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# Application of The Semi-Distributed Hydrological Model(TOPMODEL) for Prediction of Discharge at the Deciduous and Coniferous Forest Catchments in Gwangneung, Gyeonggi-do, Republic of Korea[1]

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# 京畿道 光陵의 闊葉樹林과 針葉樹林 流域의 流出量 算定을 위한 準分布型 水文模型(TOPMODEL)의 適用[1]

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## ABSTRACT

TOPMODEL, semi-distributed hydrological model, is frequently applied to predict the amount of discharge, main flow pathways and water quality in a forested catchment, especially in a spatial dimension. TOPMODEL is a kind of conceptual model, not physical one. The main concept of TOPMODEL is constituted by the topographic index and soil transmissivity. Two components can be used for predicting the surface and subsurface contributing area. This study is conducted for the validation of applicability of TOPMODEL at small forested catchments in Korea. The experimental area is located at Gwangneung forest operated by Korea Forest Research Institute, Gyeonggi-do near Seoul metropolitan. Two study catchments in this area have been working since 1979 ; one is the natural mature deciduous forest(22.0 ha) about 80 years old and the other is the planted young coniferous forest(13.6 ha) about 22 years old. The data collected during the two events in July 1995 and June 2000 at the mature deciduous forest and the three events in July 1995 and 1999, August 2000 at the young coniferous forest were used as the observed data set, respectively. The topographic index was calculated using 10 m $\times$ 10 m resolution raster digital elevation map(DEM). The distribution of the topographic index ranged from 2.6 to 11.1 at the deciduous and 2.7 to 16.0 at the coniferous catchment. The result of the optimization using the forecasting efficiency as the objective function showed that the model parameter, m and the mean catchment value of surface saturated transmissivity, $\ln T_0$ had a high sensitivity. The values of the optimized parameters for m and $\ln T_0$ were 0.034 and 0.038; 8.672 and 9.475 at the deciduous and 0.031, 0.032 and 0.033; 5.969, 7.129 and 7.575 at the coniferous catchment, respectively. The forecasting efficiencies resulted from the simulation using the optimized parameter were comparatively high ; 0.958 and 0.909 at the deciduous and 0.825, 0.922 and 0.961 at the coniferous catchment. The observed and simulated hyeto-hydrograph showed that the time of lag to peak coincided well. Though the total runoff and peakflow of some events showed a discrepancy between the observed and simulated output, TOPMODEL could overall predict a hydrologic output at the estimation error less than 10 %. Therefore, TOPMODEL is useful tool for the prediction of runoff at an ungaged forested catchment in Korea.

*Key words : TOPMODEL, semi-distributed hydrological model, topographic index, soil transmissivity, forest type*

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## 要 約

준분포형 수문모형인 TOPMODEL은 산림유역의 유출량, 주 유출경로 및 수질을 공간적으로 예측하는데 많이 적용된다. TOPMODEL은 물리모형이 아니라 일종의 개념모형이며 주요 구성요소는 지형지수와 토양의 수평전달계수로 각각 지표면과 지표하 유출의 기여면적을 계산하는데 이용된다. 본 연구는 우리나라의 소규모 산림유역에서 TOPMODEL의 적용성을 검증하기 위하여 수행되었다. 시험지는 1979년부터 임업연구원에서 운용하고 있으며 서울 근교 경기도 광릉시험림에 위치해 있다. 활엽수림 유역은 임령이 약 80년, 유역면적이 22.0ha이고, 침엽수림 유역은 임령이 약 22년, 유역면적이 13.6ha이다. 관측자료는 활엽수 유역의 경우 1995년 7월과 2000년 6월에 발생한 2개 강우 - 유출사상이고 침엽수 유역의 경우 1995년과 1999년 7월 그리고 2000년 8월의 3개 강우 - 유출사상을 이용하였다. 지형지수는 10m × 10m의 수치지형도를 만들어 계산하였다. 지형지수 분포는 활엽수림 유역의 경우 2.6에서 11.1, 침엽수림 유역은 2.7에서 16.0으로 나타났다. 모형의 예측 효율성을 목적함수로 최적화한 결과 모형매개변수(m)와 유역의 평균 포화수평전달계수($\ln T_0$)가 높은 민감도를 나타내었다. 매개변수의 최적값은 활엽수림 유역의 경우 m값은 0.034와 0.038 그리고 $\ln T_0$값은 8.672와 9.475였으며, 침엽수 유역의 경우 m값은 0.031, 0.032, 0.033 그리고 $\ln T_0$값은 5.969, 7.129, 7.575였다. 이들 값을 이용하여 모의한 결과 모형의 예측 효율성은 활엽수림 0.958과 0.909 그리고 침엽수림 0.825, 0.922와 0.961로서 비교적 높게 나타났다. 강우 - 유출량 관측치와 모의치를 이용하여 강우 - 수문곡선을 작성한 결과 두 유역 모두 유출지연시간은 잘 일치하였다. 일부 강우 - 유출사상의 경우 총유출량과 첨두유량의 관측치와 모의치 간에 다소 차이를 보였지만 TOPMODEL은 전반적으로 10%이하의 오차범위에서 총유출량과 첨두유량을 예측할 수 있었다. 결론적으로 TOPMODEL은 우리나라의 미계측 산림유역에서 유출량을 산정하는데 유용한 수문모형이다.


