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Hydrograph Separation Using EMMA Model for the Coniferous Forest Catchment in Gwangneung Gyeonggido, Republic of Korea (I)
– Determination of the End Members and Tracers –

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Abstract : This study was conducted to choose end-members and tracers for application of End Member Mixing Analysis (EMMA) model for the coniferous forest catchment, Gwangneung Gyeonggi-do near Seoul metropolitan of South Korea (N 37° 45', E 127° 09'). This coniferous forest of *Pinus Korainensis* and *Abies holophylla* was planted at stocking rate of 3,000 stems ha^{-1} in 1976. Thinning and pruning were carried out two times in the spring of 1996 and 2004 respectively. We monitored two successive rainfall events during ten days from June 26, 2005 to July 5, 2005. Two storm events were selected to determine the end members and natural traces for hydrograph separation. The event 1 amounts to 161.9 mm for two days from June 26 to 27, 2005. The event 2 precipitates to 139.2 mm for one day of July 1, 2005. Throughfall, groundwater, soil water and stream water of the two events above were sampled through the bulk and automatic sampler. Their chemical properties were analyzed for prediction of the main components using the mixing diagram. The following are the results of the analysis of each component and tracer. The end members that contribute to the stream runoff were identified from the three components including groundwater, soil water and throughfall. Each component and stream water in the two events formed the suitable mixing diagram in case of chloride-nitrate ion and sulfate-potassium ion. Especially, chloride-nitrate ion was found to be the most suitable tracers for EMMA model in the two events.

Key words **:** *Hydrograph separation, EMMA model, tracer, coniferous forest catchment*

Introduction

Increasing of atmospheric pollutants and greenhouse gases is rapidly changing the global environment. These changes are difficult to predict and have influence on rainfall patterns and storm intensities. Also the changes will largely affect water quality and quantity during hydrological processes in forest catchments. Currently, studies on forest hydrology have evolved variously.

In the 1930s, forested catchment experiments and hydrological theory for estimating a runoff mechanism were developed. Sherman (1932) proposed the unit hydrograph model for estimating storm runoff and Horton (1933) proposed a runoff process using the infiltration theory. Horton's equation is a basic method to physically analyze each parts of hydrological processes in forested catchments. Hursh suggested that infiltration-excess overland flow which is proposed by Horton was hardly appear in forested catchment and this led a Hewlett's variable source area theory (Anderson and Burt, 1990). Various hydrological theories were proposed since 1960s and environmental problems have caused researchers to focus to clarify subhydrological processes such as relationship between path ways and runoff source, runoff source and water quality in the forested catchments. However, some of the fundamental questions in catchment hydrology - 「Where does water go when it rains and where does stormflow originate?」「What flowpaths does water take to the stream?」 - has not been determined yet, although overland flow and subsurface flow can be quantified exactly based on hydrological theories up to the present (Kim, 2003).

The analysis of storm flow chemical patterns has become a tool to infer flow path contributions of pre-event and event water components. As a result, the research on tracers to identify pathways of water in the catchment has been conducted and Pinder and Jones (1969) introduced the basic hydrograph separation technique based on a mass balance approach. This two-component model

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has been applied widely and it has been expanded to three components in cases where either the discharge of one of the components was known or two tracers were used simultaneously (Genereux *et al.*, 1993). The contributions of 'old water' and 'new water' in the stream through the two-component mixing model can be calculated by solving the mass balance equations for the water and tracer fluxes in the stream, provided that the stream, 'old water' and 'new water' tracer concentrations are known.

Kim and Jeong (2002) investigated the contribution of new and old water in the stream depending on forest types including the natural-mature deciduous and two planted-young coniferous forests through the two-component mixing model using electrical conductivity (EC) as natural chemical tracer.

Christophersen *et al.* (1990) and Hooper *et al.* (1990) introduced a new technique to predict proportions of contributing sources; it assumes that streamwater quality is determined by a mixture of subsurface sources (e.g. groundwater and soil water) from various depths. These sources are called end-members because their chemical compositions constitute the extremes of possible stream water observations (Christophersen and Hooper, 1992). Therefore End Member Mixing Analysis (EMMA) model has been used to estimate contribution of each component (end-members).

This study aims to choose end-members and tracers for application of End Member Mixing Analysis (EMMA) model at the coniferous forest catchment at Gwangneung, Gyeonggi-do, Seoul, Korea.

