 53 storm events from the seven small watersheds, the following conclusions are made;

(1) The most widely used peak flow prediction models in Korea include; the Rational Method, the Kajiyama Formula, the Nakayasu Unit Hydrograph Method, the Area Routing Method, and the RRL Method. In practice, design peak flows have been selected among the estimated values computed from two to four prediction models; in most cases, small values were favored by the engineering companies.

(2) In general, the Kajiyama Method is known to give an upper limit of the peak discharge rates, and has been used only as a reference case.

(3) The weighted sum of the rainfall intensities revealed a very good correlation with the peak discharge rates. In particular, the highest simple correlation was achieved when the weighting factor n was 1.5.

(4) No significant correlation between peak discharge rates and independent variables, except $P_{1.5}$, was obtained from the correlation analysis between the variables. It is likely that the results are due to the collinearity among the variables, and the multiple correlation analysis could resolve this problem.

(5) The new equation developed in this study gave the reasonable results from the several catchment areas including the Changneung Stream Basin, the Myoungjung Stream Basin, and the Kwangju Stream Basin, and it may be used in practice. However, there should be some modifications and improvements because of the lack of data.

(6) It is recommended to collect more data from various small watersheds, and extension of this study to medium and large watersheds will be desirable. Through these studies, the range of area for small, medium, and large watersheds should be rechecked.

(7) After the completion of the research on the medium and large watersheds, it is recommended to test the models developed from the research through various hydrologic design problems concerning peak discharge calculations for several years to verify their validity.

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