## INTRODUCTION

Hydrological processes at a forested catchment have more complexity than those at other land use types e. g. an agricultural, horticultural and urban area. It is well known that runoff producing processes at a forested catchment are mainly saturated overland flow(Dunne and Black, 1970), Hortonian overland flow(Horton, 1933) and subsurface storm flow(Anderson and Burt, 1978). Various hydrological processes simultaneously happen and result in high spatial variation at a forested catchment. Mechanisms related to runoff producing processes referred as groundwater ridging linked to the capillary fringe (Gillham, 1984), Translatory flow(Hewlett and Hibbert, 1967) and preferential flow by macropore and pipe flow(Germann, 1986; Mosley, 1982). Until now, most of hydrological simulation models are based on Horton's infiltration theory and Darcy's law with a physical equation. Such a simulation model had a limitation to predict discharge at a forested catchment.

TOPMODEL(Topographical Based Hydrological Model) includes conceptually several kinds of hydrological processes referred above. The main parameters in TOPMODEL are the soil-topographical index and the decay parameter which controls the effective depth of the catchment soil profile. Actually TOPMODEL is not a hydrological simulation model. It is rather a set of conceptual tools that can be used to reproduce the hydrological behavior of catchments in a distributed or semi-distributed way, in particular the dynamics of surface and subsurface contributing areas(Beven *et al.*, 1995). It is based on some simple approximate hydrological theory but recognizes that, because of the lack of measurements of internal state variables and catchment characteristics, the representation of the internal hydrological responses of the catchment must necessarily be functional while introducing the minimal number of parameters to be calibrated(Beven, 1989). Thus, TOPMODEL may be seen as a product of two objectives. One is the development of a pragmatic and practical forecasting and continuous simulation model. The other is the development of a theoretical framework within which perceived hydrological processes, issues of scale and realism and model procedures may be researched(Beven *et al.*, 1995).

TOPMODEL has been applied in a various field. In the view of geochemical predictions, Robson *et al.*(1992) showed that the model results compared well with a two soil component mixing interpretation of chemical signals in the stream, provided that the flow generated on the saturated contributing areas was assumed to have a well mixed composition. The fact that there may be some relationship between the topographic characteristics of a catchment and its chemical characteristics, with the inference due to the effects of topography on flow pathways, has also been explored by Wolock *et al.*(1989, 1990). They showed that the mean of the topographic index distribution was strongly related to catchment acidification.

The current generation of atmospheric general circulation models(GCM) take little account of the variability of surface characteristics and hydrology in their calculation of land surface to atmosphere fluxes. TOPMODEL provides one simple way of incorporating heterogeneity into soil-vegetation-atmospheric models in a way in which the surface availability of water for evapotranspiration can be allowed to vary dynamically(Famiglietti and Wood, 1991).

As a distributed model that can make use of data on topographic, soil and vegetation information, TOPMODEL is well suited to implementation within a Geographical Information Systems(GIS) framework. Romanowicz *et al.*(1993) linked TOPMODEL to the Water Information System(WIS) developed by the Institute of Hydrology, UK. Other TOPMODEL implementations within a GIS framework have been used the SPAN Modeling Language(Stuart and Stocks, 1993); GRASS routines(Chairat and Delleur, 1993); the Pvwave modeling and visual system(Clapp *et al.*, 1992); in the RHESSys of Band *et al.*(1993) which also includes the FOREST-BGC ecological modeling components; the TAPES-G system of Moore *et al.*(1993) and the Modular Hydrological Modeling System(MHMS) of Leavesley *et al.*(1992).

Cho *et al.*(1997) analysed the relationship of rainfall and runoff using TOPMODEL in a small mountainous area. Kim(1997) applied TOPMODEL to artificially drained basin. The concept of TOPMODEL has developed in a trend of generalization or be suitable for specific hydrological schemes (Kim and Kim, 1999; Jung and Kim, 1999). Bae *et al.*(2000) tested the flood forecasting capability of TOPMODEL on a single watershed in the Soyang River basin and Cho *et al.*(2000) used TOPMODEL to predict long-term runoff analysis.

The aims of this study are to 1) validate an applicability of TOPMODEL at small forested catchment in Korea. 2) confirm how to simulate a spatial hydrological variation in two different forest types i.e. mature natural deciduous and young planted coniferous forests.

## DESCRIPTION OF TOPMODEL

### 1. General description

Figure 1 described TOPMODEL's concept schematically. TOPMODEL simplifies complex hydrological processes. Topographic index plays an important role in predicting where the runoff is contributed.

Topographic index($a/\tan\beta$) is calculated from the area of the hillslope per unit contour length(a) and the local surface slope($\tan\beta$). As shown in Figure 1, Topographic index increases in downslope and gentle area and reversely decreases in upslope and steep area. Resultantly streamside having a high value of topographic index is prone to saturate and produce saturation overland flow. Discharge takes place in the saturated area of surface and subsurface.

Evapotranspiration is taken from the root zone

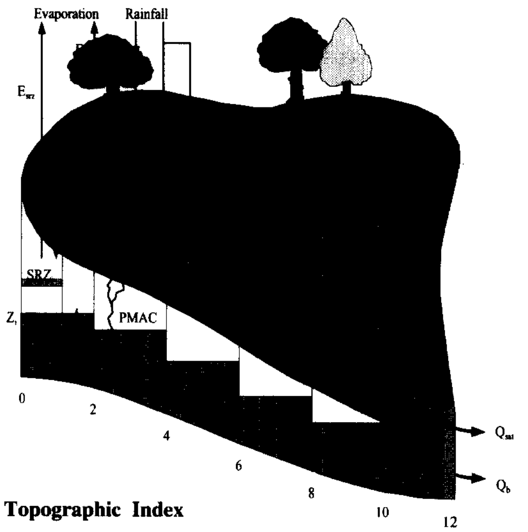


**Figure 1.** Schematic diagram of TOPMODEL's concept.

storage. Actual evapotranspiration(AET) is computed as a variable fraction of the potential evapotranspiration (PET).

$$AET = PET\frac{SRZ}{SRMAX} \quad (1)$$

where SRZ is the state variable describing the root zone storage and SRMAX is the maximum capacity. The gravity reservoir includes two storages. The upper storage is controlled by the saturation deficit of the saturated store $S_i$ which is equivalent to the quantity of water required to fill completely this upper reservoir.

