RUNOFF ESTIMATION FROM TWO MID-SIZE WATERSHEDS USING SWAT MODEL

Chulgyum Kim, Hyeonjun Kim, Cheolhee Jang, Namwon Kim

Water Resources Research Department, Korea Institute of Construction Technology, 2311 Daehwa-dong, Ilsan-gu, Goyang-si, Gyeonggi-do 411-712, Republic of Korea

Abstract: SWAT model was applied to estimate daily stream flow for Yongdam and Bocheong watersheds in Korea. The model was calibrated and validated for the two watersheds and a new routine was added to analyze runoff process in paddy fields. The model efficiencies for two watersheds were 0.77 and 0.65 for the calibration period, and 0.76 and 0.50 for the validation period, respectively. It showed that water balance method simulated the runoff from paddy fields more precisely than CN method in SWAT. As results, the SWAT model is applicable to Korean watersheds, and more accurate estimation is possible using daily water balance method in paddy fields.

Keywords: SWAT, Paddy fields, Water balance

1. INTRODUCTION

The daily stream flow estimation for water resources planning and management is important in Korea as in other countries, so the continuous rainfall-runoff models such as SSARR, NWS-PC, SLURP, and TANK etc., have been applied since the 1980s (Kim et al., 2003).

TANK model was first introduced in Korea by Han and Jeong (1976), and many studies have been carried out. SSARR model has been applied for analyzing runoff and operating reservoirs in watershed by Ahn and Lee (1989), Kang et al. (1998), and Kang (1998). Noh (1991) and Kim et al. (1996) developed a lumped model, DAWAST (DAily WAtershed STreamflow model) simplifying the soil layers of watershed into two storage layers, and applied for designing and operating irrigation reservoirs. In addition, NWS-PC, PRMS, SLURP, TOPMODEL, and USDAHL-74 have been also used to estimate stream flows in Korea. Recently, several applications of HSPF (Chun et al., 2001) and SWAT (Kim, 1998; Kang and Park, 2003; Kweon et al., 2003) have been accomplished for predicting water quantity and water quality by many researchers. Also, a grid based hydrologic routing procedure considering the water balance of paddy fields has been developed to predict daily stream discharge (Kim et al., 2003).

SWAT is a semi-distributed model partitioned into a number of subwatersheds or subbasins, and runoff is predicted separately for each HRU using the CN method or Green-Ampt method, and routed to obtain the total runoff at the outlet of watershed (Neitsch et al., 2001). But, these methods cause some error in calculating runoff from irrigated paddy fields in Korea. Runoff from paddy fields is varied with drainage outlet height and ponding depth, and this concept has been adapted in simulating the hydrological process occurs in irrigated paddy fields in Korea.

Hence, in this study, water balance method considering water movement in paddy fields was suggested, and evaluated by comparing the results with those from CN method.

The purposes of this study are testing the applicability of SWAT model to Korean watersheds, and evaluating a new water balance method considering runoff process in paddy fields.

2. METHODOLOGY

2.1 Description of the SWAT model

SWAT (Soil and Water Assessment Tool) is a river basin or watershed scale model developed to predict the impact of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils, land uses and management conditions over long periods of time (Neitsch et al., 2001).

In Figure 1, schematic diagram of the hydrologic cycle in SWAT is shown. The hydrologic cycle as simulated by SWAT is based on the water balance equation:

$$SW_t = SW_0 + \sum_{i=1}^{t} (R_{day} - Q_{surf} - E_a - w_{seep} - Q_{gw}) \quad (1)$$

Where SW_t is the final soil water content (mm), SW_0 is the initial soil water content on day i (mm), t is the time (days), R_{day} is the amount of precipitation on day i (mm), Q_{surf} is the amount of surface runoff on day i (mm), E_a is the amount of evapotranspiration on day i (mm), w_{seep} is the amount of water entering the vadose zone from the soil profile on day i (mm), and Q_{gw} is the amount of return flow on day i (mm).

2.2 Application to Korean watersheds

General description of the applied watersheds

Yongdam and Bocheong watersheds were selected for application of SWAT. Yongdam watershed is located in the upstream mountainous area of Yongdam multi-purpose dam and Bocheong watershed is one of the representative experimental watersheds of International Hydrological Program and shows a typical land use patterns in Korea. In Figure 2, the location of each watershed and hydrological and meteorological gauging stations are shown.

