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Assessing Rainfall Contribution to Storm Flow on a Small Forested Catchment in Republic of Korea

Sang Ho Lee[1,2], Sangjun Im[1,3*] and Dixon T. Gevaña[4]

ABSTRACT

The TOPMODEL was employed to analyze rainfall contribution to runoff generation in a 58.3-ha Myeong-seong catchment in Korea. The parameters of the model were calibrated using Monte Carlo simulation by comparing the observed and simulated runoff volume across nine recorded storm events. Parameter estimations gave the model an efficiency of 0.93 for the entire event set. Mean fraction of rainfall to storm flow was 23.1 %, ranging from 5.6 to 48.3 %. Variations were also observed in rainfall contribution related mainly to antecedent moisture conditions and other hydrological properties of the catchment. Quick response flow that was estimated from the saturated overland flow in the model comprised 41.9 -75.9 % of the total runoff for nine storm events, while base flow accounted for 41.7 % of streamflow for all events. No significant relationship between rainfall amount and quick response flow was found. This study introduced a modeling approach to identify the source of streamflow on a forested catchment. Difficulties in predicting accurately the runoff were encountered. In general, immense and high quality data are required to overcome the complexity of hydrologic processes that occur in forested catchments.

Key words: *Hydrology, runoff, storm, streamflow, TOPMODEL*

INTRODUCTION

The dynamics of storm flow in forested catchments have received great deal of attention from hydrologists and forest managers, over the last several years. However, little is known with respect to hydrologic processes that occur within catchments during storm events (*Ratcliffe et al. 1996*). During a storm period, runoff on hillslope topography can be generated with different hydrologic pathways including overland flow, saturated subsurface flow, and groundwater flow (*Kennedy et al. 1986; Rice and Hornberger 1998*). Overland flow, a major contributor of storm flow, is produced when rainfall intensity exceeds the infiltration capacity of soils (*Horton 1933*). In addition, saturation water stored in subsurface soil layers is also drained immediately into streams. Overland flow and saturated subsurface flow may respond quickly after rainfall occurs and may play a key role in storm flow generation on steep, forested catchments (*Dunne and Black 1979*).

Significant portion of the storm hydrograph can be associated with quick response flow. On the average, quick response flow constituted approximately 44 % of the total stream flow *(Schellekens et al. 2004*). Groundwater flow seems to make a delayed contribution to storm flow, but it has a particular significance to stream runoff during the dry season. Its contribution to stream flow mainly depends on the depth of the water table and the hydraulic conductivity of the soil.

Identifying the source of water in storm flow is difficult. However, there are several approaches that had been developed to explore the role of rainfall in storm flow generation. These include hydrochemical (e.g. *Turner and MacPherson 1990*; *DeWalle and Pionke 1994*; *Schellekens et al. 2004*) and modeling (eg. *Buchtele et al. 1996*; *Singh and Jain 2003*; C*ombalicer et al. 2010*) approaches. By comparison, hydrochemical approach is done through field experimentation that requires greater cost and labor for monitoring the hydrologic variables. On the other hand, hydrologic modeling approach is practical and widely adopted method since it utilizes computer model to quantitatively assess the relationship between rainfall and storm flow (*Buchtele et al. 1996*; *Kim et al. 1998*). As an example for the latter, *Combalicer et al.* (*2010*) applied a hydrologic rainfall-runoff model to estimate the streamflow of a small, forested tropical catchment in the Philippines. Rainfall contributed approximately 49 % in the total streamflow. In a similar study, *Buchtele et al.* (*1996*) applied BROOK and SAC-SMA models to understand the runoff-producing mechanism of five watersheds and concluded that quick response flow was responsible for approximately 50 % of runoff.