## 2. Fundamental Assumption

Figure 2 describes the relationship of topography, topographic index, soil moisture deficit and soil transmissivity. To making a conceptualization TOPMODEL is premised upon several basic assumptions (Beven *et al.*, 1995) :

1) that the topography of surface runs parallel with that of subsurface;

2) that the dynamics of the saturated area can be approximated by successive steady state representations;

3) that the hydraulic gradient of the saturated area can be approximated by the local surface topographic slope, $\tan\beta$.

These assumptions lead to simple relationships between catchment storage or soil moisture deficit and local levels of the water table in which the main factor is the topographic index first proposed by Kirkby(1975) and developed as a complete hydrological model by Beven and Kirkby(1976, 1979). The Kirkby index represents the propensity of any point in the catchment to develop saturated conditions. High values will be caused by high values due to either long slopes or upslope contour convergence, and low slope angles.

TOPMODEL takes advantage of the mathematical simplifications allowed by a following assumption.

4) that the distribution of downslope transmissivity with depth is an exponential function of storage

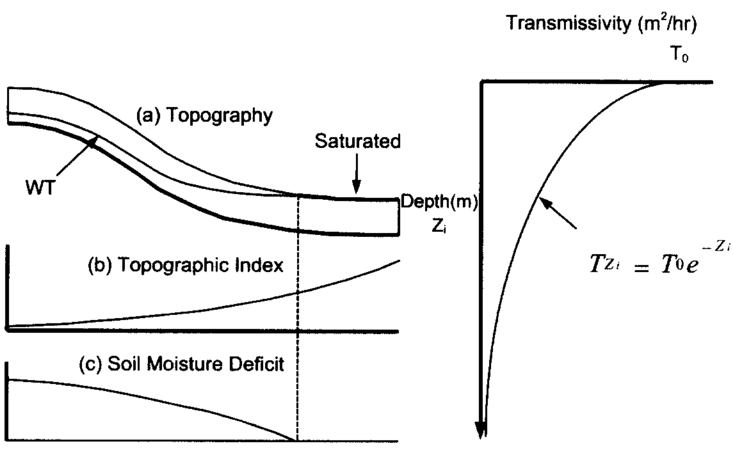


**Figure 2.** The relationship of topography and flow.

deficit or depth to the water table.

$$T = T_0 e^{-\frac{S}{m}} \quad (2)$$

where $T_0$ is the lateral transmissivity when the soil is just saturated($m^2/h$), S is local storage deficit(m) and m is a model parameter(m). Beven(1984) has provided data to suggest that an exponential decline in vertical soil conductivity with depth may be adequate to describe the vertical changes in the hydraulic properties of a wide range of soils and has shown that the equivalent exponential transmissivity function can be derived under the assumption of isotropy.

$$T = T_0 e^{-fz} \quad (3)$$

where z is local water table depth(m) and f is a scaling parameter($m^{-1}$). The parameters f and m are approximately related by $f = \Delta\theta_1/m$ where $\Delta\theta_1$ is an effective water content change per unit depth in the unsaturated zone due to rapid gravity drainage. A physical interpretation of the decay parameter m is that it controls the effective depth of the catchment soil profile.

Under the assumption 3) of an effective water table gradient and saturated flow parallel to the local surface slope $\tan\beta$, then at any point i on a hillslope, the downslope saturated subsurface flow rate $q_i$ from the saturated zone is assumed to be (Beven, 1986).

$$q_i = T_0 \tan\beta\, e^{-fz_i} \quad (4)$$

Under assumption 2) that quasi-steady-state flow exists throughout the soil, then assuming 5) a spatially homogeneous recharge rate r(m/h) entering the water table, the subsurface downslope flow per unit contour length $q_i$ may also be given by(Beven *et al.*, 1995) :

$$q_i = ra \quad (5)$$

where a is the area of the hillslope per unit contour length($m^2$) that drains through point i.

By combining equations (4) and (5) it is possible to derive a formula for any point relating local water table depth to the topographic index at that point, the parameter f, the local saturated transmissivity and the effective recharge rate r(Beven *et al.*, 1995):

$$z_i = -\frac{1}{f}\ln\frac{ra}{T_0\tan\beta} \quad (6)$$

An expression for the catchment lumped or mean water table depth($\bar{z}$) may be obtained by integrating equation (6) over the entire area of the catchment (A) that contributes to the water table. In what follows we will express this areal averaging in terms of a summation over all points within the catchment (Beven *et al.*, 1995) :

$$\bar{z} = \frac{1}{A}\sum_i -\frac{1}{f}\ln\frac{ra}{T_0\tan\beta} \quad (7)$$

By using eqation (6) in equation (7), if it is assumed that r is spatially constant, $\ln r$ may be eliminated and a relationship found between mean water table depth, local water table depth, the topographic variables and saturated transmissivity (Beven *et al.*, 1995).

$$f(\bar{z} - z_i) = \left[\ln\frac{a}{\tan\beta} - \lambda\right] - [\ln T_0 - \ln T_e] \quad (8)$$

