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Variations of Annual Evapotranspiration and Discharge in Three Different Forest-Type Catchments, Gyeonggido, South Korea

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임상이 다른 3개 산림소유역의 장기 증발산량과 유출량의 변화

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ABSTRACT

This study was to clarify the effects of forest stand changes on hydrological components of evapotranspiration and discharge. The forest-hydrological experimental stations in Gwangneung and Yangju, Gyeonggido near metropolitan Seoul have been operated by the Korea Forest Research Institute since 1979 to clarify the effects of forest types and practices on the water resources and nutrient cycling and soil loss. The hydrological regime of the forested catchments may change as forests develop. The ranges of change may be different depending on forest types. Evapotranspiration can be estimated to 679 mm, 580 mm and 368 mm in planted young coniferous (PYC), natural old-growth deciduous (NOD) and rehabilitated young mixed (RYM), respectively. The slope of the discharge-duration curve shows the capacity of discharge control in a specific catchment. The slope tended to be steeper in RYM than NOD, the better forest condition. The slope in RYM became more gentle as the forest stand developed. Forests can modulate peak flows through interception, evapotranspiration and soil storage opportunity. PYC and RYM showed 100 and 50 mm of threshold rainfall for modulating peak flows, respectively. The deciduous forest did not represent sudden changes of peak flow rates to rainfall, even 200 mm rainfall. Forest development in PYC may play an important role in modulation of peak flows because peak flow rates reduced after 10 years.

Key words **: Evapotranspiration, Discharge-duration curve, Peak flows**

I. INTRODUCTION

Forested land in South Korea is susceptible to erosion due to the geological and climatic characteristics. The geological and climatic conditions often combine to produce serious a runoff and environmental damage. Forests in South Korea play an important role on conserving soil and water resources because forests comprise about 65% of the total area. By the 1950s, more than 10 percents of forest land had been denuded. Main causes of forest devastation were illegal logging for fuel wood, shifting cultivation and over cutting by Japan before 1950s. Korea Forest Service had tried to rehabilitate a degraded watershed since 1970s. In South Korea, soil and water conservation have been the basis of national forest policy. Therefore, forest policy was forced to emphasize the rehabilitation of devastated land.

Forests have several environmental functions like a reduction of the damages by a flood and drought and soil conservation etc. The water storage capacity of forest soils in forested lands increases as trees are grow-

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ing. When the forest stand grows, the amount of litter falls and roots also increases. The litter falls and roots become into decay in the forest soil. The mineral soils and humus materials tend to aggregate into their structure. Aggregation may change the distribution of pore sizes and often increase total porosity. In South Korea coniferous species such as *Pinus koraiensis*, *Pinus rigida* and *Larix leptolepis* have been planted in the density of 3,000 trees per ha since 1970s. These planted-coniferous forests may deteriorate topsoil owing to water repellence and decrease the available water resources due to high evapotranspiration rate. To conserve the resources of topsoil and water, the dense-planted coniferous forest has to be tended through the forest practice like pruning and thinning. The research on the hydrological cycle depending on forest types and practices has been conducted since 1979 in order to quantify the hydrological components such as interception loss, discharge and soil loss (Lee *et al.*, 1989).

Forest practices are exampled one of methods to yield water resources sustainable in Korea. We understand the effects of forest development on hydrological schemes to adopt forest practices to sustain water resources. Forest growth may increase evapotranspiration including interception loss. Forest soil may change physically after forest practices. More rain water can infiltrate into a developed forest soil. We would like to understand how to change hydrological regimes in different forest types with the lapse of time. This information may be useful to find the best forest structure for the conservation of soils and water resources. This study aims to clarify the effects of the long-term forest stand changes on hydrological components such as evapotranspiration, peak flow and discharge.