Input data collection and delineation of sub-basins and HRUs

Hydrological and meteorological data were collected and compiled including river stages, stage-discharge relations, rainfall, temperature, and humidity etc., on daily basis. Daily discharges at each watershed's outlet were calculated and checked for data reliability.

1" DEM (prepared by MOE), land use digital data (1:25,000) from the product of NGIS were used, and both of detailed soil map (1:25,000) and generalized soil map (1:50,000) were also selected. The details of each watershed are described in Table 1. As shown in Table 1 and Figure 3, the areas of each watershed are 930 km^2 and 348 km^2 respectively, and the dominant land use for both watersheds is forest. The stream flows of Bocheong watershed are strongly affected by irrigation water use and drainage pattern.

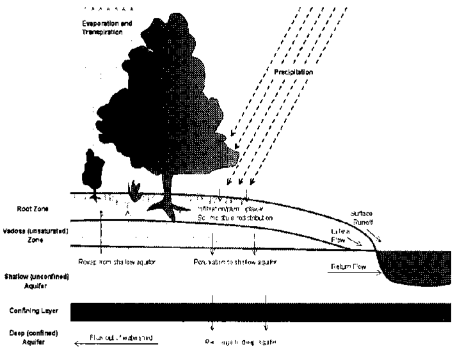

Figure 1. Schematic representation of the hydrologic cycle (Neitsch et al., 2001)

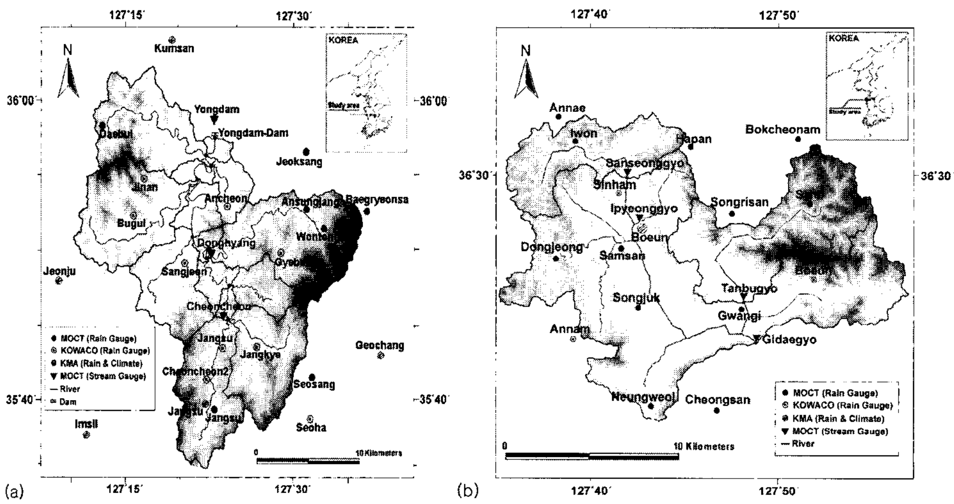

Figure 2. Location map of (a) Yongdam and (b) Bocheong watersheds and gauging stations

Table 1. Land uses and soil types of the applied watersheds

Watershed	Area (km^2)	Land use (%)				Soil type (%)		
		Forest	Paddy	Upland	Others	Sandy Loam	Clay Loam	Others
Yongdam	930.0	77.0	10.4	7.8	4.8	93.2	-	6.8
Bocheong	348.0	63.1	16.6	10.4	9.9	71.8	18.4	9.8