Where $T_e$ is a separate areal average value of transmissivity and $\lambda$ is a topographic constant for the catchment as shown below(Beven *et al.*, 1995):

$$\ln T_e = \frac{1}{A}\sum_i \ln T_0 \quad (9)$$

$$\lambda = \frac{1}{A}\sum_i \ln\frac{a}{\tan\beta} \quad (10)$$

Equation (8) may also be written in terms of storage deficit as following ;

$$\frac{(\bar{S} - S_i)}{m} = \left[\ln\frac{a}{\tan\beta} - \lambda\right] - [\ln T_0 - \ln T_e] \quad (11)$$

These equations (8) and (11) express the deviation between the catchment average water table depth or soil moisture deficit and the local water table depth or soil moisture deficit at any point in terms of the deviation of the local topographic index from its areal mean, and the deviation of the logarithm of local transmissivity from its areal integral value (Beven *et al.*, 1995).

## METHOD AND MATERIALS

### 1. Study area

The study area is located at Gwangneung experimental forest, Gyeonggi-do near Seoul metropolitan (Figure 3). Two experimental catchments in this area have been operating since 1979. Table 1 shows the condition of the topography and vegetation in the two experimental sites.

The mature natural deciduous forest(MND) is about 80-year old and covered predominantly with *Quercus serrata* and *Carpinus laxiflora*. The young planted coniferous(YPC) forest which consists of *Pinus koraiensis* and *Abies holophylla* was planted at a stocking rate of 3,000 stems $ha^{-1}$ in 1976. As shown in Figure 4(a)-(b), the deciduous and coniferous forest catchments shape laterally wide.

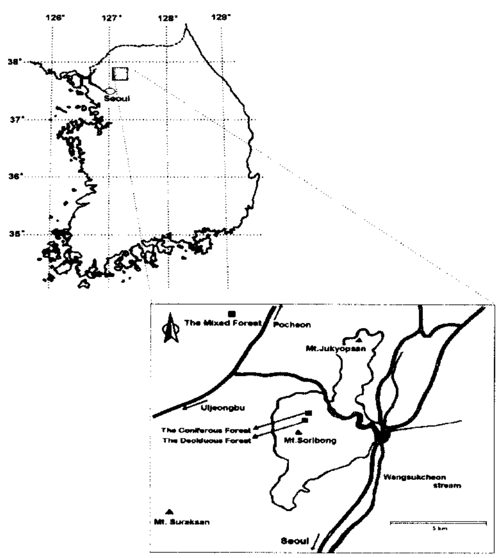


**Figure 3.** Location of the experimental area in Gwangneung, Gyeonggi-do.

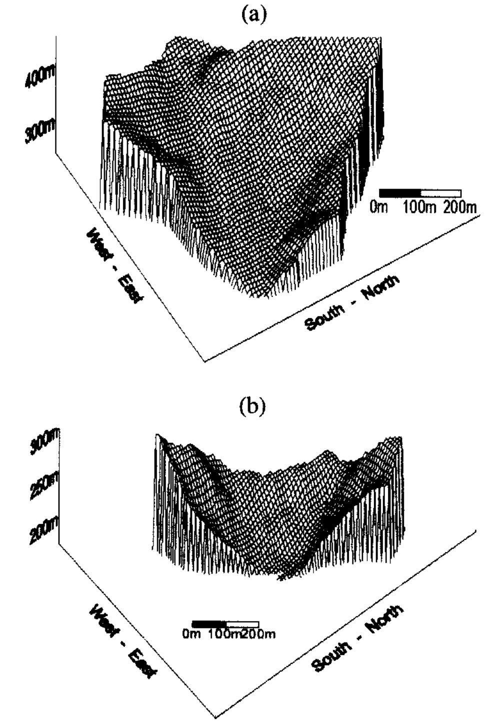


**Figure 4.** 3D-topographic views of the deciduous(a) and coniferous(b) forested catchments.

### 2. Instrumentation

Rainfall was recorded continuously by tipping bucket recorder at every 0.5 mm $tip^{-1}$ on the chart and snowfall also is measured as an equivalent depth. Water level has recorded by long-term recorder since 1979 at 90° sharp crested V-notch weir.

## RESULTS AND DISCUSSION

### 1. Model application

#### 1) Topographic index

The model was applied on a continuous basis over periods of approximately for one month, July,

**Table 1.** The conditions of topography and vegetation in experimental catchments.

| Watershed | Area (ha) | Elevation (m) | Parent material | Tree height (m) | DBH (cm) | Remark |
|---|---|---|---|---|---|---|
| MND | 22.0 | 280~470 | Gneiss | 16.0 | 30 | Natural forest |
| YPC | 13.6 | 160~290 | Gneiss | 4.0 | 12 | Planted in '76 |

1995. In the case of conceptual model such a TOPMODEL, periods of one month might be too short for a reliable assessment of parameters. Sorooshian *et al.*(1983) suggested that at least a one year period is necessary to calibrate conceptual models and stressed the importance of activating all model components during calibration. TOPMODEL is parameterized by the topographic index distribution and five single valued parameters : the exponential transmissivity function or recession curve m(m), the root zone maximum storage SRmax(m), the initial storage deficit in the root zone SRinit(m), the effec - tive transmissivity of the soil when just saturated $T_0(m^2\ h^{-1})$ and an effective surface routing velocity for scaling the distance and area or network width function. Linear routing is assumed ChVel$(m\ h^{-1})$.