Storm runoff is produced where rainfall intensity exceeds soil infiltration capacity, or when soil storage is saturated with water. In many forested catchments, runoff is predominantly produced from saturated land areas while

[1] Department of Forest Sciences, College of Agriculture and Life Sciences, Seoul National University, 1 Gwanak-ro, Gwanak-gu, Seoul, 151-921, Republic of Korea
E-mail:junie@snu.ac.kr (*corresponding author)
[2] The Korean Association of Soil and Water Conservation (KASWC), 51-10 Chyeongryangri-dong, Dongdaemun-gu, Seoul, 130-867, Republic of Korea
[3] Research Institute for Agriculture and Life Sciences, Seoul National University, 1 Gwanak-ro, Gwanak-gu, Seoul, 151-921, Republic of Koreas
[4] College of Forestry and Natural Resources, University of the Philippines Los Baños, College, Laguna, Philippines 4031

infiltration-excess overland flow is nonexistent or rarely observed (*Dunne and Black 1979*). This is mainly due to the high infiltration capacity of soils at steeper topography. Thus, water draining in saturated land is considered as a major source of storm hydrographs in forested catchments during storm periods.

The TOPMODEL has been widely applied technique in assessing hydrologic response in steep forested watersheds even though such model was originally developed for small, upland watersheds (*Beven and Kirkby 1979*). It is considered as a semi-distributed hydrologic model that captures both topography and soil transmissivity as major factors affecting runoff generation.

In this study, TOPMODEL was used to simulate hydrologic response in a small, forested catchment of Korea because of its capacity to account topographic aspects of forested catchment in predicting runoff, and also because of its ability to apply the concept of saturation overland flow (*Beven and Kirkby 1979*). Thus, this study was conducted to analyze how much rainfall contributes to storm flow generation during storm periods. Achieving this aim, hydrologic parameters were calibrated using Monte Carlo simulation method. Streamflow was also analyzed to estimate the portion of rainfall that contributed to runoff generation.

MATERIALS AND METHODS

Study site

The study was conducted in Myeongseong watershed in Gyeonggi Province, Korea. It lies between 35º32´43″ - 35º37´42″ N latitude and 127º37´28" - 127º39´01" E longitude with a drainage area of 58.3 ha (**Figure 1**). Its elevation ranges from 200 - 657 m asl (above sea level) with an average slope of 17 percent. It is primarily comprised of mixed forest stands dominated by *Pinus rigida*, *Pinus koraiensis*, and *Larix kaempferi*. Soil texture is mostly sandy loam. Climate is typically monsoon i.e. characterized by wet, moderately warm summer and a dry, cool winter. Mean monthly temperature ranges from -10.6 ºC in winter (January) to 30.2 ºC in summer (August). Mean annual precipitation is approximately 1,300 mm which is occurred during the months of June to August.

To monitor precipitation, an automatic tipping bucket rain gauge was placed at about 100 m distance apart from the outlet of catchment. A sharp-crested rectangular weir with a water stage recorder was also constructed at the stream outlet of the watershed to collect continuous recording of streamflow.

Hydrologic Model

The TOPMODEL (*Beven and Kirkby 1979*) was selected to produce storm hydrographs for the Myeongseong catchment. It is a semi-distributed hydrologic model that can simulate the contributing factors of runoff within a watershed based on a topographically defined wetness index. Several versions of water movement simulations can also be produced using this model (*Beven and Kirkby 1979*; *Wolock 1993*; *Beven 1997*). For instance, soil layer can be conceptually divided into three vertical zones: root; unsaturated layer; and saturated layer. The root zone is mainly used for estimating water loss by evapotranspiration. On the other hand, water flux can be used to simulate water in the saturated zone; while the vertical flux can be used to predict the water displaced from the unsaturated soil layer.

