RUNOFF ANALYSIS BY SCS CURVE NUMBER METHOD

Yoon, Tae Hoon*

ABSTRACT/The estimates of both runoff depth and peak runoff by the basin runoff curve numbers, which are CN - Ⅱ for antecedent moisture condition - Ⅱ and CN - Ⅲ for antecedent moisture condition - Ⅲ, obtained from hydrological soil - cover complexes of 26 watersheds are investgated by making use of the observed curve numbers, which are median curve number and optimum curve number, computed from 250 rainfall - runoff records. For gaged basins the median curve numbers are recommended for the estimation of both runoff depth and peak runoff. For ungaged basin, found is that for the estimate of runoff depth CN - II is adequate and for the peak runoff CN - II is suitable. Also investigated is the variation of the runoff curves during storms. By the variable runoff curve numbers, the prediction of runoff depth and peak runoff can be improved slightly.

1. Introduction

Design discharge in most cases is a peak flow, however, for the design of detention structures a complete hydrograph is needed. For relatively small watersheds, the rational method is popular for the peak flow determination and even for detention basin a modified rational method is used.

If a watershed becomes larger, the use of the rational method is discouraged and hydrograph method is used for the determination of design flow. For the hydrograph method rainfall excess should be given or can be obtained by infiltration method or SCS curve number method. Of the infiltration method, the Green - Ampt method has received considerable attention in researches and field applications due to its advantages. However, the parameter evaluation needs more research for field application.

More extensively investigated and widely applied is the SCS runoff curve number method. The curve number (CN) method was developed by using annual flow data from watersheds with drainage area of 2.6㎢ or less and with uniform hydrologic soil - cover complexes(6). These facts call for verification studies of the curve number method for application to watersheds with larger drainage

---

* Prof., Dept. of Civil Engineering, Hanyang University, Seoul

area and nonuniform hydrologic soil – cover complexes.

A naturally occurring problem in applying the curve number is the effect of watershed wetness in the curve number. The curve number must reasonably be expected to vary with rainfall and soil moisture. Hence, the variability of CN and the effect of CN on runoff volume and peak runoff are analysed.

2. Storm and Watershed Data

A total of 250 storm events from 26 watersheds are analysed. The drainage areas range from 1.46㎢ to 519.78㎢ with median 105㎢(1,2). In the development of curve number method, annual flows are used. This implies that storm data used for determining CN must be large storm. However, in this study no restriction is imposed on selecting storm data except very small storm event to include more data. The large storm is defined as $P/S > 0.465$ or $Q/P > 0.115$ by Hawkins and this criterion is used in selecting storm data(4).

3. Curve Number Equations

The runoff curve number equations are given as

$$Q = \frac{(P-0.2S)^2}{P+0.8S} \qquad P \geq 0.2S \tag{1}$$

$$Q = \qquad P < 0.2S \tag{2}$$

in which Q is depth of runoff, P depth of rainfall, and S maximum potential retention.

The curve number, CN is related to the maximum potential retention S by

$$CN = \frac{1{,}000}{10 + \frac{S}{25.4}} \tag{3}$$

All units in the previous equations are millimeters.

The typical use of these relationships on ungaged basins involves the determination of a watershed CN based on the observed hydrologic soil – cover complex information, and the determination of storm runoff volumes for storms of various sizes. The procedure for determining the basin CN, or the hydrologic soil – cover complex number, for ungaged basin is given by the SCS(6). The procedure essentially involves determining hydrologic soil type, land uses and treatment, and percentages of each within the basin. The hydrologic soil – cover complex number or CN is read from the appropriate table supplied by the SCS(6) and weighted by the portion of the basin that it represent. A composite basin CN for whole basin is then determined. Finally, an antecedent moisture condition, AMC is assumed and the CN is adjusted up or down accordingly. The usual procedure is to assume an average antecedent moisture condition (AMC – Ⅱ). This composite curve number can then be used to estimate runoff volumes for any number of storms in that basin. Obviously, then, the basin CN is assumed independent of storm rainfall.