Grid size effects influence distributed model of runoff generation and surface processes. Weihua and Montgomery(1994) examined the effect of digital elevation model(DEM) grid size on the hydrologic simulation in small forested catchment. Among 2-, 4-, 10-, 30- and 90-m grid size, a 10-m grid size presents a rational compromise between increasing resolution and data volume for simulating geomorphic and hydrological processes. The topo - graphic index in Figure 5 was derived from a raster digital elevation model(DEM) with a 10-m grid size using the multiple flow direction algorithm proposed by Quinn *et al.*(1991).

**2) Calibration of parameters**

The quality of the numerical fit between observed and simulated hydrographs was evaluated with the Nash and Sutcliffe(1970) efficiency criteria. The results of the parameter optimization show that m and $T_0$ among five parameters only responded actively to the objective function : the Nash and Sutcliffe's model forecasting efficiency criteria (NSFE).

$$NSFE = 1 - \frac{\sum(Q_{obs} - Q_{\sim})^2}{\sum(Q_{obs} - \overline{Q})^2} \quad (12)$$

where the summations apply over all time steps. The efficiency measure goes to 1 as the fit improves, if less than zero the model is worse than assuming that the discharge is always equal to the mean value.

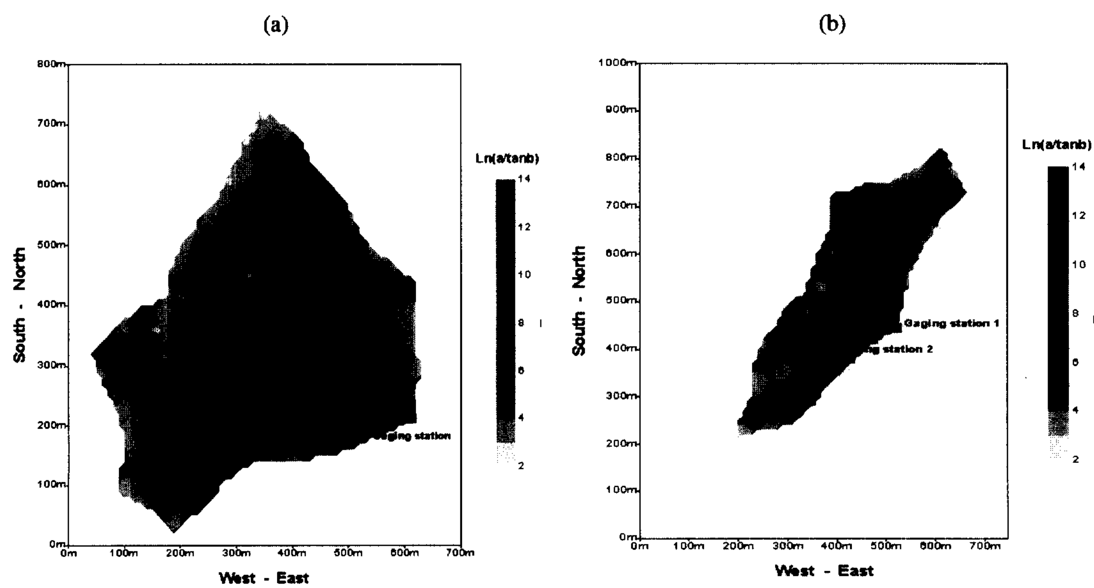


**Figure 5.** Topographic index maps of the MND (a) and YPC (b).

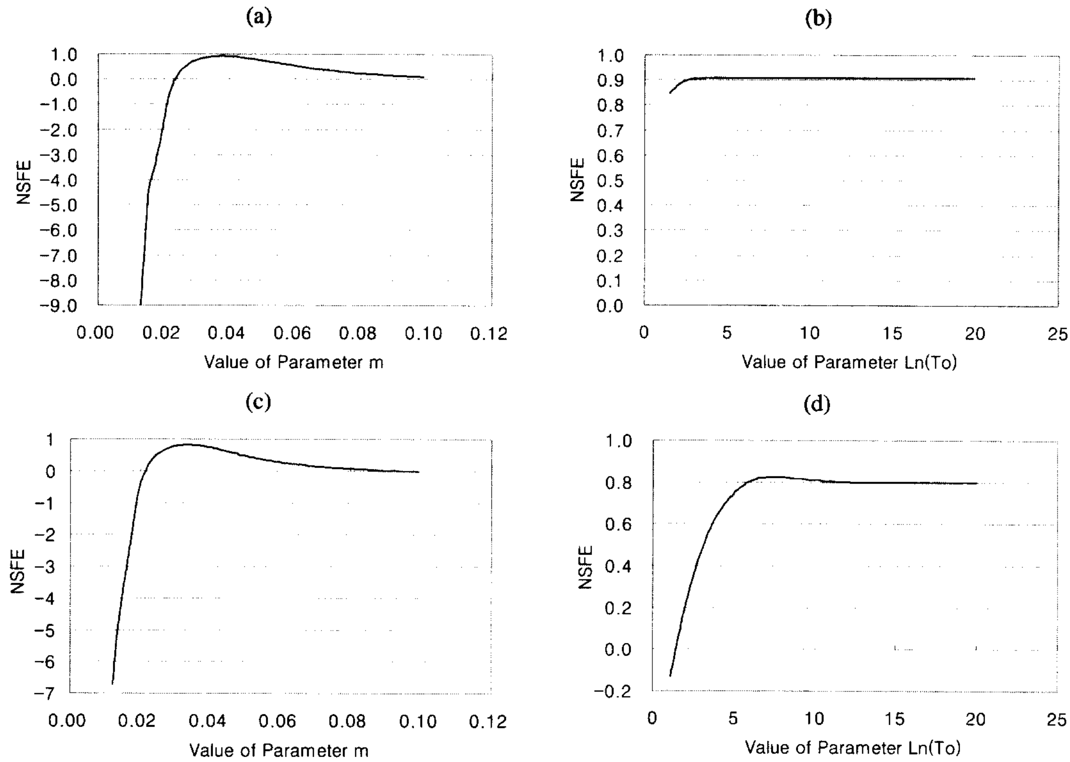


**Figure 6.** Optimization of parameter m and $\ln T_0$ using the objective function for the Nash and Sutcliffe's model forecasting efficiency criteria in the MND(a, b) and YPC(c, d).