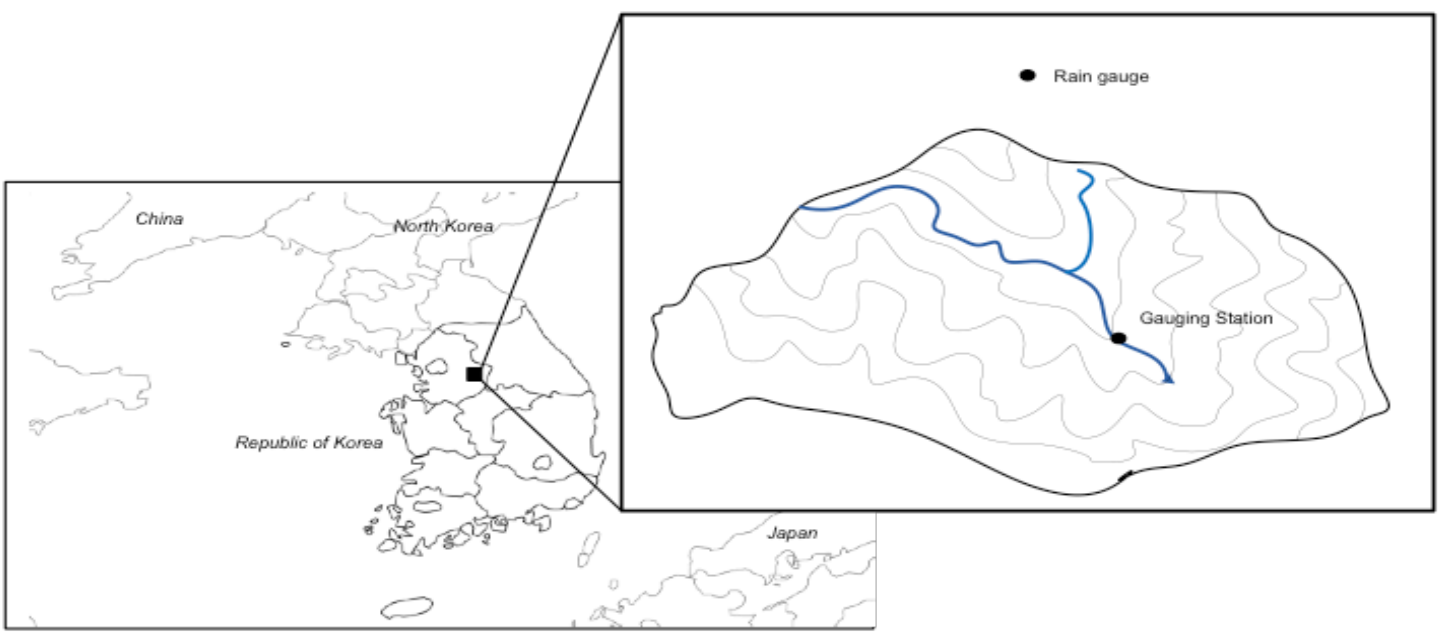

Figure 1. Location of the Myeongseong catchment.

The unsaturated water flux is considered as a minor contributor to streamflow at the basin outlet because the water moves vertically into saturated soil that causes the groundwater table to increase during the storm period. On the other hand, saturated overland flow is calculated from the areal extent of the saturated land-surface areas. Subsurface flow is computed as a function of the maximum subsurface flow rate and the average depth to the water table. Rainfall on saturated areas or the surface of water bodies also becomes overland flow immediately. In small and mountainous watersheds, quick response flow such as saturated overland flow from saturated land-surface areas and water that exceeds the infiltration capacity of soils, is likely to be critical in producing the storm hydrograph (*Dunne and Black 1979*). Therefore, the direct contribution of rainfall to storm flow can be estimated from quick response flow.

Saturated land-surface area is a very important source of storm flow generation during the storm period in TOPMODEL. The water table rises when rainfall infiltrates into the soil, then drains to the saturated soil zone. The depth of the water table also decreases as water drains laterally into other parts of the watershed. If the water table rises to the land surface, the area becomes the saturated condition in the model. Saturated zone first develops near existing stream channels when soil saturation reaches its maximum. As more water enters the soil layer and drains into the saturated zone, the zone of soil saturation may extend through the catchment. The extent of this saturated land-surface areas is affected by basin topography and soil hydraulic characteristics. A topographic index can be introduced to represent the topographic effect of the catchment on hydrologic response (*Beven and Kirkby 1979*).

Parameter Estimation

The reliability of the hydrologic model typically depends on the accuracy of model parameter estimation. Parameter estimation is an iterative procedure that involves parameter evaluation and refinement by means of comparing simulated with observed streamflows (*Jacomino and Fields 1997*). It involves the adjustment of a parameter set until the observed and simulated values are at an acceptable level.

Parameter estimation can be made either manually or automatically. The manual approach is simple following an empirical method of adjusting parameters interactively throughout successive model runs. This is relatively time-consuming and labor-intensive technique that requires good hydrological judgment when evaluating the quality of model fit. The general solution in overcoming such limitations is employing an automatic algorithm that reproduces an accurate result within a reasonable amount of running time. The automatic approach uses a computer algorithm to search the parameter space, performing multiple trials of the model. Various techniques have been developed to automatically calibrate the hydrologic model (*Kuczera and Parent 1998*; *Eckhardt 2001*; *Cheng et al. 2002*).