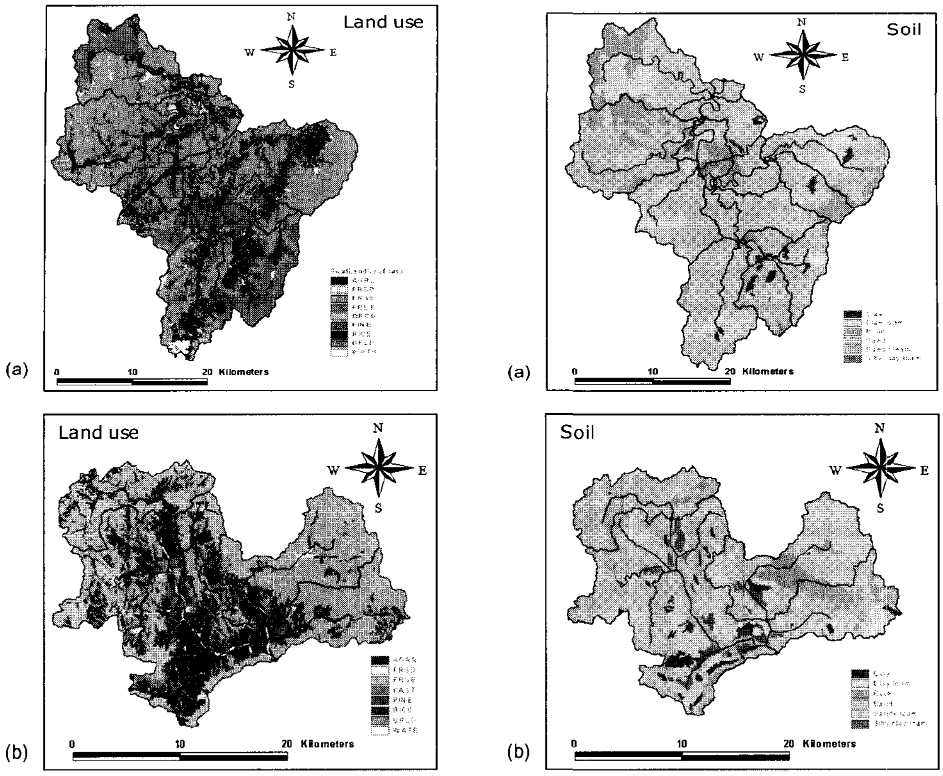

Figure 3. Map of land uses and soil types: (a) Yongdam watershed, (b) Bocheong watershed

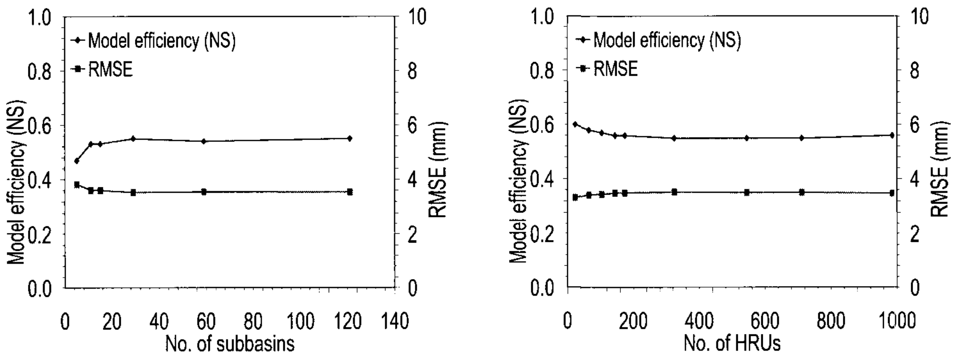

Figure 4. Scale effect of subbasins and HRUs for Yongdam watershed

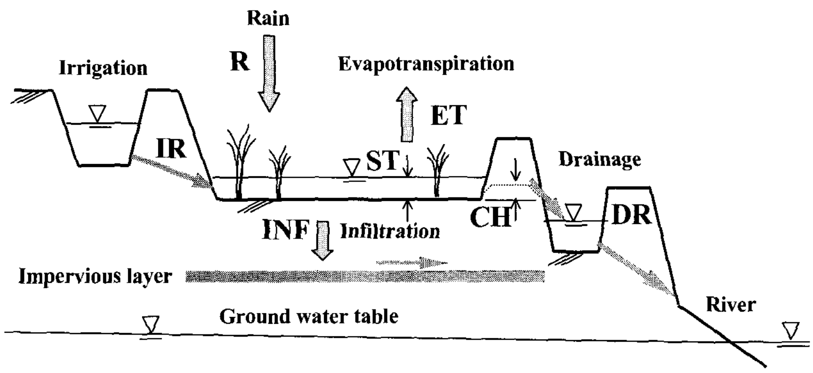

Figure 5. Water balance in paddy fields

HRUs (Hydrologic Response Units) in SWAT are lumped land areas within the subbasin that are comprised of unique land cover, soil, and management combinations. In this study, the number of subbasins and HRUs was determined after some investigation of the scale effect. Figure 4 shows that there are no significant changes on the Nash-Sutcliffe coefficient (Nach and Sutcliffe, 1970) and RMSE (root mean square error) by increasing the number of subbasins and HRUs for Yongdam watershed.