Increament of parameter m and $\ln T_0$ resulted that the NSFE's value approached 1(Figure 6). Parameter m had more influence on the NSFE compared with parameter $\ln T_0$. Parameter m controls the depth of saturated zone because m value determines the decay rate of soil transmissivity. Parameter m may be derived from an analysis of catchment recession curves. Since this is one of the most important model parameters it reinforces the idea that to simulate hydrological reponses at the catchment scale, the most useful measurement will be made at the same scale especially in ungaged catchments.

The optimal value of four major parameters(Table 2) showed a narrow range even though different value in five events. The parameter m and $\ln T_0$ in MND were higher value than in YPC. It was because MND may have deeper in a soil depth and higher in soil transmissivity compared to YPC.

**Table 2.** Optimal parameter's value at the highest NSFE in five events.

| Watershed | Starting day | Duration (Days) | Optimal Parameters of each event | | | | NSFE |
|---|---|---|---|---|---|---|---|
| | | | m | $\ln(T_0)$ | Srmax | Srint | |
| MND | July 1, 1995 | 31 | 0.038 | 9.475 | 0.05 | 0.0 | 0.909 |
| | June 24, 2000 | 21 | 0.034 | 8.672 | 0.05 | 0.0 | 0.958 |
| YPC | July 1, 1995 | 31 | 0.033 | 7.129 | 0.05 | 0.0 | 0.825 |
| | July 28, 1999 | 17 | 0.032 | 5.969 | 0.05 | 0.0 | 0.922 |
| | Aug. 19, 2000 | 23 | 0.031 | 7.575 | 0.05 | 0.0 | 0.961 |

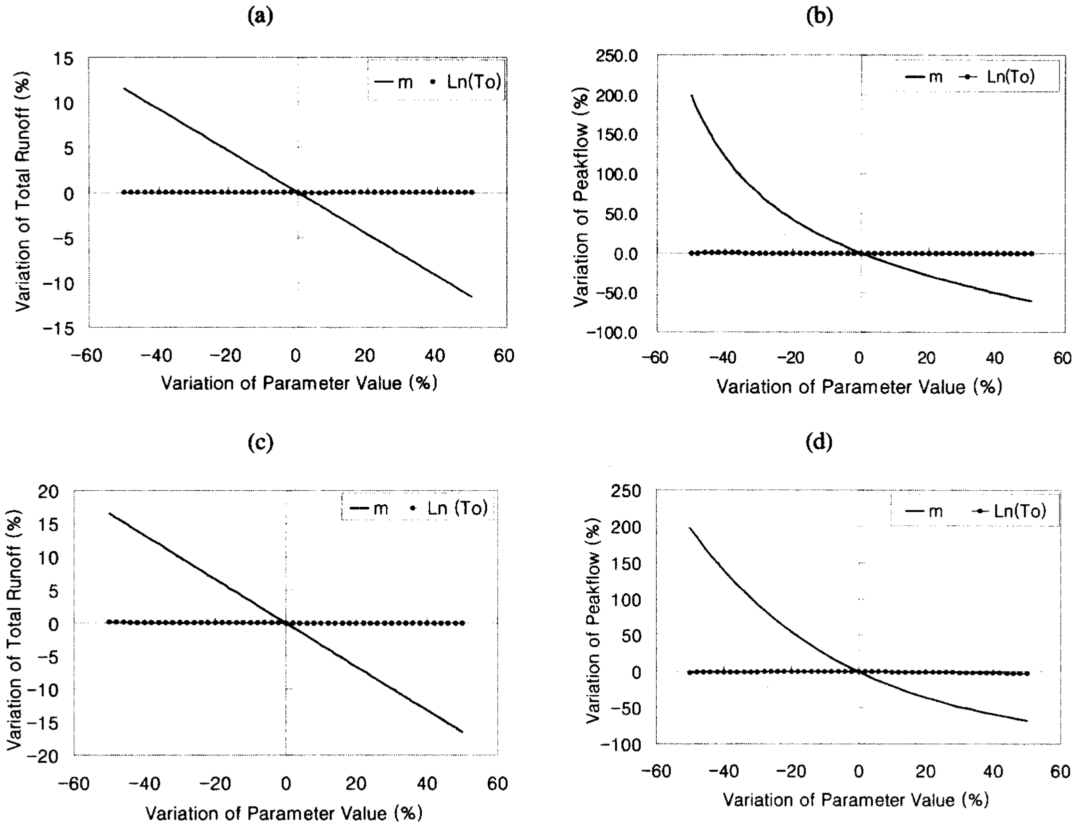


**Figure 7.** Sensitivity of parameter m and $\ln T_0$ for the total runoff and peakflow in the MND(a, b) and YPC(c, d).

### 3) Parameter's sensitivity

Parameter m had a high sensitivity to the total runoff and peakflow in the both catchments(Figure 7). Especially about 40 % decrease of parameter m caused two times increase of the peakflow in the both catchments. Rapid increase of peakflow caused by reducing parameter m may happen because parameter m may have a great influence on the depth of the saturated zone.