Saturated hydraulic conductivity (m), watershed mean value of transmissivity (T_0), time delay factor (t_d), maximum storage of root zone (SR_{MAX}), and root zone deficit (Srzl) were considered for parameter estimation (**Table 1**). The first two parameters were used to estimate storage deficit from water table depth. Parameter m is the variation of saturated hydraulic conductivity with soil depth. This can be practically obtained by analyzing the shapes of observed recession curves (*Beven 1997*). Parameter T_o means the lateral hydraulic conductivity when the saturated zone reaches ground surface (*Brooks et al. 2004*). Even if hydraulic conductivity measurements are available, To can be considered as a calibration parameter because measurements have been conducted within the root zone and from small samples or from vertical rather than lateral fluex (*Ambroise et al. 1996*). The parameter t_d is time constant factor for saturated zone recharge which functionally relates to parameter T_o.

The optimal values of TOPMODEL parameters were determined using the Monte Carlo simulation technique. Monte Carlo simulation is a widely accepted technique for automatic calibration of hydrologic model parameters (*Kuczera and Parent 1998*; *Demaria et al. 2007*; *Cibin et al. 2014*). In this method, a parameter set is generated with the feasible parameter space, in which each parameter is randomly derived according to the pre-defined probability distribution. In parameter estimation, TOPMODEL runs with randomly selected parameters over a range of values (**Table 1**). The corresponding prediction are then evaluated whether the output of each simulation is acceptable or unacceptable.

Table 1. Parameters and its range of TOPMODEL used in the study (*Beven 1997*).

Parameter	Description	Range
m	Parameter controlling the decline of saturated hydraulic conductivity with depth (m)	0.003 - 0.25
T_0	Watershed mean value of transmissivity at saturation of the soil (m hr^{-2})	0.0007 - 8.27
t_d	Unsaturated zone time delay factor (hr)	1 - 100
SR_{MAX}	Maximum storage of root zone (m)	0.01 - 0.20
Srz1	Initial value of root zone storage deficit (m)	0 - SR_{MAX}

Parameter values within the range were randomly selected using uniform sampling distribution for 100,000 Monte Carlo simulations for each storm event. Model efficiency, as a goodness-of-fit criterion (*Nash and Sutcliffe 1970*), was computed for each model run. The parameter that model efficiency is greater than 0.8 was selected as a narrower range for the parameter set. An additional 1,000 Monte Carlo runs were made over the reduced range for the final parameter estimation.

Hydrologists are often interested in assessing the accuracy and reliability of a model by comparing simulated results with observed data. The degree to which a model prediction conforms to the corresponding observed values could be quantitatively evaluated. Some statistical criteria for assessing model performance were introduced in this study. Differences in relative errors among peak flow and total flow were examined for each storm event using the relative error in storm flow (RES) and relative error in peak flow (REP) equations. In addition, differences in the shape of hydrographs across simulated and observed hydrographs were also measured using the standard error of estimate (SEE) formula. Lastly, the proportional error of estimate (PEE) was computed for each event to equally weigh the proportional errors in the hydrograph ordinates.

$$\text{Relative Error in Storm flow (RES)} = \frac{V_s - V_o}{V_o} \times 100 \quad (1)$$

$$\text{Relative Error in Peak Flow (REP)} = \frac{Q_{Ps} - Q_{Po}}{Q_{Po}} \times 100 \quad (2)$$

$$\text{Standard Error of Estimate (SEE)} = \left(\frac{1}{n-2}\sum_{i=1}^{n}(q_o(t) - q_s(t))_i^2\right)^{1/2} \quad (3)$$

$$\text{Proportional Error of Estimate (PEE)} = \left[\sum_{i=1}^{n}\left(\frac{q_o(t) - q_s(t)}{q_o(t)}\right)_i^2\right]^{1/2} \quad (4)$$

RESULTS AND DISCUSSION

Rainfall-Runoff Data

A summary of the hydrologic observations in the Myeongseong catchment is presented in **Table 2**, listing all rainfall and runoff characteristics for the three year period. Since June 1997 (first measurement period), nine storm events were selected in which depths and maximum intensities of flow and rainfall were measured.