If observed rainfall and runoff records are available, then from these data can be calculated a curve number termed as an observed curve number. The observed CN can be calculated from equations 1 and 4. Or, by substituting Eq.3 into Eq.1 and solving for CN one obtains the observed runoff curve number, CN – OBS.

$$\text{CN-OBS} = 25{,}400 / (254 + 5P + 10Q - 10(Q^2 + 1.25QP)^{1/2}) \qquad (4)$$

4. Curve Number Determination and Analyses

4. 1 Basin Curve Numbers

For each watershed composite basin runoff curve number was determined based on the soil type, land use and treatment. An average antecedent moisture condition, AMC – Ⅱ, was assumed and the curve number is denoted as CN – Ⅱ.

An optimized CN, CN – OPT, was also determined for each basin from the observed rainfall – runoff data from that basin. The CN was obtained by minimizing the sum of the differences of the observed and the predicted runoffs squared for that watershed. Equation 5 gives the objective function for the determination of CN – OPT for a basin⁽³⁾.

$$\text{Min } \left(\sum_{i=1}^{n} (Q_{obs} - Q_{pre})_i^2 \right) \qquad (5)$$

where Q_{obs} is the observed runoff, Q_{pre} is the predicted runoff using a single CN for all storms, and n is the total number of observed events in the basin.

Using equation 4, an observed CN was calculated for each of the 250 storm events. A median basin CN, CN – MED was then determined for each of the watersheds from the observed storm CN values. CN – MED is recommended by the SCS⁽⁶⁾ as a basin CN where observed data are available.

It is noted that CN – OPT and CN – MED have most similar distributions. If the CN – MED values are taken as being the best estimate of the basin CN, the CN – Ⅱ values will usually underestimate runoff depths and the CN – Ⅲ will overestimate.

In comparison of CN – Ⅱ and CN – Ⅲ with CN – MED values, it is noted that 88 percent of the total CN – Ⅱ values are less than their corresponding CN – MED, and 23 percent of the total CN – Ⅱ values are within 10 percent of CN – MED. Meanwhile, in CN – Ⅲ values, only 27 percent are smaller than their corresponding CN – MED and 88 percent of the CN – Ⅲ values are within 10 percent of the associated CN – MED.

The facts that runoff is underpredicted by CN – Ⅱ and overpredicted by CN – Ⅲ are shown in terms of observed and predicted runoff depths in Figs.1 and 2.

To examine the validity of CN – MED as a representative basin CN, CN – MED was used to compute runoff, and the resulting runoff depths are compared with the observed runoff in Fig.3, which shows a close agreement.