## 2. Results of simulation

Figure 8 to 12 show the hyeto-hydrographs using observed and simulated data set of five events at the MND and YPC. The overall fit between observed and simulated hydrographs is satisfactory. The simulated runoff in a initial stage tended to under-estimate in comparison with the observed one. That might be discrepancy between an outdoor and the model parameter conditions.

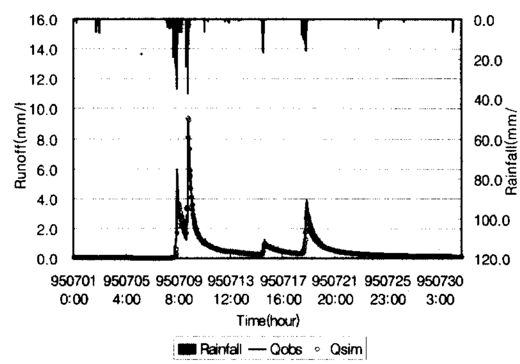


**Figure 8.** The result of simulation with the optimized parameters in the MND during the period of July 1 to 31, 1995.

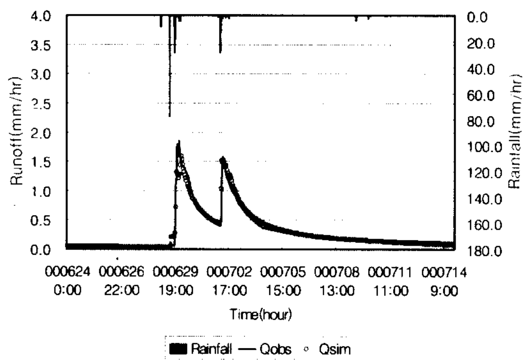


Figure 9. The result of simulation with the optimized parameters in the MND during the period of June 24 to July 14, 2000.

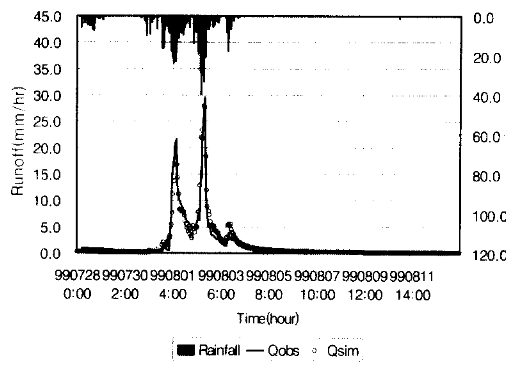


Figure 11. The result of simulation with the optimized parameters in the YPC during the period of July 28 to August 13, 1999.

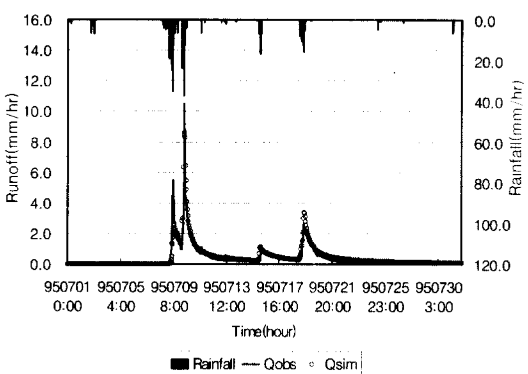


Figure 10. The result of simulation with the optimized parameters in the YPC during the period of July 1 to 31, 1995.

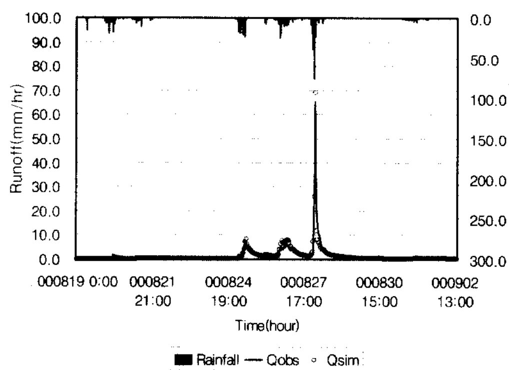


Figure 12. The result of simulation with the optimized parameters in the YPC during the period of August 19 to September 2, 2000.

Table 3 shows the percentage of error between the observed and simulated data for total runoff and peakflow at the MND and YPC in all events. The percentage of error for total runoff was less than 10 % except the event at July 1, 1995 at the YPC. In the case of peakflow, the simulated data fitted the observed one at the percentage of error less than 20 %. Total runoff of the event at July 1, 1995 at the YPC overestimated owing to the flow of recession part even underestimated peakflow. Why does this event result discrepancy between the observed and simulated? A cause may happen to observe the amount of runoff less than real one.