The amount of rainfall per storm event varied from 33.0 mm to 245.0 mm. Similarly, variation in flow discharge was observed according to rainfall amount. The lowest flow volume was approximately 5.7 mm in event No. 8, while the highest flow occurred in event No. 2 at 115.2 mm. Highest rainfall intensity was recorded on 25 July with 32.0 mm h^{-1}.

On average, the proportion of rainfall to storm flow was 37.6 %, ranging from 11.7 to 66.8 %. Maximum flow rate also varied widely from 0.14 mm h^{-1} to 4.14 mm h^{-1}, which can be attributed to the amount and distribution of rainfall prior to the occurrence of peak flow.

Model Set-up

The distribution of topographic index was initially derived from a 10-m raster grid topographic map using a multiple direction flow algorithm. The topographic index is useful to identify hydrological similarities, and it reflects the spatial distribution of soil moisture and the propensity of landscape areas to become wet. The frequency distribution of the topographic index in the watershed is right-skewed, with a minimum value of 1.46 and maximum of 14.30 (**Figure 2**). The average value of the topographic index was 4.87. Moreover, high topographic index was observed in the valley bottom while lower values were observed on the upper slopes of mountainous areas. Land area with higher values of topographic index tend to be saturated first and rain water are likely directed to stream when a rain event begins.

Optimal parameter sets with the highest efficiency coefficient conformed very well with the observed and simulated flows (**Table 3**). These parameter sets have a mean

Table 2. Datasets of rainfall and runoff used in this study.

Event	Start	Duration (hr)	Total Rainfall (mm)	Total Flow (mm)	Max. Rainfall (mm h^{-1})	Max. Flow (mm h^{-1})
1	JUN. 25, 1997	134	95.5	12.9	15.0	0.19
2	JUN. 30, 1997	312	222.0	115.2	21.5	4.14
3	JUL, 15, 1997	234	118.0	53.9	22.5	1.61
4	JUL. 25, 1997	584	245.0	108.7	32.0	2.29
5	AUG. 19, 1997	528	69.0	46.1	2.85	1.54
6	SEP. 10, 1997	179	38.5	18.1	11.5	0.45
7	MAY 16, 1998	113	33.0	10.0	7.0	0.17
8	MAY 18, 1999	60	51.5	5.7	10.0	0.14
9	JUL. 22, 1999	139	107.5	29.7	18.5	0.45

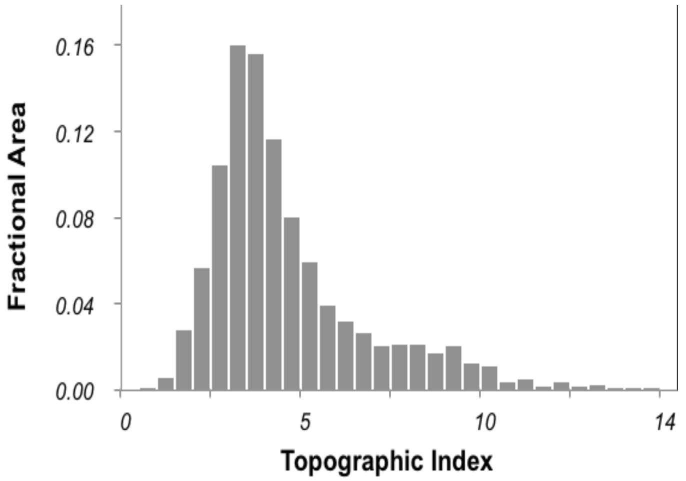

Figure 2. Distributed function of the topographic index for the Myeongseong catchment.

model efficiency (E) of 0.93, ranging from 0.88 to 0.97. As a result, the parameter controlling for the decline of saturated hydraulic conductivity with depth (M) ranged from 0.02 m to a maximum of 0.06 m. In addition, the watershed mean value of transmissivity at saturation of the soil (T_0) ranged from 0.405 to 0.905 m h^{-2}. The time delay factor of saturated zone storage recharge (t_d) varied from 5.33 h in event No. 3 to 8.41 h in event No. 8, with a mean value of 6.49 h. Lastly, the mean SR_{MAX} was 0.00048 m and the initial root zone storage deficit (Srzl) was 0.00040 m.