The Nash-Sutcliffe coefficient of model efficiency, NS, is a statistical criterion for evaluating hydrologic goodness of fit between measured and predicted values. This coefficient is calculated as follows:

$$NS = 1 - \frac{\sum_{i=1}^{n}(Q_i - Q_i^*)^2}{\sum_{i=1}^{n}(Q_i - \bar{Q})^2} \qquad (2)$$

Where Q_i are the measured values, Q_i^* are model predicted values, $\bar{Q}$ are the average of measured values, and n is the number of values. A NS value of 1 indicates a perfect fit between measured and predicted values, and a value of zero indicates that the fit is as good as using the average value of all the measured data.

The subbasins and HRUs were delineated considering the gauging stations, tributaries, land uses and soil types. Yongdam watershed is composed of the 15 subbasins and 175 HRUs, and Bocheong watershed has 3 subbasins and 24 HRUs.

Water balance in paddy fields

The runoff characteristics at paddy fields in Korea are shown in Figure 5. It was specified that the drainage and retention were varied with the drainage outlet height and ponding depth. The SWAT model utilizes the CN method or Green-Ampt method for surface runoff calculation, so it cannot consider a specific runoff process in paddy fields. Therefore, the following relationships (Kim et al, 2000; Kang and Park, 2003) were suggested:

$$DR_t = ST_t - CH \text{ if } ST_t > CH \qquad (3)$$

$$DR_t = 0 \text{ if } ST_t \le CH \qquad (4)$$

$$ST_t = ST_{t-1} + IR_t + RAIN_t - INF_t - ET_t - DR_t \qquad (5)$$

Where DR_t is the amount of surface drainage from paddy (mm), ST_t is ponding depth for a given day (mm), ST_{t-1} is ponding depth for the previous day (mm), CH is drainage outlet height (mm), IR_t is the amount of irrigated water (mm), $RAIN_t$ is the amount of rainfall (mm), INF_t is the amount of infiltration (mm), and ET_t is the amount of evapotranspiration (mm).

3. RESULTS AND DISCUSSIONS

3.1 Model calibration and validation

Model calibration and validation were carried out and the criteria for model performance was checked with the Nash-Sutcliffe coefficient based on the sequence of observed and simulated daily stream flows over the calibration and validation periods as shown in Figure 6. The NS values for each watershed were 0.77 and 0.65 from the calibration results, and 0.76 and 0.50 during the validation period respectively.

Figure 7 provides the comparison of observed and simulated daily stream flows for each watershed. It shows that SWAT model simulated stream flows successfully except during spring and winter seasons, and this is the reason that snowmelt-related parameters were not calibrated or the observed data during the seasons were unreliable.

3.2 Water budget estimation

The detailed results of the annual simulation are described in Table 2. The surface flow, lateral flow, and base flow were estimated individually to be about 23%, 54%, and 23% of the total runoff, and the annual deviations were varying highly with the amount of rainfall. The annual averaged evapotranspiration was over 440 mm and equaled to about 40% of the annual rainfall, but the annual variation was insignificant.

Figure 8 shows the schematic diagram of estimated water budget for each watershed.

3.3 Runoff simulation in paddy fields

The surface runoff from paddy fields in Bocheong watershed was simulated by the water balance method and compared with the results from SWAT model using the CN method during the irrigation periods for 10

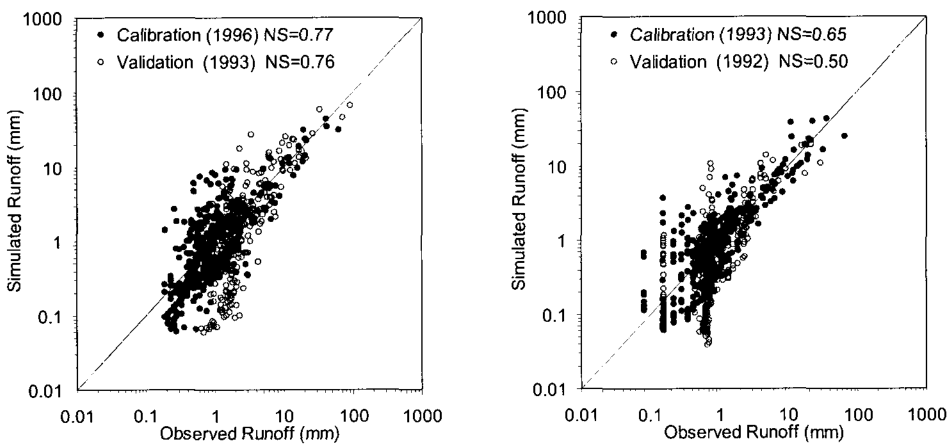

Figure 6. Results of calibration and validation: (a) Yongdam watershed, (b) Bocheong watershed

