ESTIMATION OF SCS RUNOFF CURVE NUMBER FOR AGRICULTURAL RESERVOIR WATERSHED BY ANALYSIS OF RESERVOIR OPERATION RECORD

ESTIMATION DU NOMBRE DE LA COURBE DE RUISSELLEMENT SCS DES BASSINS VERSANTS AGRICOLES PAR L'ANALYSE DU DOSSIER D'EXPOITATION DU RESERVOIR

Shin Gil Chai[1], Kwang Sik Yoon[2] and Kuk Heon Han[3]

ABSTRACT

The rainfall-runoff potential of a agricultural reservoir watershed was studied based on SCS (Soil Conservation Service; now the NRCS, Natural Resources Conservation Service, USDA) runoff curve number (CN) technique. The observed precipitation and the reservoir operation data such as irrigation amount, reservoir storage, river maintenance requirement, and flood control discharge were collected for ten years period and analyzed. The runoff of each storm event from the watershed of the reservoir was estimated by reservoir water balance model using reservoir operation records. The maximum retention, S, for each storm event from rainfall-runoff pair was estimated for selected storm events. The estimated S values were arranged in descending order, then its probability distribution was determined as log-normal distribution, and associated CNs were found about probability levels of Pr=0.1, 0.5, and 0.9, respectively. CNs determined from observed rainfall-runoff estimated by reservoir water balance analysis was compared to the suggested CNs by the method of SCS-NEH4. The CN- estimated from water balance analysis in this study were 80. However, the CN- , which was determined based on hydrologic soil group, land use was 67 indicating that actual runoff potential of the reservoir watershed is higher than that evaluated by SCS-NEH4 method. The results showed that watershed runoff potential for large scale agricultural reservoirs needs to be examined for efficient management of water resources and flood prevention.

Key words: *Reservoir remodeling, Runoff Curve Number, Agricultural Reservoir, Watershed.*

1 Rural Community &Agricultural Corporation, Korea, E-mail : utb1974@hanmail.net
2 Rural & Bio-Systems Engineering Dept., Chonnam National University, Korea
3 Rural Research Institute, Rural Community &Agricultural Corporation, Korea

RESUME

La lame d'eau pluviale d'un bassin versant d'un réservoir agricole a été étudiée selon la technique de lame d'eau (CN), sur la base SCS (Département de la conservation de terre ; actuellement le NRCS, Département de la conservation des ressources naturels, USDA). Les précipitations observées et les données d'exploitation du réservoir comme la quantité d'irrigation, les réservoirs, l'exigence d'entretien du fleuve, et le contrôle de décharge des inondations ont été recueillies pendant dix ans et ils ont étés analysées. L'écoulement de chaque tempête provenant du bassin versant du réservoir a été estimé par le modèle d'équilibre de réservoir d'eau, en utilisant des dossiers d'exploitation du réservoir. La rétention maximale, S, pour chaque tempête de la paire pluie-débit a été évaluée pour les événements de tempêtes choisis. Les valeurs estimées S étaient disposés en ordre décroissant, puis l'on a trouvé que sa loi de probabilité a été la loi log-normale, et les lames d'eau associées ont été trouvées sur les niveaux de probabilité de Pr = 0,1, 0,5 et 0,9, respectivement. La lame d'eau déterminé à partir pluie-débit observés, celui-ci estimé par l'analyse du bilan réservoir d'eau a été comparée à la lame d'eau suggérée par la méthode SCS-NEH4. Les lames d'eau- estimées à partir de l'analyse du bilan d'eau dans cette étude étaient 80. Toutefois, la lame d'eau- , qui a été déterminé en fonction du groupe hydrologique de sols, l'utilisation des terres a été de 67, ce qui indique que le potentiel réel de ruissellement du bassin versant du réservoir est supérieur à celui estimé par la méthode SCS-NEH4. Les résultats montrent que le potentiel de ruissellement des bassins versants pour les réservoirs agricoles à grande échelle doit être examiné pour une gestion efficace des ressources en eau et la prévention des inondations.