II. MATERIAL AND METHODS

2.1. Study area

The study area is located at the forest-hydrological experimental stations which have been operated by Korea Forest Research Institute in Gwangneung and Yangju Gyeonggido near Seoul in Fig. 1. The forest-hydrological experimental stations were established in natural old-growth deciduous forest (NOD), planted young coniferous forest (PYC) consisting of *Pinus koraiensis* and *Abies holophylla* and rehabilitated

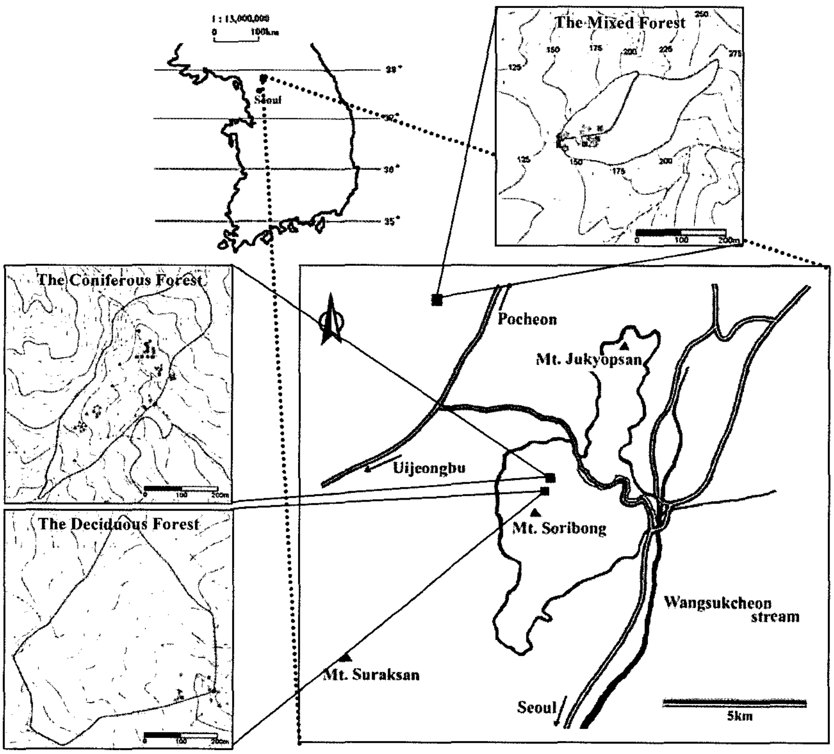

Fig. 1. Location of the study sites for the natural old-growth deciduous (NOD), planted young coniferous (PYC) and rehabilitated young mixed (RYM) forests in Gwangneung and Yangju, Gyeonggido, Korea.

Table 1. The forest stand structures of the study plots in the dimension of 10 m×10 m

Plots	Number of trees	Crown coverage (%)	Average height (m)	Average clear-length (m)	Average Diameter at Breast Height (cm)	Total Basal Area (m^2)
NOD	17	98.8	10.5	4.1	22.7	0.85
Pinus in PYC	19	89.5	12.8	3.0	16.7	0.44
Abies in PYC	26	96.8	11.0	2.2	13.3	0.38
RYM	17	65.8	9.5	3.6	11.1	0.19