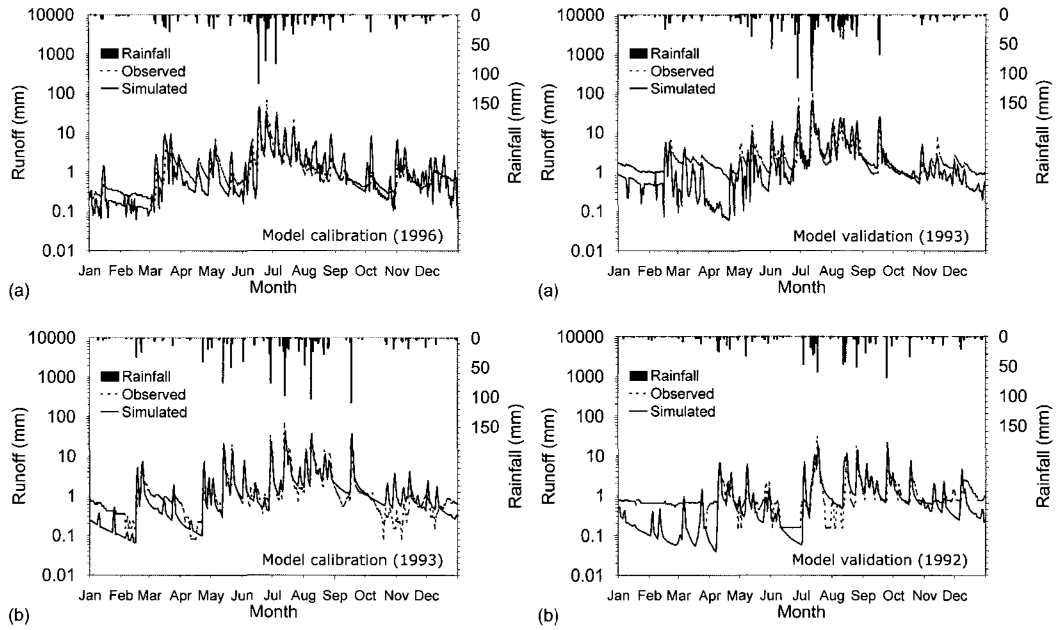

Figure 7. Comparison of observed and simulated runoff: (a) Yongdam watershed, (b) Bocheong watershed

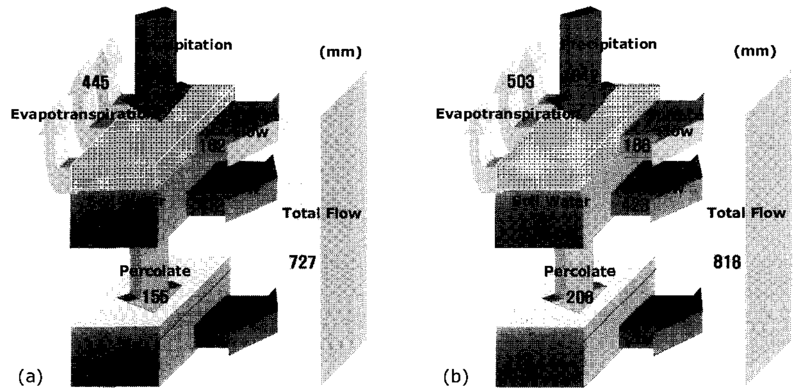

Figure 8. Water budget diagram: (a) Yongdam watershed (1996), (b) Bocheong watershed (1993)