Table 3. Comparison of the observed and simulated data for total runoff and peakflow at the MND and YPC in 5 events.

| Watershed | Starting day | Rainfall (mm) | Total runoff (mm) | | | Peakflow (mm/hr) | | |
|---|---|---|---|---|---|---|---|---|
| | | | Observed | Simulated | Error (%) | Observed | Simulated | Error (%) |
| MND | July 1, 1995 | 535.0 | 376.4 | 373.1 | -0.9 | 9.17 | 9.36 | 2.1 |
| | June 24, 2000 | 229.0 | 140.7 | 149.8 | 6.5 | 1.86 | 1.59 | -14.3 |
| YPC | July 1, 1995 | 535.0 | 262.6 | 341.9 | 30.2 | 10.51 | 8.69 | -17.3 |
| | July 28, 1999 | 730.7 | 603.8 | 660.2 | 9.3 | 29.60 | 27.90 | -5.7 |
| | Aug. 19, 2000 | 669.5 | 505.4 | 520.9 | 3.1 | 65.27 | 69.10 | 5.9 |

### 3. Prediction of saturated area

Figure 13 shows that the saturated area during the event is predicted during the event of July 1, 1995 at the MND(a) and the YPC(b). By the simulating result, the saturated areas were predicted less in the MND than in the YPC. It seems that parameters m and $lnT_0$ of the MND is applied more than those of the YPC. This means that the soil surface is difficult to be saturated at the MND compared to the YPC.

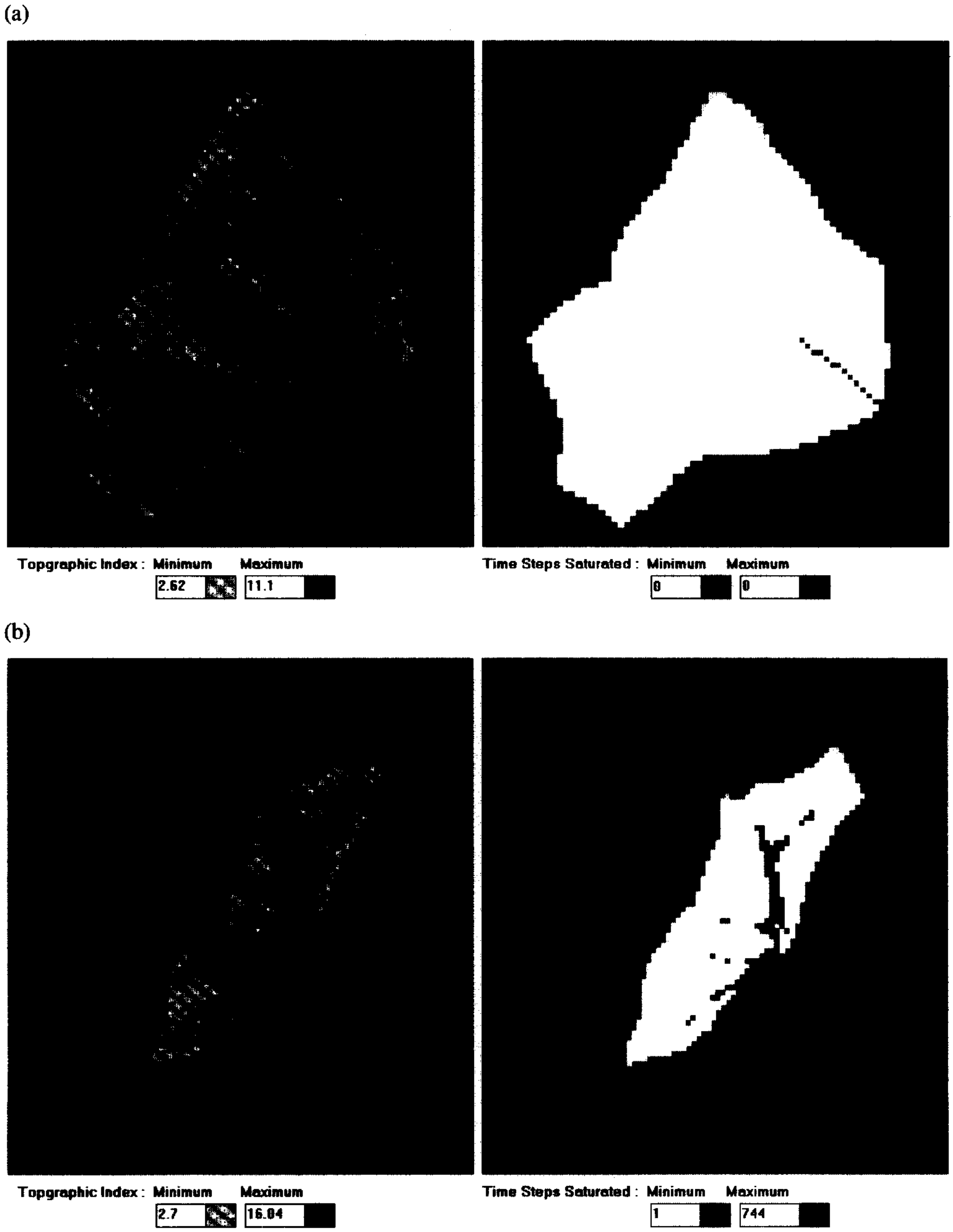


**Figure 13.** Prediction of the saturated area during the event of July 1, 1995 at the MND(a) and the YPC(b).

## CONCLUSIONS

The approach which led to TOPMODEL is one of the most promising directions in modeling research. This modeling tour is not enough to conform completely whether TOPMODEL is fit or not at a forested catchment in Korea. Even though not enough times for confirmation of TOPMODEL's applicability, NSFE was comparatively high over 0.9. Among five parameters, parameter m affecting the depth of saturation and recessed flow had the most influence on total runoff and peakflow at the both watersheds. If a TOPMODEL's applicability increase, the information on the relationship of internal hydrological status e. g. soil moisture, water level depth, bed rock surface etc. with the model parameters need more in detail. In conclusion TOPMODEL is assured that it has a high potential for prediction of ungaged catchment's discharge at a forested catchment of Korea even though a spatial hydrological variations.

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