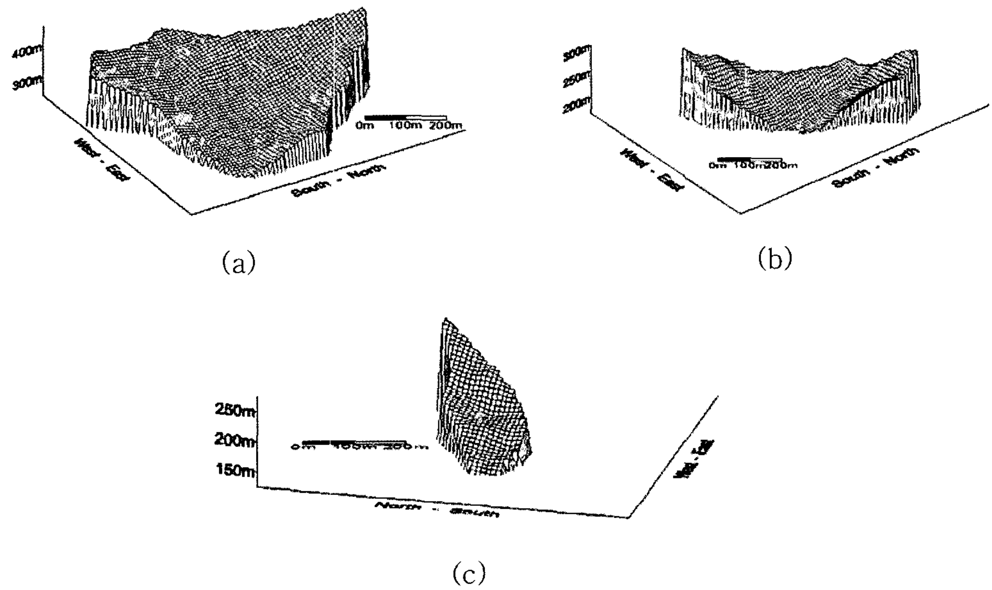

Fig. 2. Topographic views of deciduous (a), coniferous (b) and mixed (c) forest catchments.

young mixed forest (RYM). Table 1 is the forest stand structures of the study plots. NOD is about 90 year old and consists of *Quercus serrata, Carpinus laxiflora* and *Carpinus cordata*. PYC was planted with 3000 trees per ha in 1976. The forest practises such as thinning and pruning were conducted in 1996 and 2004. RYM was rehabilitated in 1974 and is covered predominantly with *Quercus mongolica, Pinus densiflora* and *Alnus firma*. As shown in Fig. 2 (a)-(c) deciduous and coniferous forest catchments shape laterally wide while the mixed forest is longitudinally long.

2.2. Instrumentation

Automatic weighing-typed rainfall gauge (PLUVIO) recorded the amount of rainfall and snowfall to 0.01 mm. Also rainfall was recorded continuously by tipping bucket recorder at every 0.5 mm per tips on the chart and CR10X data-logger. The water level overflowing at the top of sharp-crest typed notch has recorded by long-term recorder since 1979. Recently automatic encoder typed recorder (Thalimedes) recorded the water level simultaneously. Gauging weirs were constructed by concrete. The notch types are 120 degree sharp-crest at PYC and NOD, and 90 degree sharp-crest at RYM respectively. The rating curves were equation (1) for PYC and NOD and equation (2) for RYM as following;

$$Q = 1.485 \times 10^{-9} \times (H + 62.5869)^{3.0821} \quad (1)$$

$$Q = 1.2131 \times 10^{-8} \times H^{2.7048} \quad (2)$$

where Q is discharge (m^3/sec) and H is water level (cm).

2.3. Data analysis

Annual evapotranspirations were calculated by a water balance equation which subtracts the annual discharge from the annual rainfall in each year. We have

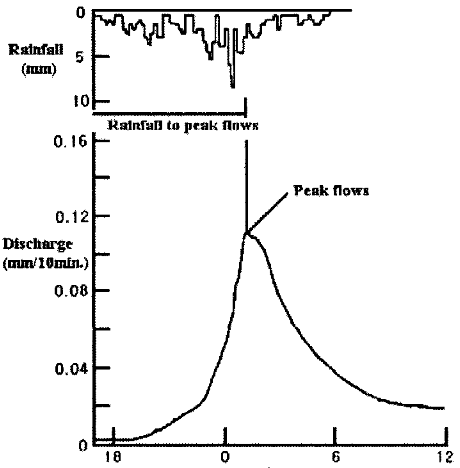

Fig. 3. The relationship between rainfall to peak flows and peak flows.

collected the hydrological data including the amounts of rainfall and discharge since 1982 at three forest typed catchments. About 110 independent events which have a clear peak stage shown in Fig. 3 were selected. For each event, flow rate of a peak was decided as a maximum value in an independent hydrograph, and the amount of rainfall was accumulated till the flow rate of a peak occurred.