Flow Simulation

The mean observed and simulated flows for all events were 26.40 L s^{-1} and 29.39 L s^{-1}, respectively. Percentage error in flow volume, which represents the amount of loss from rainfall during a storm period, yielded a discrepancy of 1.06 %. In terms of percent error in peak flow (REP), values varied from -27.65 to 6.95 %, which suggests that the parameters that related to routing components are adequately adjusted within each individual event. The percent errors in flow rate and peak flow indicated a good agreement between simulated and observed values. Among the events, SEE was lowest in event No. 8 at 1.02 l s^{-1} while highest in event No. 2 at 18.16 L s^{-1}(T**able 4**). Scale effects were also noticeable when SEE was examined across storm events. This can be explained by the dimensional and sensitive response of this criterion toward the magnitude of flow rate. Bias in the hydrograph estimate was largest in event No. 5, where SEE was 9.1 L s^{-1} with a mean flow rate of 14.14 L s^{-1}. As a rule, the effect of flow rate can be removed by dividing the residuals of the hydrograph ordinates by the observed flow rate. Hence, PEE varied from a minimum of 0.82 to a maximum of 16.2. A mean PEE value of 4.70 demonstrated that the model developed in this study achieved the best one-to-one fit of corresponding ordinates between observed and simulated hydrographs over the storm period.

Simulation results showed that the calibrated TOPMODEL has the ability to effectively simulate flow rate, peak flow, and hydrograph shape of rainfall events in Myeongseong catchment. It is also evident that the hydrologic processes of the model can be considered acceptable for representing water movement within the watershed.

Contribution of Rainfall to Stream Flow

Rainfall fraction contributing to storm flow production can be examined using the calibrated TOPMODEL model, in which rain can be divided into different hydrologic components. In general, streamflow volume and quick response flow projected a straightforward trend. A predictable relationship between rainfall and its contribution to storm flow generation was also observed (**Figure 3**). These relationship show that as rainfall increases, direct contribution of rainfall to storm flow also increases.

On the average, rainfall contributed to 58.3 % of the total stream discharge across nine storm events. Estimates ranged from 11.0 to 65.0 %, which can be attributed to varying antecedent moisture conditions and to the amount of rainfall in each event. Further, approximately 58.3 % of the

Table 3. Optimal parameter values and estimated model efficiency.

Event	M (m)	T_0 (m h^{-2})	t_d (h)	SR_{MAX} (m)	Srzl (m)	E
1	0.044	0.523	6.51	0.00057	0.00035	0.94
2	0.060	0.529	5.58	0.00041	0.00041	0.97
3	0.051	0.405	5.33	0.00046	0.00042	0.93
4	0.059	0.677	7.01	0.00052	0.00051	0.88
5	0.029	0.771	7.42	0.00054	0.00054	0.89
6	0.020	0.905	5.40	0.00045	0.00040	0.93
7	0.029	0.689	6.62	0.00038	0.00023	0.94
8	0.032	0.821	8.41	0.00043	0.00035	0.97
9	0.059	0.736	6.10	0.00054	0.00037	0.91
Mean	0.042	0.664	6.39	0.00047	0.00039	0.93

Table 4. Evaluation model performances.

Event	Mean Streamflow (L s^{-1})			Peak Flow (L s^{-1})			PEE	SEE (L s^{-1})
	observed	Simulated	REE (%)	Observed	Simulated	REP (%)		
1	15.41	15.42	0.06	30.75	29.12	-5.30	1.63	2.00
2	59.81	60.66	1.42	669.98	634.63	-5.27	4.91	18.16
3	37.28	37.57	0.78	259.85	251.05	-3.39	3.34	12.38
4	30.15	29.78	-1.23	370.37	267.97	-27.65	8.69	15.84
5	14.14	13.75	-2.76	250.02	196.90	-21.25	16.20	9.10
6	16.36	16.45	0.55	72.83	72.00	-1.14	4.10	4.27
7	14.37	14.29	-0.56	27.78	29.71	6.95	1.11	1.63
8	15.44	15.21	-1.49	22.70	22.81	0.48	0.82	1.02
9	34.62	34.38	-0.69	72.07	75.18	4.32	1.52	4.47
Mean	26.40	26.39	0.04	197.37	175.49	-11.09	4.70	7.65