Material and Methods

1. Site description

This study was performed in the coniferous experimental catchment (13.6ha; Figure 1), located on Gwangneung experiment forest (N 37° 45', E 127° 09'), Gyunggido near Seoul metropolitan, Korea. This coniferous forest of *Pinus Korainensis* and *Abies holophylla* was planted at stocking rate of 3,000 stems ha^{-1} in 1976. Thinning and pruning were carried out two times in the spring of 1996 and 2004. The altitude of experimental catchment ranges from 160 m to 290 m. The slope of that shows from 13° to 35°. The underlying bedrock consists of gneiss and the soil texture is classified as sandy loam.

2. Methods of sapling and Chemical Analysis

Stream flow level was measured every 10 minutes using the float-encoder water level gauge at the catchment outlet with a 120° V-notch sharp crest weir. Rainfall was recorded at 10 minutes interval in the weighing rain gauge with a data logger. Stream water samples starting at rainfall intensity more than 3 mm per 15 minutes were collected automatically at 2 hours interval during 48 hours. Groundwater was sampled directly from screen well with 10 cm diameter just after event. Ground-

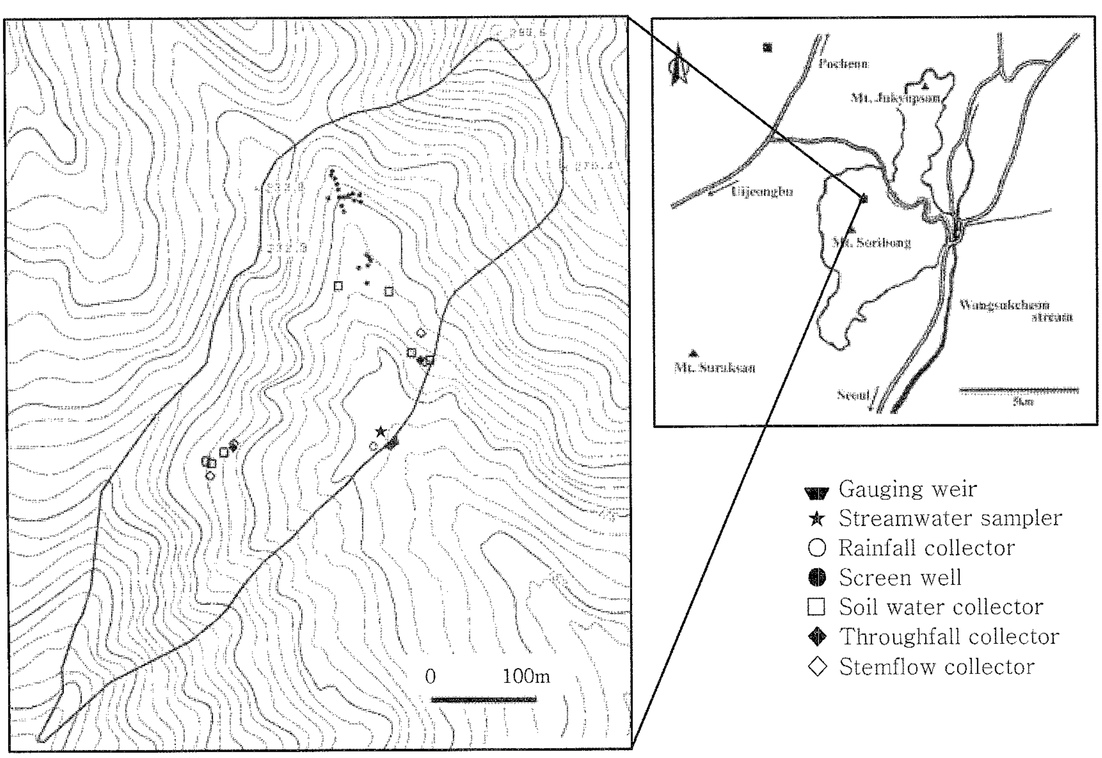

Figure 1. Location of the experimental catchments in Gwangneung, Gyeonggi-do, Korea.

water level was measured at every 10 minutes by the pressure sensor typed water level gauge. Soil water was collected by zero tension lysimeter dimensioned to 10 cm by 100 cm in the B horizon on hillslope. The samples of rain and throughfall water take from the buckets with 30 liter capacity and automatic wet-deposit sampler. All water samples from a stream, screen well, lysimeters and buckets were analyzed in the laboratory immediately. Concentrations of cations (Na^+, K^+, Mg^{2+}, Ca^{2+}) and anions (Cl^-, NO_3^-, SO_4^{2-}) were determined with ion chromatograph.