III. RESULTS AND DISCUSSION

3.1. Evapotranspiration

Evapotranspiration can be estimated by use of the long-term rainfall-discharge data set. If there is no leaks in the closed catchments system, evapotranspiration may be the amount that subtract the discharge from the total rainfall. Robert (2001) explained the relationship between stream flow and evapotranspiration depending on the different climate condition (Fig. 4). In Hubbard Brook of USA, there is considerable year to year variation in rainfall which is closely matched by fluctuations in the stream flow. There is a strong positive rainfall and stream flow and there is an almost constant difference between rainfall and stream flow, the annual catchments evapotranspiration. The evapotranspiration is virtually constant at around 500 mm year^{-1} even the rainfall ranges from 800 mm to 1,800 mm.

We can estimate the annual evapotranspiration for the three different forest-typed catchments. The annual evapotranspiration can be interpreted from the annual

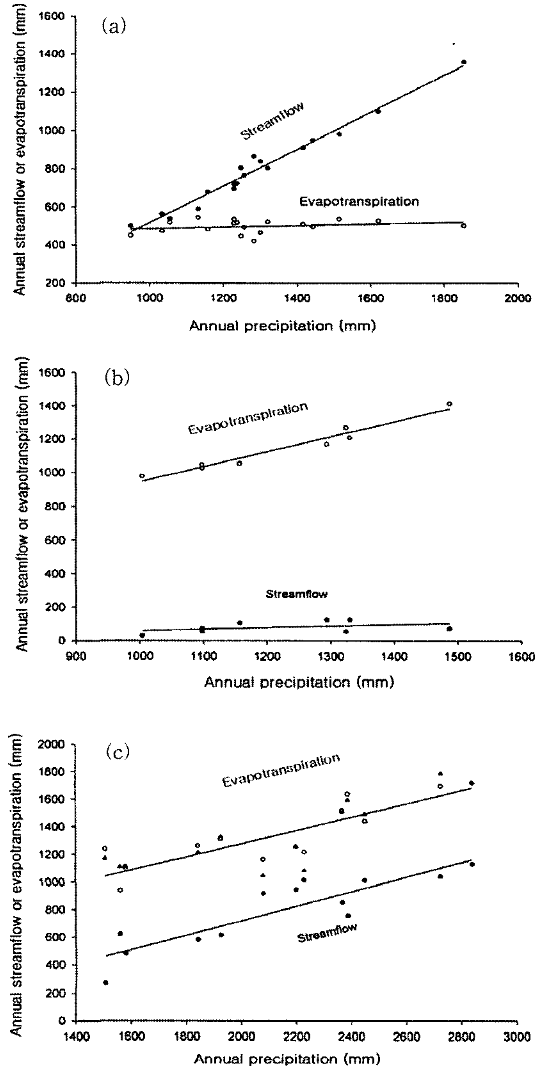

Fig. 4. Relationship among precipitation, streamflow and evapotranspiration in different climatic zone: mixed hardwoods at the Hubbard Brook Experimental Forest (a), eucalyptus forest at Western Australia (b) and tropical rainforest at Kenya (c) (incited from Robert, 2001).

precipitation minus the annual streamflow. The data which are used to analyse the relationship among the annual streamflow and evapotranspiration were the annual one for 20 years from 1982 to 2003.

Fig. 5 shows the annual rainfall and discharge over an extended periods for around 20 years in the three catchments. In the figures what the annual evapotranspiration did not increase even though the annual precipitation increased means no soil water deficit in the forested land of Korea throughout year.