Mots clés: *Restructuration du réservoir, lame d'eau, réservoir agricole, bassins versants.*

1. INTRODUCTION

The Republic of Korea (Korea) like many other countries in the world has faced a serious challenge to sustainable water use. In the context, the water for agricultural production needs to be developed economically and utilized efficiently and in harmony with natural environment, but should not be over-exploited to a degree affecting the future water supply. The sustainable water use is particularly important to Korea where more than the one third of the renewable water resources or the runoff from precipitation is now being diverted for the agricultural, domestic, and industrial uses. Additional water resources need to be explored without adversely affecting the natural ecosystems.

The average annual precipitation ranges from approximately 770 to 1,640 mm, with the mean of 1,270mm. About two-third of the total precipitation (65%) is concentrated in summer, while precipitation in winter is less than 10% of the total. Irrigation for rice paddy culture ranks first among water uses and accounts for about half of the total water consumption in Korea. During the summer season in Korea, rice paddies occupy an area of over 11,000 km2,or approximately11.9%of the nation's total area (KOSIS, 2009).

For the purposes of agricultural mechanization in Korea, small paddy fields have been rearranged to form larger paddy fields. As determined in the land consolidation project, the paddy field is composed of several paddy plots (100 m by 50 m each) separated by main and lateral irrigation canal, lateral drainage, and a main drainage canal. Paddy fields in Korea are blocked by levees to maintain flooding conditions. The paddy fields are kept in flooding over 20–50mm during most of the growing season. Previous studies showed that paddy field water input during a growing season may vary from 500 to 800 mm and reach more than 3,000 mm in the world (De Datta et al., 1973; Hukkrei and Sharma, 1980). The irrigation amount reported in Korea ranged 490 mm ~ 1498 mm. (Yoon et al., 2006).

The Soil Conservation Service (SCS) runoff curve number method (CN method) for estimating runoff volume from a storm is well established in hydrologic engineering and environmental impact analysis. The main reason the method has been adopted by most hydrologists is because of its simplicity and applicability to those watersheds with minimum of hydrologic information: soil type, land use and treatment, surface condition, and antecedent moisture condition (AMC). Methods of selecting the runoff curve number for a watershed under various conditions are available in the National Engineering Handbook, Section 4, Hydrology or "NEH-4" (SCS, 1972). This method was used for estimating design flood of hydraulic structures in Korera (Yoon, 1991; Sonu et al., 1977; Kim, 1990; Kim et al., 1995). The method was also used for estimating daily runoff using long-term data (Choi et al., 2002).

To cope with global warming and subsequent water scarcity, remodeling of existing agricultural reservoirs; increasing dam height to get enhanced storage for irrigation and river maintenance, is undergoing in Korea. To evaluate effects of remodeling reservoirs, accurate estimation techniques for rainfall–runoff from watershed is prerequisite. Hydrologic analysis for agricultural reservoir design has been conducted by SCS runoff curve number (CN) method. However, the accuracy of curve number method for Korean agricultural reservoir conditions rarely been investigated due to lack of observed runoff data from agricultural reservoir watershed. The objective of the present study was to evaluate CN method on rainfall-runoff potential of a agricultural reservoir watershed in Korean conditions.

2. MATERIALS AND METHODS

Observed long-term rainfall-runoff data are required to evaluate CN values. Therefore, event based rainfall-runoff data were estimated from water balance method using daily reservoir operation record. CN values obtained using observed rainfall and estimated runoff were compared to the values determined by SCS-NEH4.

1. Study Area

Jangseong irrigation dam was constructed on 1976. The size of watershed is 122.8km2; total storage is 89.7million m3; effective storage is 84.8million m3 and beneficiary area for irrigation is 139km2. Figure 1 and Table1show Jangseong lake watershed area and landuses of the watershed. The dominant land uses are forest (84.9%), and paddy field(5.1%).