3. End Member Mixing Analysis (EMMA) model

Variations in stream water chemistry have been viewed as stemming from a dynamic mixture of source solutions, such as groundwater and precipitation, event and preevent water, groundwater, soil water solutions etc. Therefore EMMA model can estimate distribution of each component (end members) through the mass balance of tracers. Viable end member solutions have concentrations more extreme than the stream, have a low variability relative to the stream variation, and are distinctly different from other end members. EMMA model use isotope (e.g. ^{18}O, ^{2}H, ^{3}H) or chemical tracers (e.g. EC, SiO_2, Cl^-, SO_4^{2-}, Na^+, Mg^{2+}, Ca^{2+}) (Hooper *et al.*, 1990; Buttle, 1994; Hooper, 2001).

On the basis of each component, mixing diagrams can be represented using tracers. As shown in Figure 2, stream samples must lie within triangle defined by end members. The mixing models also share several assumptions as follows; i) tracers don't participate in chemical reactions. ii) the tracer concentrations of the storm flow sources must be different. iii) the tracer concentrations of the end members don't change during events, and their spatial variability is small compared to the differences between end members.

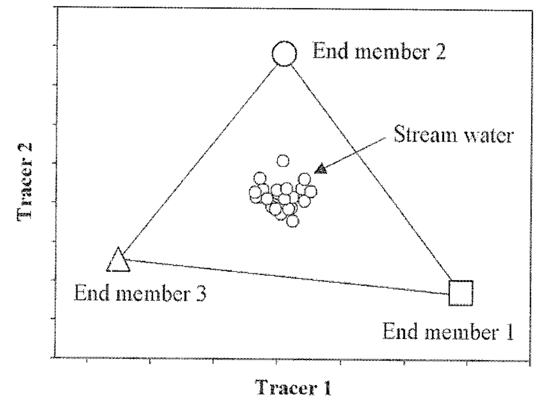

Fig. 2. The schematic mixing diagram of the end members.

Results and Discussion

1. Hydrological responses

We monitored two successive rainfall events during ten days from June 26, 2005 to July 5, 2005. The amount of the event 1 which is 161.9 mm on 26 June 2005 showed more than that of the event 2 which amounts to 139.2 mm on 1 July 2005. The 10 day-antecedent rainfall of the event 1 and 2 were 1.3 mm and 163.2 mm respectively. Also maximum rainfall intensity in the event 1 was lower than that in event 2. Maximum stream discharge of the event 2 was more than that of the event 1 as shown in the Table 1.

The maximum peak flow of the event 1 showed lower rate of a sixth in comparison with the event 2 despite of the more amount of rainfall. It may be caused by big difference of the antecedent rainfall between the two events. The difference of soil water content between the event 1 and 2 was very clear as shown in Figure 4. The soil water content just before the event 2 was 32% while that of the event 1 was 20%. The event 2 sustained to higher and longer flow owing to high soil water content. The groundwater level developed quickly in response to rainfall in both the event 1 and 2 (Figure 3).

2. Choice of end-members and tracers

Mixing models have been used to estimate the hydrological pathways, the sources of solutes and contributions of each component. Variability of streamwater chemistry was caused by changes in the mixing ratio of components that contribute to the stream runoff. Hooper *et al.* (1990) identified the three end members (groundwater from the floodplain, groundwater from the upper part of the catchment, and vadose zone water collected at the bottom of the A-horizon of the soil) at PMRW (Panola Mountain Research Watershed). Kim *et al.* (2005) also reported that much of streamwater were recharged

Table 1. Characteristics of rainfall and stream discharge in the two storm events.