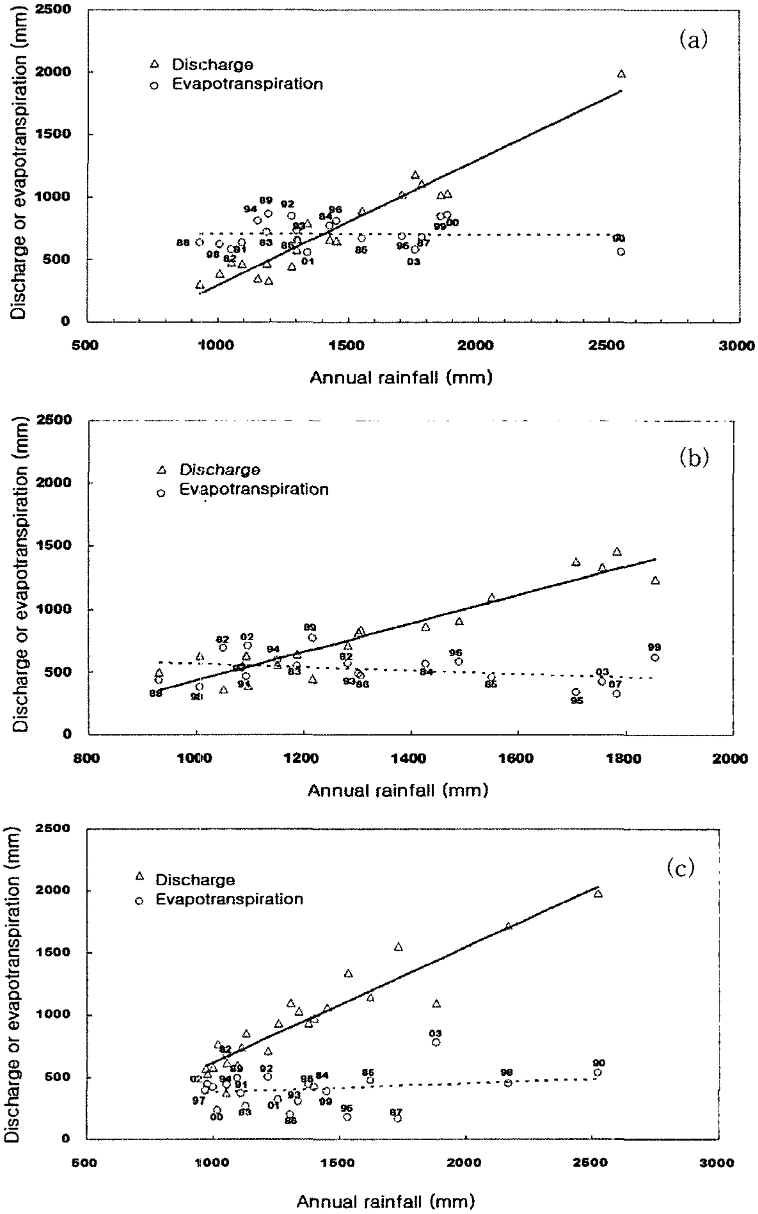

Fig. 5. Relationship among the annual rainfall, discharge and evapotranspiration for PYC (a), NOD (b) and RYM (c) during 1982-2003.

Korea has planted coniferous species such as *Pinus koraiensis*, *Abies holophylla* and *Larix leptolepis* in much area of 2.3 million ha since 1970s. These plantedconiferous forests may deteriorate topsoil owing to water repellence and decrease the available water resources due to high evapotranspiration rate. To conserve the resources of topsoil and water, a dense planted coniferous forest must be tended through the forest practice like thinning and pruning, which influence on water quantity and quality.

As shown in Fig. 5 (a), especially in PYC, the annual evapotranspiration was larger than the annual discharge in case of the annual rainfall less than about 1,400 mm. That means, if the annual rainfall is relatively small (less than 1,400 mm) in PYÇ, more than half annual rainfall is lost from the catchment by evapotranspira-