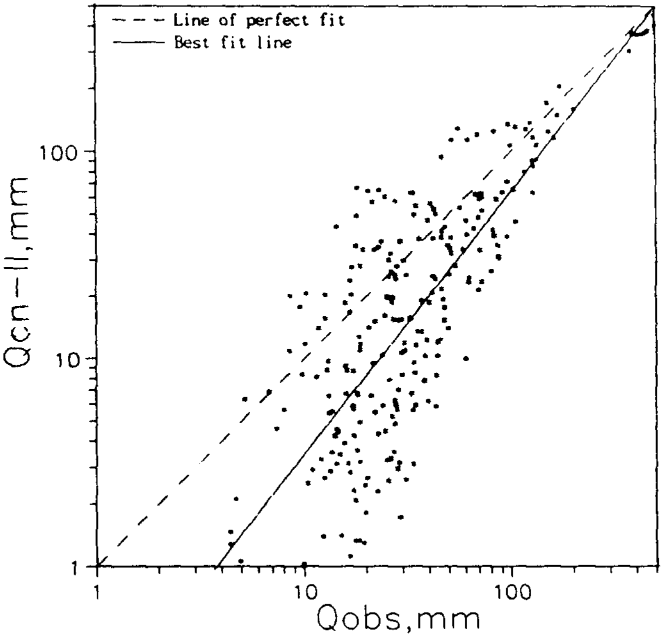

Fig. 1. Comparison of observed runoff and computed runoff by CN - Ⅱ

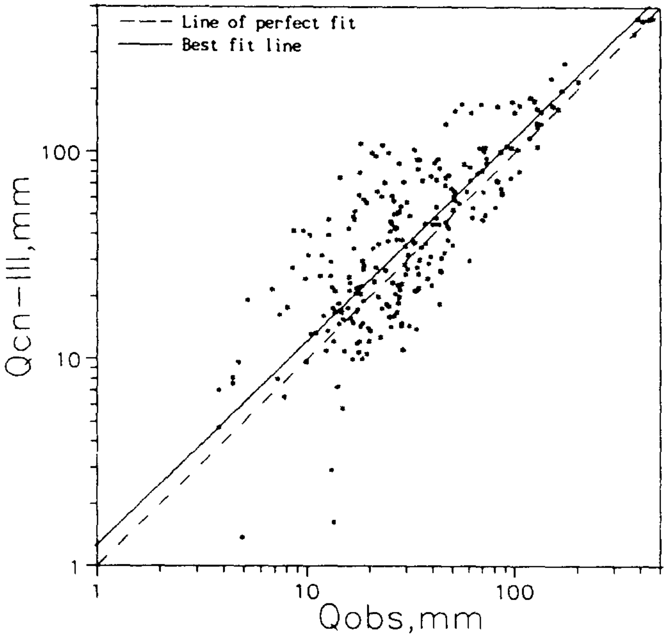

Fig. 2. Comparison of observed runoff and computed runoff by CN - Ⅲ

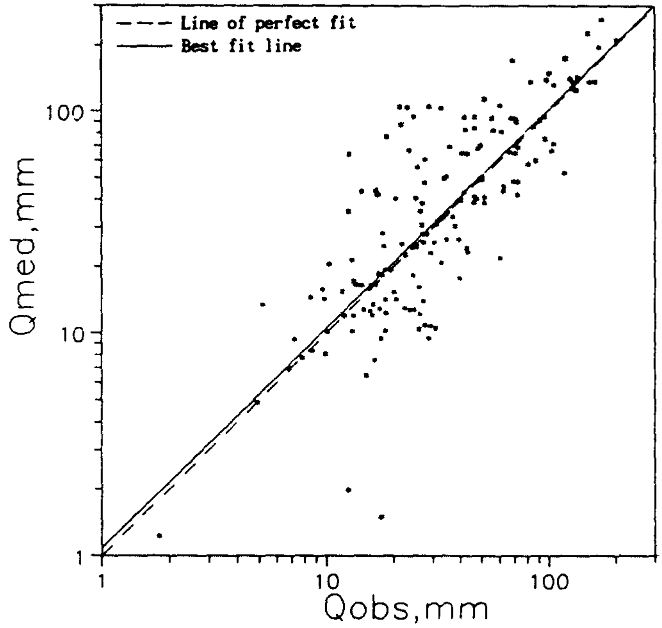

Fig. 3. Comparison of observed runoff and computed runoff by CN-MED

4. 2 Observed Runoff Curve Numbers

For each of the 250 storm events, an observed curve number, CN-OBS, was computed using Eq. 4. The statistics of CN-OBS as well as of the basin curve numbers are given for comparison in table 1.

Table 1. Statistics of observed and basin curve numbers

	CN-OBS	CN-Ⅱ	CN-Ⅲ	CN-OPT	CN-MED
Mean	78.7	68.5	83.9	73.3	80.4
Median	81.9	67.5	83.4	75.0	81.9
Mode	78.8	68.5	84.1	73.6	80.9
Standard Deviation	11.8	4.3	2.8	8.1	6.7

As can be noted from Table 1, the CN-OBS and CN-MED appear to be the most similar of the statistics presented. Both of CN-Ⅱ and CN-OPT would appear to underpredict runoff depth and CN-Ⅲ to overpredict as pointed out by Bales and Betson(3).

The basin curve numbers, CN-Ⅱ and CN-Ⅲ are interpreted in terms of runoff determined by them. 77 percent of the runoff depths are underpredicted by CN-Ⅱ, while 33 percent are underpredicted using CN-Ⅲ and the rest of 67% is overpredicted. Some of the predictions are excessively high and they range to 100-400 percent. Runoff coefficients of all those events are very low, ranging from 10 to 20 percent, which is not realistic. It is also seen that the result by CN-

MED is moderate in predicting runoff.