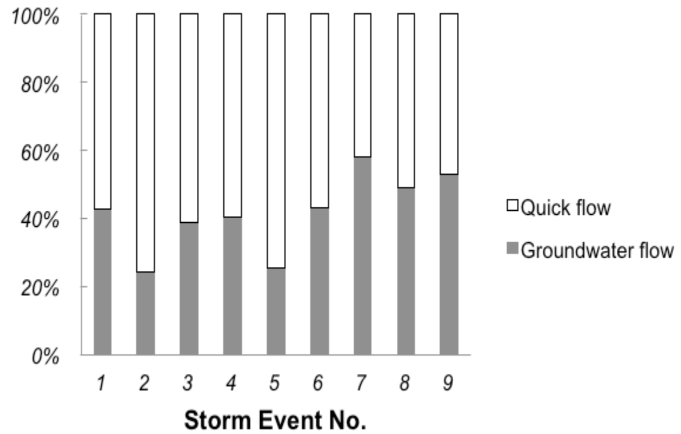

Figure 3. Portion of quick flow and groundwater flow in streamflow generation.

storm flow was due to quick flow. However, the distribution of quick flow did not conform well to how rainfall values were distributed across events. Among the storm events, rainfall contribution was highest in No. 2 at 76 %. On the other hand, groundwater flow shared approximately 41.7 % of the total storm flow, ranging from 24 to 58 %.

In a similar study, *Weiler et al.* (*2003*) estimated the rainfall contribution using transfer function hydrograph separation model of two storm events on the 17 ha watershed in New Zealand wherein, rainfall has contributed between 35 % and 40 % in the total runoff. Recent researches also demonstrated that rainfall was responsible for nearly 50 % of streamflow during storm periods (*Buchtele et al. 1996 Combalicer et al. 2010*). Given these estimates, this study has yielded comparable findings that can be used to analyze the hydrologic components of forested watersheds in Korea.

CONCLUSION

The TOPMODEL was applied to simulate storm flow and estimate rainfall contribution to storm flow generation in a small, forested catchment of Korea. Model parameters were evaluated and optimized using the Monte Carlo simulation technique for nine storm records in the Myeongseong catchment. Mean fraction of rainfall to storm flow was 23.1 %, ranging from 5.6 to 48.3 %. Such variations can be associated with different rainfall amounts, durations, patterns, and soil moisture conditions during each event prior to rain on-set. Simulated results also indicated that rainfall contribution to quick response flow and groundwater flow varied across events. The rainfall-induced quick flow was approximately 58.3 % of the total storm flow, while 41.7 % of storm flow originated from groundwater.

Overall, TOPMODEL is a reliable model in predicting rainfall contribution to storm flow generation as shown in this study. It provided valuable results as far as exploring water movement in small and steeped watersheds of Korea are concern. The technique also proposes a practical approach in hydrological modelling where recording instruments are often lacking in the field.

REFERENCES

Ambroise, B., Beven, K. and J. Freer. 1996. "Towards a generalisation of the TOPMODEL concepts: topographic indices of hydrological similarity". *Water Resources Research* 32:2135-2145.

Beven, K. 1997. "Topmodel: A critique". *Hydrological Processes* 11: 1069-1085.

Beven, K. and M.J. Kirkby. 1979. "A physically based variable contributing area model of basin hydrology". *Hydrological Sciences Bulletin* 24(1): 43-69.

Brooks, E.S., Boll, J. and P.A. McDaniel. 2004. "A hillslope-scale experiment to measure lateral saturated hydraulic conductivity". *Water Resources Research* 40:W04208.

Buchtele, J., Elias, V., Tesar, M. and A. Herrmann. 1996. "Runoff components simulated by rainfall runoff models". *Hydrological Sciences Journal* 41(1): 49-60.

Cheng, C.T., Ou, C.P. and K.W. Chau. 2002. "Combining a fuzzy optimal model with a genetic algorithm to solve multi-objective rainfall-runoff model calibration". *Journal of Hydrology* 268: 72-86.