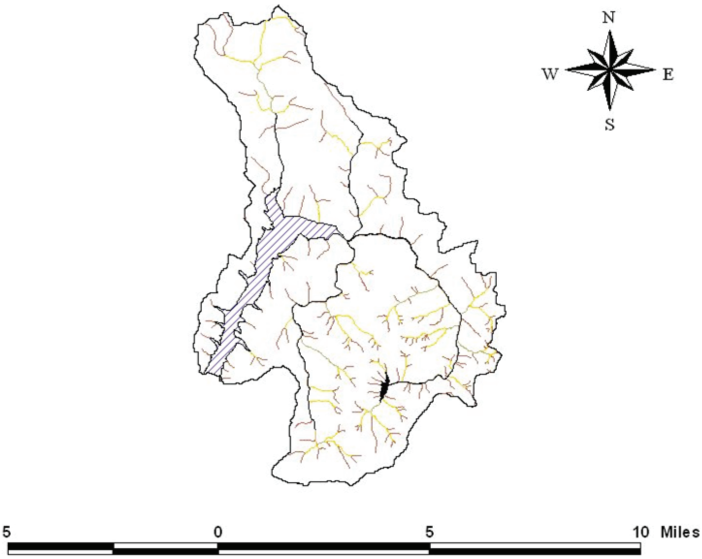

Fig. 1. Jangseong reservoir watershed

Table 1. Land use of the Jangseong reservoir watershed

Unit : ha, (%):						
Study area	Forest	Paddy	Upland	Residential and Roads	Reservoir	Total
Jangseong reservoir watershed	10,431					
(84.9)	630					
(5.1)	230					
(1.9)	302					
(2.5)	687					
(5.6)	12,280					
(100)						

2. Runoff determination by water balance method using reservoir operation record

Ten year operation records of Jangseong reservoir such as daily rainfall, irrigation amount, flood control discharge (spillway over flow) amount, discharge for river maintenance were collected. Watershed runoff, which is inflow into reservoir was estimated using water balance method.

$$St = St\text{-}1+Qt+Pt–It–Dt–Lt–Et \qquad (1)$$

Where, St : storage for time t
Qt : inflow
Pt : precipitation onto reservoir
It : irrigation amount
Dt : flood control discharge
Lt : other losses
Et : reservoir evaporation

Daily inflow was estimated using mass balance equation (1) and direct runoff and base flow were separated using N-day method.

3. CN Method

The well-known relationship for direct rainfall is gives as (SCS, 1972)

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

where Q=runoff depth(mm), P=rainfall depth(mm), and S=maximum retention storage(mm) after runoff begins. Eq. (2) assumed that initial abstraction=0.2S.
When rainfall and runoff data are available, the maximum retention storage, S is calculated from the following expression.

$$S = 5(P + 2Q - \sqrt{4Q^2 + 5PQ} \qquad (3)$$

And, the maximum retention storage is related to the CN value by the following equation.

$$CN = \frac{24500}{245+S} \qquad (4)$$

The CN value is a dimensionless index, and has an integer value ranging from 0 (no runoff) to 100 (all rainfall becomes runoff). CN=100 represents a theoretical upper bound the potential retention, and CN=0 denotes a theoretical lower bound the potential.

The CN value should be grouped to three antecedent moisture conditions. CN- is the average conditions, while CN- and CN- represent dry and wet conditions, respectively. CN- , , or is associated with AMC , , or , which are defined by five-day antecedent rainfall amount as defined in the NEH-4.

The CN value for various hydrologic soil-cover complexes were defined from rainfall-runoff data at watersheds of relatively homogeneous conditions (Bonta, 1997; Hauser and Jones, 1991; Hjelmfelt, 1980; SCS, 1972). And rainfall and runoff data from mine field (Ritter and Gardner, 1991), tillage practice (Yoo et al., 1993), and paddy fields (Im et al., 2007) were also used to define the CN value undefined in NEH-4.