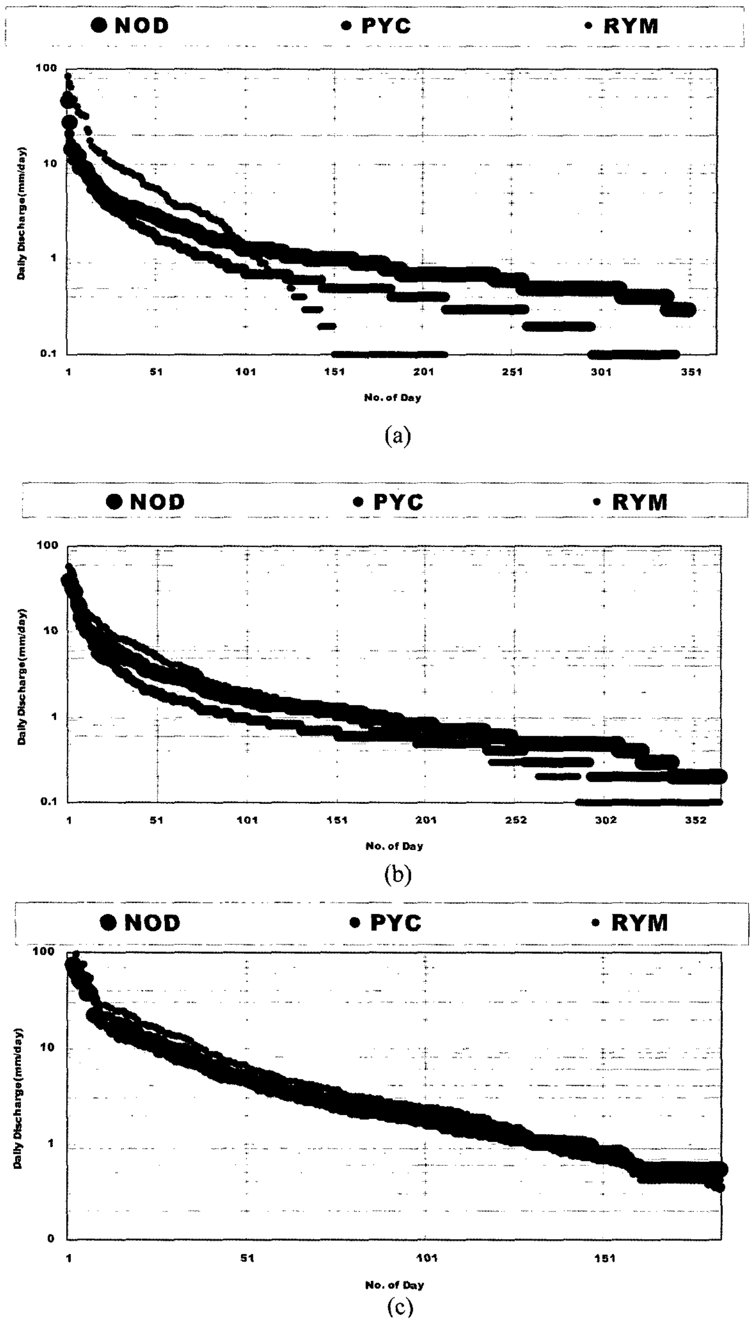

Fig. 6. The discharge-duration curves for NOD, PYC and RYM during 1983 (a), 1993 (b) and 2003 (c).

tion, and relatively small runoff response is created. This higher evapotranspiration response of PYC could be revealed again in the camparison of mean annual evapotranspiration to the other catchments, i.e. the mean annual evapotranspiration of PYC (687 mm) was much higher than those of other catchments (580 mm in NOD and 368 mm in RYM). Mean annual evapotranspiration of NOD was similar to that of the mixed hardwoods at Hubbard Brook (500 mm). In case of PYC, forest practices such as thinning and pruning may decrease the amount of evapotranspiration loss and increase discharges during the dry season.