In an effort to alleviate the excessive predictions by CN－Ⅱ and CN－Ⅲ, intermediate values in between CN－Ⅱ and CN－Ⅲ may be developed in a fashion below.

$$CN46 = 0.4(CN-\text{II}) + 0.6(CN-\text{III}) \tag{6}$$

The percentage of underpredicted runoffs by various CN values and the percentage of errors exceeding a given allowance are calculated and are given in Table 2.

Table 2 indicates that : (1) CN－Ⅲ is the least underpredicted CN values with 32 percent followed by CN37(48%), CN－MED(50%) and CN3565(51%) ; and (2) in errors that the predicted runoffs differ from the observed runoffs by ±10%, ±20% and 50%, CN－MED is superior than any other CN values.

Table 2. Comparison of underpredicted runoffs and errors by various CN values

	Underpredicted Events (%)		Percentage error, $\mid Q_{obs} - Q_{pre} \mid > \varepsilon$ beyond error band			
			±10% error	20% error	±50% error	
	Q < 50㎜	All data			Q < 50㎜	All data
CN－Ⅱ	68.8	76.4	90.8	78.7	76.5	54.5
CN－Ⅲ	21.2	32.4	87.3	77.2	68.7	47.2
CN－55	45.7	57.2	85.6	73.8	72.3	46.0
CN－46	43.0	52.0	89.1	77.3	71.5	45.8
CN－3565	40.4	50.8	84.0	77.1	70.3	45.1
CN－37	37.7	48.0	84.3	76.8	70.1	44.7
CN－OPT	52.7	64.3	88.1	89.6	70.6	46.0
CN－MED	38.8	49.8	74.6	63.8	58.3	36.8

Based on the extent of excessive predictions and the accuracy of the prediction, CN－MED is found to be best suited as a representative curve number of a watershed, where observed data are available, as suggested by SCS. For ungaged basins, intermediate values in between CN－Ⅱ and CN－Ⅲ may be considered to be adequate as a basin curve number.

5. Peak Flow

The use of curve number in calculating peak flow is examined. The peak flow is obtained by calculating direct runoff hydrograph through convoluting unit hydrograph by rainfall excess for each storm event. The unit hydrograph used is 2-hour representative unit hydrograph derived for each basin, and 2-hour rainfall excess is determined by applying curve number method. The curve numbers used are basin curve numbers (CN－Ⅱ for AMC－Ⅱ conditions and CN－Ⅲ for AMC－Ⅲ conditions), median basin curve number, CN－MED from the observed curve numbers and variable CN.

The computed peak flows for 250 storm events by four different CN are plotted with observed peak flows in Figs. 4, 5. In these figures, computed peak flows by CN − Ⅱ and CN − MED are seen to be closer to the observed peak flows than those by CN − Ⅱ and variable CN. From these figures and Table 3, it is noted that in watersheds where storm data are avariable, CN − MED can be used as a representative basin CN as suggested by SCS, meanwhile in ungaged watersheds CN − Ⅱ can be taken as a basin CN as commonly used.

Table 3. Comparision of overpredicted peak runoff and errors

	Overpredicted Events(%)	Percentage error $\mid Q_{peak(obs)} - Q_{peak(pre)} \mid > \varepsilon$ beyond error band		
	All data	±10% error	±20% error	±50% error
CN − Ⅱ	72.7	95.2	86.7	66.7
CN − Ⅲ	97.6	97.6	95.2	88.5
Variable CN	96.4	96.4	95.2	86.1
CN − MED	86.1	92.1	86.7	74.5