Two procedures have been used to derive the CN values from rainfall (P) and runoff (q) data pairs. SCS described a graphical method where the data are fitted by a median curve at the rainfall-runoff curve and the value is defined to be CN- . Hjelmfelt (1980; 1991) and Hjelmfelt et al. (1982) proposed an analytical method to define the CN values from the probable retention storages at 10, 50, and 90 percent. The method proposed by Hjelmfelt is summarized as follows.

1. From P and Q data pairs, compute S for each storm from Eq. (3). And arrange P, Q, and S data sets in a descending order.
2. Fit a lognormal probability function to S by the method of moments.
3. Compute S and the associate CN-II at probability of 50%.
4. Calculate S at probabilities of 10 and 90% to estimate CN- , and , respectively.

Hawkins et al. (1985) proposed that storms in which P/S values are greater than 0.46 were used for the estimation of the CN values, since the S value varies significantly from storm to storm. We have applied the methodology proposed by Hjelmfelt and Hawkins to estimate the CN values in paddy fields.

3. RESULTS AND DISCUSSION

Fig. 2 shows precipitation and estimated direct runoff relationship using water balance model for the Jangsung watershed.

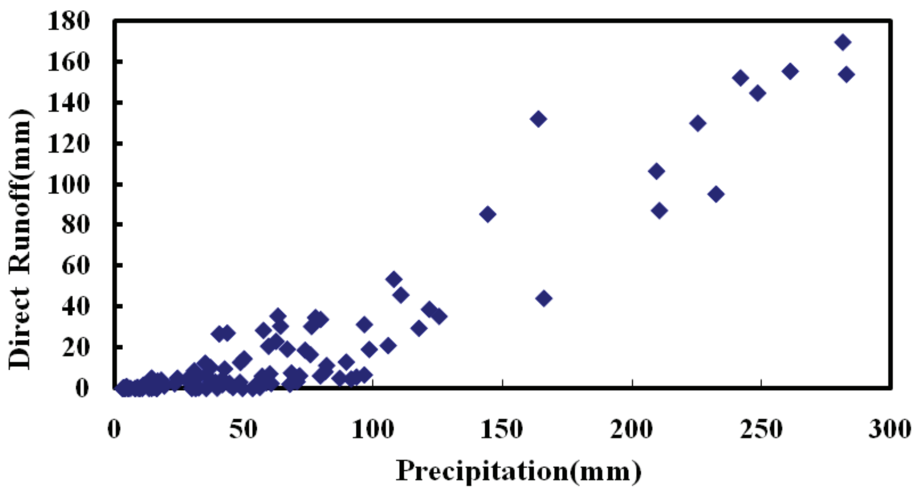

Fig. 2. Precipitation and estimated direct runoff relationship using water balance model for the Jangsung watershed.

The probability distribution of S derived from rainfall and runoff data is fitted as shown in Fig. 3. A lognormal probability function is used to fit the measured data with good results.

The value of CN-II corresponding with S at probability of 50% is 80.2. The corresponding CN-I and CN-III are 56.4 and 92.7, respectively. The calculated CN values are tested by plotting the observed rainfall and runoff data pairs, and the calculated rainfall-runoff curves as shown in Fig. 4. Fig. 4 shows that approximately half the measured values fall on either side of the CN-II curve, and the CN-I and CN-III curves well envelope most of the measured data.

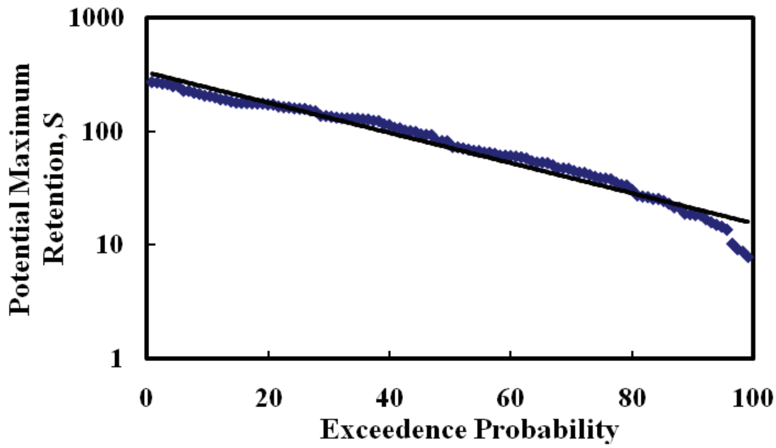

Figure. 3 Exceedence probability distribution of potential maximum retention, S.