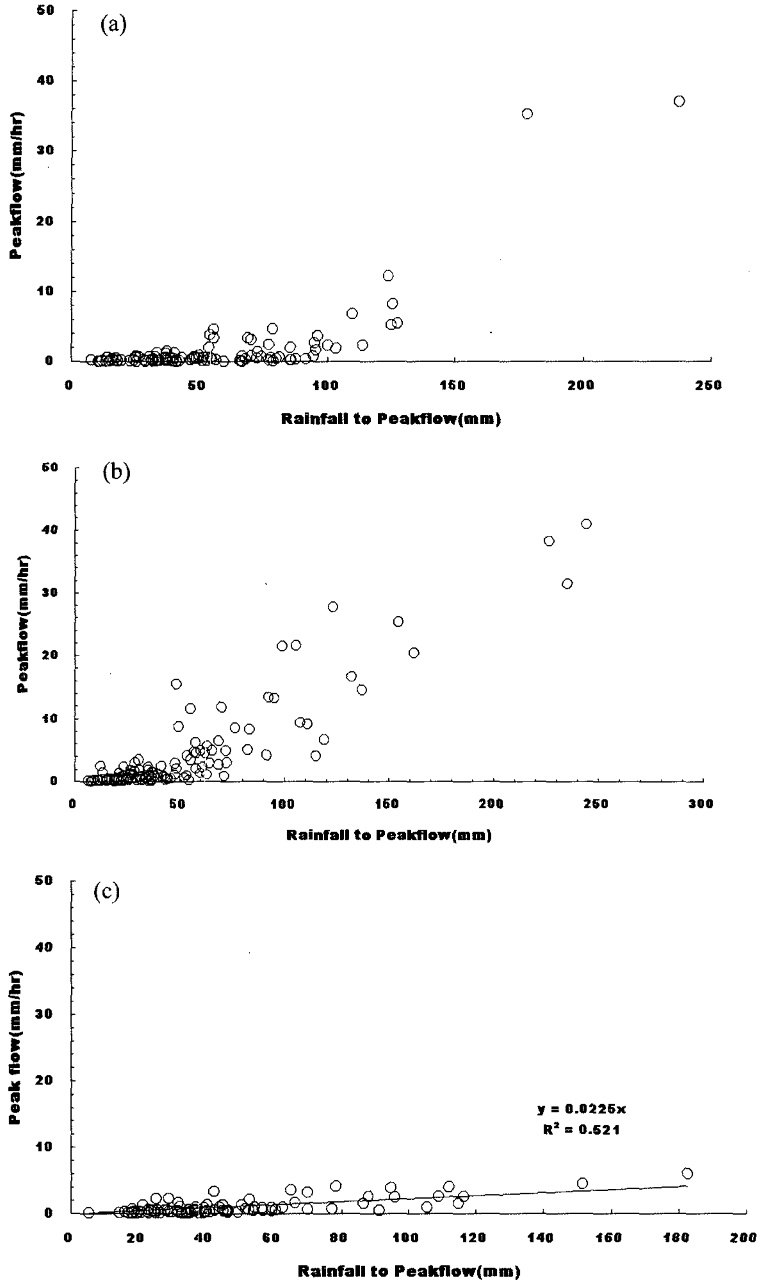

Fig. 7. The relationship between the accumulated rainfall to peak flow and peak flows in PYC (a), RYM (b) and NOD (c).

3.2. Discharge-duration curve

The discharge-duration curve describes the pattern of the daily discharge in the specific water year. Such a curve may be considered to represent the annual flow frequency characteristics with its discharges arranged in order of magnitude. For example, when the daily discharges are arranged in a descending series for a year, the daily discharge at the 95th days of a year is called as the high flow whereas one of the 275th days of a year means the low flow. The low flow in RYM obviously increases in 2003 compared with 1983. This may mean that forest soil properties in RYM improved after erosion control works in 1974. Also the slope of the discharge-duration curve in RYM became gentler in

2003 than 1983. Meanwhile the discharge-duration curve of NOD did not change.

3.3. Peak flows

The hydrological data including the amount of rainfall and discharge since 1982 at three forest types were analyzed to understand how peak flows change with a forest growth. About 110 events which have a clear peak were selected. For each event, flow rate of a peak was decided as a maximum value in an independent hydrograph, and the amount of rainfall was accumulated till the flow rate of a peak occurred.

Fig. 7 represents the relationships between the amounts of rainfall and peak flows in the three experimental catchments including NOD, PYC and RYM.

As shown in Fig. 7, peak flows in PYC increased suddenly when the accumulated rainfall to peak increased over 100 mm. PYC reduced peak flows significantly because of higher interception and evapotranspiration rate compared with other forest types. The coniferous forest intercepted about 18.9% of rainfall and moved up about 9.1% of rainfall through sapwood in wet periods because of high tree density (KFRI, 2001). Although threshold rainfall of the coniferous forest for modulating peak flows is difficult to decide exactly owing to high variations of climatic and forest stand structure, threshold rainfall may be estimated at 100 mm. Analyzing peak flows to rainfall must be considered soil moisture content, antecedent rainfall and rainfall intensity (Kim, 1987). The facts that forests modulate peak flows can be found through peak flows increases after clear cutting. In the western Cascade Range of Oregon, peak flow increases averaged approximately 13-16% after clear cutting of coniferous forest (Beschta *et al.*, 2000). In a southern Appalachian peak flow rates increased 14-15% after harvesting (Swank *et al.*, 2001).