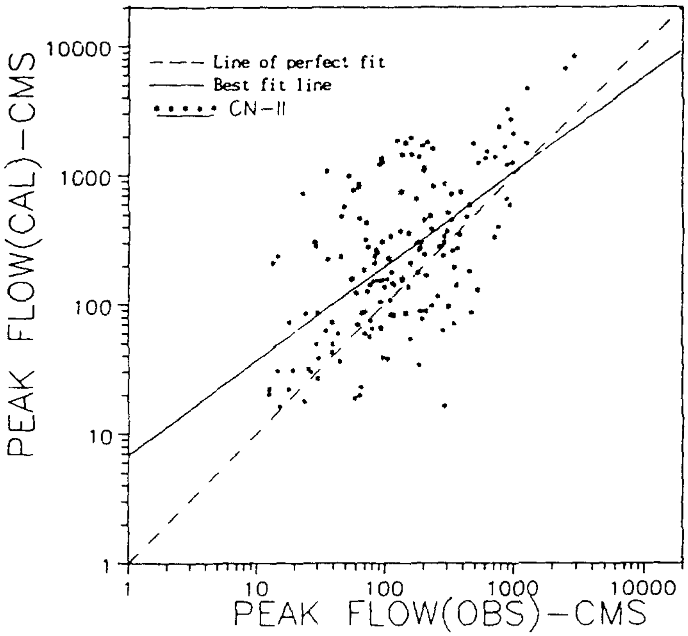

Fig. 4. Observed peak flow versus computed peak flow by CN − Ⅱ

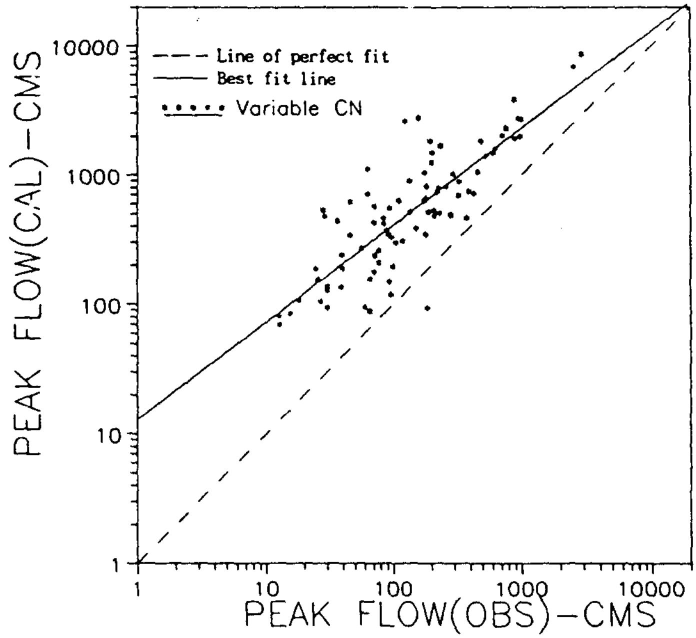

Fig. 5. Observed peak flow versus computed peak flow by variable CN

6. Variability of Curve Number

The variability of CN may be due to infiltration, evaporation, soil moisture, rainfall intensity and

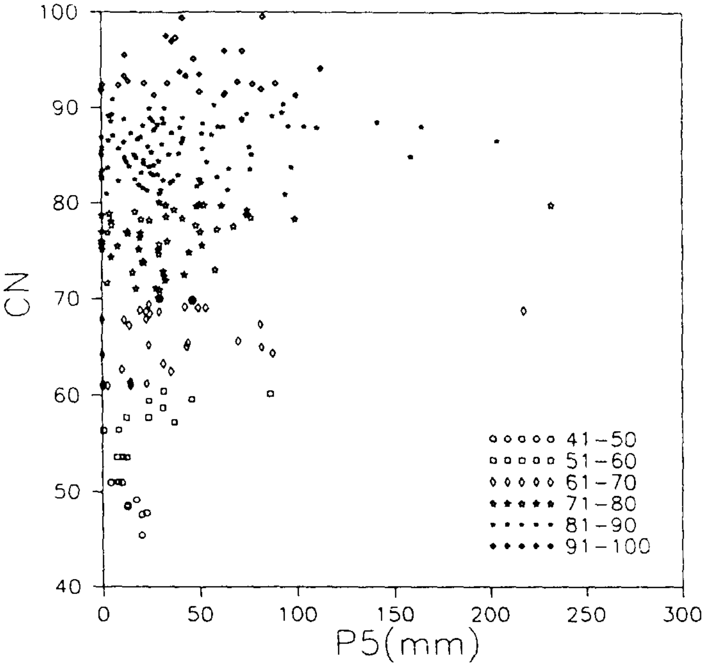

Fig. 6. Relation between 5 day antecedent precipitation and observed CN

duration and temperature. In this study it is attempted to include the influence of rainfall and soil moisture in terms of 5 day antecedent precipitation in the curve number. A graph of the curve number versus the 5 day antecedent precipitation, P_5 is shown in Fig. 6.