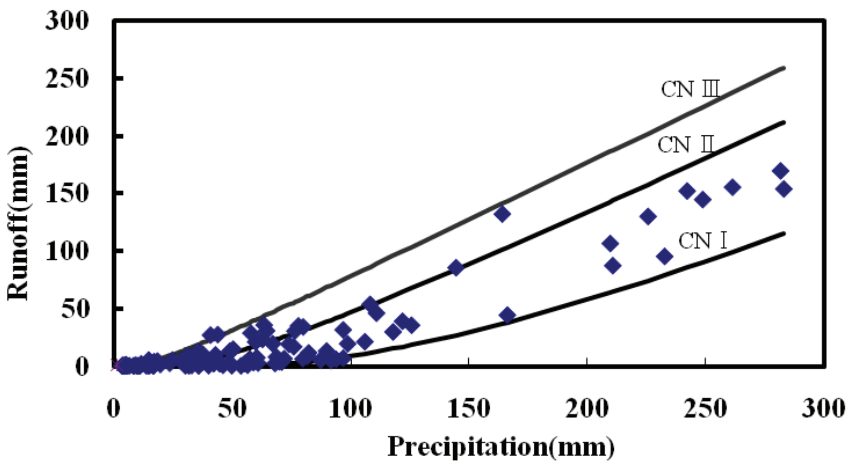

Fig 4. CNs estimated from estimated CNs by water balance model for Jangsung reservoir watershed.

Table 2. show comparision of CNs determined by NEH-4 and this study. The CN- estimated from water balance analysis in this study were 80. However, the CN- , which was determined based on hydrologic soil group, land use, and was 67.2 indicating that actual runoff potential of the reservoir watershed is higher than that evaluated by SCS-NEH4 method. Kim et al. (1999) and Yoon (1992) reported similar results that CN-II from observed data was higher

than that determined by SCS-NEH4. Yoon (1992) suggested selecting CN-III instead of CN-II in NEH-4 to apply SCS method on to Korean watershed conditions. This study results also show that observed CN-II (80.2) was close to CN-III (82.6) by SCS-NEH4 rather than that of CN-II (67.2).

Table 2 Estimated CNs of Jangsung reservoir watershed

Selected Value for Design 1)	This study	
CN-I	47.1	56.4
CN-	67.2	80.2
CN-	82.6	92.7
1) : KARICO (2000), Safety Appraisal of the Jangsung Reservoir		

4. CONCLUSIONS

The CNs estimated from water balance analysis using reservoir operation record in this study were higher than those determine by the method suggested in SCS-NEH4. The results indicate that actual runoff potential of the reservoir watershed is higher than that used for initial dam design. This could be useful information for remodeling effort on existing agricultural reservoirs; increasing dam height to get enhanced storage, which is undergoing in Korea. Therefore, watershed runoff potential for large scale agricultural reservoirs needs to be examined using SCS-CN technique, if reservoir operation records are available, for efficient management of water resources and flood prevention.

Another important finding was that the suitable cropping pattern relative to climate, soil type and society culture of each region and of course the crop yield marketing would improve the project outcomes considerably.

REFERENCES

Bonta, J.V., 1997. Determination of watershed curve number using derived distributions.J. Irrig. Drain. Eng. 123, 28–35.

Choi, J. Y., B. A. Engel, and H. W. Chung, 2002, Daily streamflow modelling and assessment based on curve number technique, Hydrological Processes, Vol.16 (16), pp. 3131-3150.