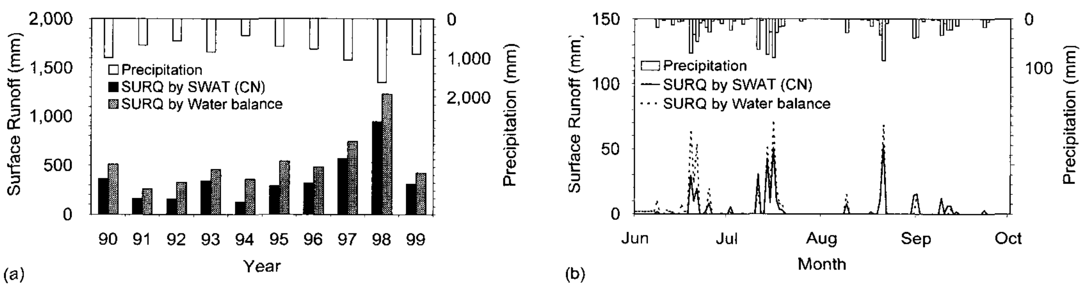

Figure 9. Comparison of surface runoff from paddy fields between CN method in SWAT and water balance method: (a) annual surface runoff, (b) daily surface runoff (1992)

Table 2. Application results of SWAT model

Watershed	Year	Rainfall (mm)	Surface flow (mm)	Lateral flow (mm)	Base flow (mm)	Percolation (mm)	Evapo-transpiration (mm)	Simulated runoff (mm)	Observed runoff (mm)
Yongdam	1993	1543.4	259.8	566.1	236.4	243.0	453.1	1087.3	1133.2
	1994	686.0	48.3	190.2	58.0	54.0	415.9	296.1	328.1
	1995	1111.3	135.2	361.3	157.8	157.8	447.3	653.6	576.5
	1996	1184.7	161.9	412.4	153.6	154.7	445.4	727.0	705.5
	Mean	1131.4	151.3	382.5	151.5	152.4	440.4	691.0	685.8
Bocheong	1990	1501.2	180.3	477.6	231.9	236.6	564.6	888.9	919.7
	1991	1007.0	83.9	288.2	142.2	144.0	489.9	513.8	621.7
	1992	943.2	75.2	262.4	114.5	114.3	500.2	451.6	479.5
	1993	1342.4	188.1	423.4	207.4	205.6	502.9	818.2	824.9
	1994	765.3	63.7	201.0	83.4	81.2	460.9	347.6	436.3
	1995	983.9	137.0	271.2	94.6	94.1	487.6	502.3	534.4
	1996	1164.0	142.0	328.7	137.0	139.1	527.3	607.2	796.4
	1997	1663.7	343.1	522.2	229.3	237.7	538.9	1094.0	1068.1
	Mean	1171.3	151.7	346.8	155.0	156.6	509.0	653.0	710.1

Table 3. Comparison of annual surface runoff from paddy fields

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Rainfall (mm)	997	674	570	858	429	711	776	1,053	1,642	898
Surface runoff by CN method (mm), (A)	365	160	152	342	124	292	315	568	944	309
Surface runoff by water balance method (mm), (B)	509	263	324	459	358	540	480	743	1,231	425
{(B−A)/A}×100 (%)	39	65	113	34	189	85	52	31	30	38

years. The compared annual and daily results between the methods from June to September are shown in Figure 9 and Table 3.

The annual surface runoff in paddy fields by water balance method is higher than that by CN method with the range of 30% to 189%, and the average of difference is about 68%. This trend is more significant during drought period (1994~1995). The water balance method gives better results because its explanation comes closer to the actual irrigation condition in Korea.

4. CONCLUSIONS

The SWAT model was applied to estimate the daily stream flow for two mountainous and typically agricultural watersheds in Korea. Also, in order to reflect the characteristics of the runoff process in paddy fields, a new routine was added and tested. The calibration and validation results showed a good agreement with the simulated and observed daily stream flow. Even though it was difficult to get proper parameters of SWAT model, the model performed successfully to Korean watersheds.

Drainage outlet height in paddy fields is usually managed seasonally for the prevention of excess or shortage of water during the irrigation periods. So, the newly suggested water balance method will be able to simulate the runoff process in paddy fields more precisely.

Finally, further studies including accurate monitoring and validation of the water balance method in paddy fields are necessary for the application of the improved SWAT model (named SWAT-K).

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Water Resources Research Department, Korea Institute of Construction Technology, 2311, Daehwa-dong, Ilsan-gu, Goyang-si, Gyeonggi-do, 411-712, Republic of Korea
(E-mail :)