Cibin, R., Athira, P., Sudheer, K.P. and I. Chaubey. 2014. "Application of distributed hydrological models for predictions in ungauged basins: a method to quantify predictive uncertainty". *Hydrological Processes* 28:2033-2045.

Combalicer, E.A., Cruz, R.V.O., Lee, S.H. and S. Im. 2010. Modelling hydrologic processes distribution in a tropical forest watershed in the Philippines. *Journal of Tropical Forest Science* 22(2): 155-169.

DeWalle, D.R. and H.B. Pionke. 1994. "Streamflow generation on a small agricultural catchment during autumn recharge: II. Stormflow periods". *Journal of Hydrology* 163(1-2): 23-42.

Demaria, E.M., Nijssen B. and T. Wagener. 2007. "Monte Carlo sensitivity analysis of land surface parameters using the Variable Infiltration Capacity model". *Journal of Geophysical Research* 112: D11113.

Dunne, T. and R.D. Black. 1979. "Partial area contributions to storm runoff in a small New England watershed". *Water Resources Research* 6(2): 478-490.

Eckhardt, K. and J.G. Arnold. 2001. "Automatic calibration of a distributed catchment model". *Journal of Hydrology* 251: 103-109.

Horton, R.E. 1933. "The role of infiltration in the hydrological cycle". *Transactions of the American Geophysical Union* 14: 446-460.

Jacomino, V.M.F. and D.E. Fields. 1997. "A critical approach to the calibration of a watershed model". *Journal of the American Water Resources Association* 33(1): 143-154.

Kennedy, V.C., Kendall, C., Zellweger, G.W., Wyerman, T.A. and R. Avanzino. 1986. "Determination of the components of rainstormflow using water chemistry and environmental isotopes, Mattole River Basin, California". *Journal of Hydrology* 84:107-140.

Kim, J., Norman, L.M., Alexander, K.G. and P.G. Konstantine. 1998. "River flow response to precipitation and snow budget in California during the 1994/95 winter". *Journal of Climate* 11: 2376–2386.

Kuczera, G. and E. Parent. 1998. "Monte Carlo assessment of parameter uncertainty in conceptual catchment models: the Metropolis algorithm". *Journal of Hydrology* 211: 69–85.

Nash, J.E. and J.V. Sutcliffe. 1970. "River flow forecasting through conceptual models: A discussion for principles". *Journal of Hydrology* 10: 282-290.

Ratcliffe, E.B., Peters, N.E. and M. Tranter. 1996. "Short-term hydrological response of soil water and groundwater to rainstorms in a deciduous forest hillslope, Georgia, USA". In: Anderson, M.G. Brooks, S.M. (Eds). *Advances in Hillslope Processes* Vol (1), John Wiley; pp. 129-147.

Rice, K.C. and G.M. Hornberger. 1998. "Comparison of hydrochemical tracers to estimate source contributions to peak flow in a small, forested, headwater catchment". *Water Resources Research* 34(7): 1755-1766.

Schellekens, J., Scatena, F.N., Bruijnzeel, L.A., van Dijk, A.I.J.M., Groen, M.M.A. and R.J.P van Hogezand. 2004. "Stormflow generation in a small rainforest catchment in the Luquillo Experimental Forest, Puerto Rico". *Hydrological Processes* 18: 505–530.

Singh, P. and S.K. Jain. 2003. "Modelling of streamflow and its components for a large Himalayan basin with predominant snowmelt yields". *Hydrological Sciences Journal* 48(2): 257-276.

Turner, J.V. and D.K. MacPherson. 1990. "Mechanisms affecting streamflow and stream water quality: An approach via stable isotope, hydrogeochemical, and time series analysis". *Water Resources Research* 26(12): 3005-3019.

Weiler, M., McGlynn, B.L., McGuire, K.J. and J.J. McDonnell. 2003. "How does rainfall become runoff? A combined tracer and runoff transfer function approach". *Water Resources Research* 39(11):1315-1317.

Wolock, D.M. 1993. "Simulating the variable-source-area concept of streamflow generation with the watershed model TOPMODEL;" USGS Water-Resources Investigations Report 93-4124; U.S. Geological Survey: Lawrence, KS, USA. pp. 1-33.

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