High antecedent precipitation is associated with moderate values of CN. Low antecedent precipitation is, however, associated with a wide range of values of CN. Thus, under wet conditions, much of the rainfall runs off, whereas under dry conditions storm and watershed conditions becomes important. Similiar results in terms of maximum potential retention, S has been presented by Hjelmfelt(5).

In the plot of total rainfalls with the observed curve numbers it is indicated that the curve numbers seem to decrease with increasing rainfall. A group of large storms shows lower CN than does a group made up of smaller storms

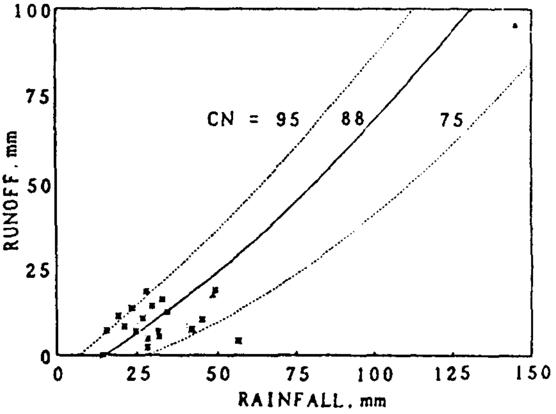

Fig. 7. Rainfall, runoff and curve number plot, Treynor, Iowa(5)

In general, the low rainfall values that are plotted must be associated with high CN. The low rainfall values associated with low CN will not appear because there is no runoff. For instance in Fig. 7, the curve for CN = 88 predicts no runoff for all rainfall less than 6.9㎜. Any runoff events with rainfall less than 6.9㎜ must be associated with CN greater than 88(5).

The variability of CN is examined by calculating observed curve number from 6 hr period rainfall-runoff data. The 6 hr period runoff or rainfall excess is evaluated by using 6 hr period hydrograph and 6-hr unit hydrograph through the convoluting equation.

$$Rn = \sum_{i=1}^{n} Q_i U_j \qquad (7)$$

where Rn is the hydrograph ordinates, Q_i is rainfall excess and U_j $(j = n - i + 1)$ is the unit hydrograph ordinates.

Once Qi is determined, CN at every 6 hr is calculated by Eq. 4. These curve numbers are plotted with the rainfall in Fig. 8. It indicates the decrease in CN with increasing rainfall and expressed as an exponential function.

$$CN = 107.2P^{-0.064} \qquad (8)$$

Using CN obtained by Eq. 8, runoff depth is computed at every 6 hr period and plotted with the observed runoff depth in Fig. 9.