De Datta S.K., Abilay W.P., and Kalwar G.N., 1973. Water Stress Effects in Flooded Tropical Rice. In: Water Management in Philippine Irrigation Systems: Research and Operations. International Rice Research Institute, Los Banos, Philippines, pp 19-36.

Hauser, V.L. and O.R. Jones 1991. Runoff curve numbers for the southern high plains. Transaction of the ASAE 34(1): 142-148.

Hawkins, R.H., A.T. Hjelmfelt and A.W. Zevenbergen 1985. Runoff probability, storm depth, and curve numbers. Journal Irrigation and Drainage Engineering, ASCE 111(4): 330-340.

Hjelmfelt, A.T., 1980. Empirical investigation of curve number technique. J. Hydr.

Div., ASCE 106 (HY9), 1471–1476.

Hjelmfelt, A.t. Jr., K.A. Kramer, and R.E. Burwell 1982. Curve Number as Random Variables. Proceeding, International Symposium on Rainfall-Runoff Modeling, held at Mississippi State Univ., Mississippi State.

Hjelmfelt, A.T., 1991. Investigation of curve number procedure. J. Hydraul. Eng. 117, 725–737.

Hukkeri S. B. and Sharma A. K., 1980. Water-Use Efficiency of Transplanted and Direct-Sown Rice Under Different Water Management Practices. Indian J Agric. Sci. 50:240-243

Im, S.J., Park, S.W., Jang, T.I., 2007. Application of SCS curve number method for

irrigated paddy field. KSCE J. Civil Eng. 11, 51–56.

KARICO(2000), Safety Appraisal of the Jangsung Reservoir.

Kim. J. D. 1990. Surface Runoff Computations From a small Watershed Using SCS Triangular Unit Hydrograph Method.

Kim, J. H., K. S. Jung and K. Y. Lee. 1999. Esitimating Curve number of SCS method for caculated runoff. Proceedings of the 1999 Annual conference KOREA WATER RESOURCES ASSOCIATION, 227-231.

Kim, T. C., S. K. Park., S. T. Kim, and J. B. Cu. 1995. New Concept of curve Number Applicable to the Korean Watersheds. Proceedings of the 1995 Annual conference KOREA WATER RESOURCES ASSOCIATION, 295-300.

KOSIS, 2009. Korean statistical information service (National Landuse Area). Korea

National Statistical Office.

Ritter, J.B and T.W. Gardner 1991. Runoff curve numbers for reclaimed surface mines in Pennsylvania. Journal Irrigation and Drainage Engineering, ASCE, 117(5): 656-666.

SCS (1972). National Engineering Handbook, Section 4, Hydrology, U. S. Department of agriculture, U. S. Government Printing Office, Washington, DC.

Sonu, J. H., Y. Y. Nam, S. B. Shim, and S. T. Lee. 1977. Determination of Effective Rainfall by US SCS Method and Regression Analysis. JOURNAL OF KOREA WATER RESOURCES ASSOCIATION, 10(2): 101-111.

Yoo, K.H., K.S Yoon, and J.M. Soileau 1993. Runoff curve numbers determined by three methods under conventional and conservation tillages. Transaction of the ASAE 36(1): 57-63.

Yoon, Kwang-Sik, Jae-Young Cho, Jin-Kyu Choi, and Jae-Gwon Son, 2006. Water Management and N, P Losses From Paddy Fields in Southern Korea. Journal of the American Water Resources Association (JAWRA) 42(5):1205-1216.

Yoon, T. H. 1991. Validity of Runoff Curve Number Method for Estimating of Effective Rainfall. JOURNAL OF KOREA WATER RESOURCES ASSOCIATION, 24(2): 97-108.

Yoon, T. H. 1992. Estimation of Runoff Depth and Peak Discharge by SCS Curve Numbers and Time Variation of curve Numbers. JOURNAL OF KOREA WATER RESOURCES ASSOCIATION, 25(4): 87-95.