RYM showed threshold rainfall for modulating peak flows was about 50 mm, which was a half of PYC (Fig. 7). RYM has poor stand structure with a thin soil layer because the forested area had been rehabilitated in 1974. RYM also showed higher peak flows rates than PYC.

NOD did not show changes of peak flow rates with rainfall increases (Fig. 7 (c)). NOD had a deep soil over 100 cm and good development over 200 m^3 per ha in stocking volume. In Taiwan, despite rainfall intensity that often exceeds 100 mm hr^{-1} a well-developed forest rarely produces overland flow (Cheng *et al.*, 2002). The threshold rainfall of the deciduous forest was not sure because these results only represented the relationship of peak flows and rainfall less than 200 mm. The threshold rainfall may be greater than 200 mm.

IV. CONCLUSION

The hydrological regime of the forested catchments may change as forests develop. The characteristics of its change may be different depending on forest types. PYC showed the highest interception and transpiration loss compared with NOD and RYM because of its high LAI and long leaf period. Evapotranspiration can be estimated to 679 mm, 580 mm and 368 mm in PYC, NOD and RYM, respectively.

The discharge-duration curve represent the distribution of the daily discharge in a specific year. The slope of the discharge-duration curve shows the capacity of discharge control in a specific catchment. The slope tended to be steeper in RYM which is worse forest condition than NOD in better forest condition. The slope in RYM was getting gentle as forest stand developed.

Forests can modulate peak flows through interception, evapotranspiration and soil storage opportunity. PYC and RYM showed 100 and 50 mm of threshold rainfall for modulating peak flows respectively. The deciduous forest did not represent sudden changes of peak flow rates to rainfall even for 200 mm of rainfall. Forest development in PYC may play an important role in modulation of peak flows because peak flow rates reduced after 10-year from planting.

적 요

이 연구는 임분구조가 다른 3가지 임상에서 장기 증발산량과 유출량의 변화를 분석하여 증발산량, 첨두유출량 및 유출량에 미치는 장기 임상변화의 효과를 밝히기 위하여 수행하였다. 시험지는 경기도 광릉에 소재한 국립산림과학원 유역수문시험지로서 인공침엽수 유령림과 천연활엽수 장령림 그리고 경기도 양주에 소재한 혼효 사방복구림을 대상으로 하였다. 수문자료는 1982년부터 1999년까지 양수댐에서 측정한 유출량과 강수량을 분석하여 각 시험지별로 약 110개의 홍수수문곡선을 선별한 후 첨두유출량과 그 시점까지의 강수량 합계를 분석하였다. 강수량과 유출량의 관계로부터 증발산량을 추정한 결과, 증발산량은 인공침엽수 유령림에서 679 mm, 천연활엽수 장령림에서 580 mm이었

으며 혼효 사방복구림에서는 368 mm이었다. 또한, 유역의 유출량조절효과를 보여주는 유출량-지속기간 곡선에 대한 분석 결과, 임상이 가장 불량한 혼효 사방복구림에서 곡선의 기울기가 가장 급한 것으로 나타났으나, 산림이 생장함에 따라 그 기울기가 감소하는 것으로 분석되었다. 강수량과 첨두유출량의 관계를 분석한 결과, 인공침엽수 유령림과 혼효 사방복구림의 경우 각각 강수량 100 mm 및 50 mm에서 첨두유출량의 증가율이 높아지는 역치값을 보이는 반면에 천연활엽수 장령림은 200 mm로 나타났다. 장기간에 걸친 홍수수문곡선의 비교 결과, 인공침엽수 유령림에서는 10년이 경과한 후 첨두유출량이 감소한 것으로 나타나, 산림이 생장함에 따라 홍수유출조절 효과가 커지는 것으로 분석되었다.

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