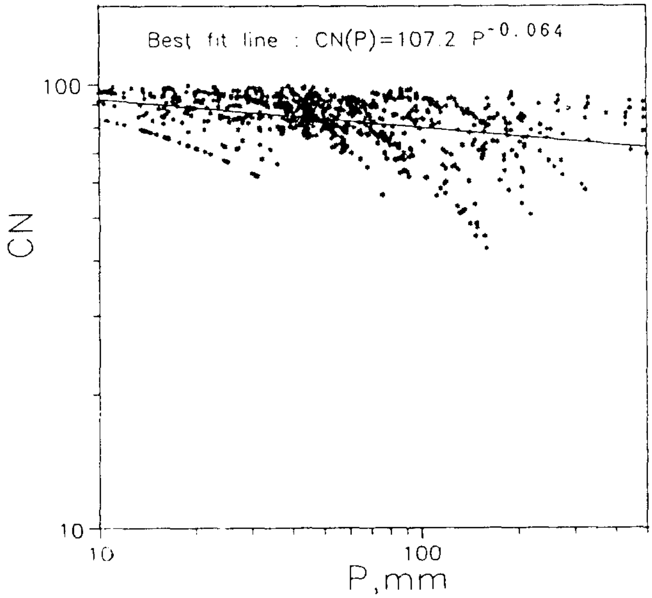

Fig. 8. Rainfall and curve number at every 6 hr period

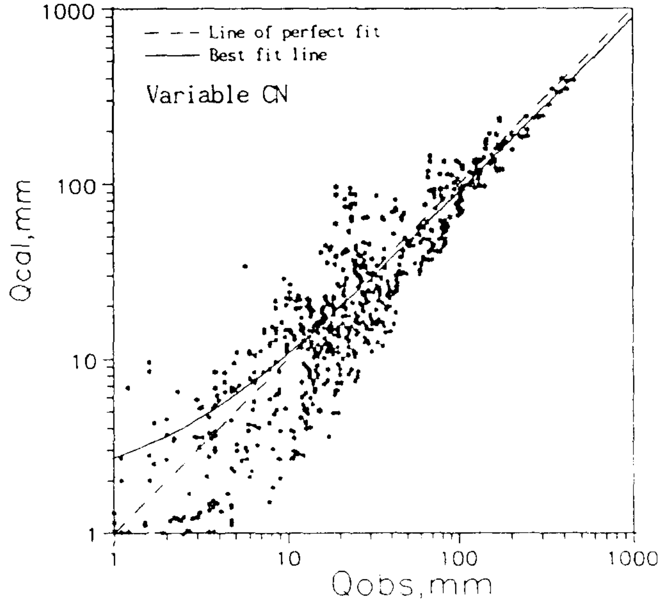

Fig. 9. Observed runoff depth and computed runoff depth by variable CN

Table 4. Comparision of runoff depth

	Underpredicted Events (%)		Percentage error, $\mid Q_{obs} - Q_{pre} \mid > \varepsilon$ beyond error band			
			±10% error	20% error	±50% error	
	Q < 50㎜	All data			Q < 50㎜	All data
CN − Ⅱ	56.7	75.1	94.9	89.9	52.8	72.1
CN − Ⅲ	35.8	51.3	86.7	76.0	25.7	49.6
VariableCN	42.7	59.7	92.0	79.5	31.3	50.7

From Fig. 9 and Table 4 it is noted that there is a slight improvement in predicting runoff volume by using the variable CN. In prediction of peak flow by making use of the variable CN, however, no particular improvement is indicated as can be seen in Fig. 5 and Table 3.

7. Conclusions

The following conclusions are drawn from runoff analyses by curve number method using 250 storm events from 26 watersheds.

The analyses reveal that in predicting runoff volume, CN − MED is superior. In estimating peak flow, CN − Ⅱ is found most adequate. The observed curve number is shown to decrease with increasing rainfall but no tendency is observed with 5 day antecedent precipitation. According to curve numbers computed at every 6 hr interval during storms the curve numbers are noted to decrease slightly with rainfall. By the variable CN the predictions of the both runoff volume and peak flow can be improved slightly.

Based on the prediction of peak flow and runoff depth, CN − MED is found to be best suited as a representative curve number, where observed data are available, as suggested by SCS. Meanwhile, in ungaged basins CN − Ⅱ is found to be rational in predicting peak flow and in estimating effective rainfall CN − Ⅲ and intermediate CN is considered adequate.

8. References

1. International Hydrological Program, Annual Report, 1976 − 1988, Ministry of Construction, Republic of Korea.
2. International Hydrological Program, Annual Report, 1991, Ministry of Construction, Republic of Korea.
3. Bales, J. and B.P. Roger, The Curve Numbers as a Hydrologic Index, Rainfall − Runoff Relationship, Edited by V.P. Singh, Water Resources Pub., 1981, pp.371 − 386.
4. Hawkins, R.H. et al, Runoff Probability, Storm Depth and Curve Numbers, J. of Irrigation and

Drainage Div., ASCE, Vol.111, No.4, 1985,pp.330 – 340.

5. Hjelmfelt, A.T., Investigation of Curve Number procedure, J. of Hydr. Eng., ACSE, Vol.117, No. 6, June, 1991, pp.725 – 737.
6. National Engineering Handbook, Section 4, Hydrology, U.S. Department of Agriculture, Washington, D.C., 1963.