	Event 1	Event 2
Observed period	June 26~30, 2005	July 1~5, 2005
Rainfall (mm)	161.9	139.2
Antecedent rainfall within 10 days (mm)	1.3	163.2
Maximum rainfall intensity (mm/10 min)	11.1	17.7
Maximum peak flow (mm/10 min)	0.2	1.3

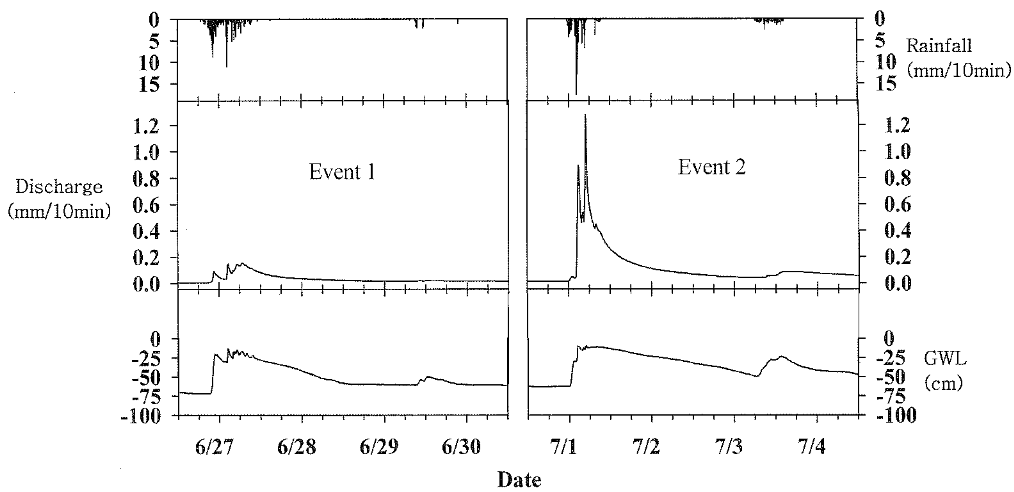

Figure 3. Rainfall, discharge and groundwater level fluctuation during the two sampled events.

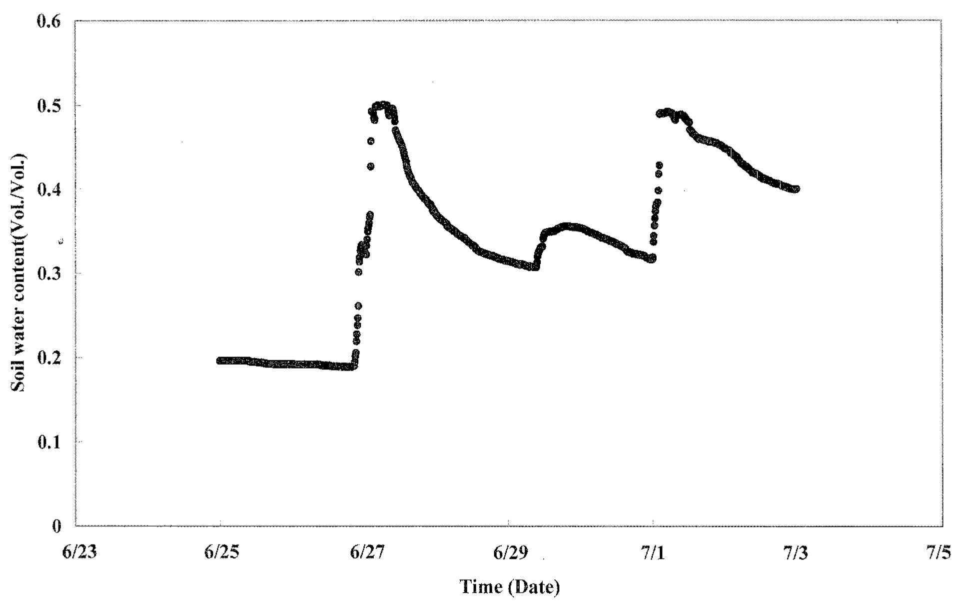

Figure 4. Variation of the soil water content between the two events.

through subsurface in the study area with change of streamwater chemistry and contribution of subsurface discharge. Therefore we selected throughfall, groundwater, soil water as the main components. Then ion concentrations of each component are analyzed and represented by their median (Figure 5); variability in concentration is drawn as bars and means as circles in the figures.

As shown in Figure 5, the mean concentration of chloride and magnesium ions were in the order of soil water > groundwater > throughfall > rainfall; soil water > throughfall > groundwater > rainfall in nitrate and sulfate ions; groundwater > soil water > rainfall > throuhgfall in natrium ion; soil water > throuhgfall > rainfall > groundwater in potassium ion; groundwater > soil water > throuhgfall > rainfall in calcium ion. In particular, natrium ion showed a remarkable difference among each component. Much ions appeared high concentrations in soil water and low concentrations in rainfall. There were also large variations in the concentrations of these ions within the soil water and throughfall, low variations within the rainfall. This represented every end-member's characteristics well and these changes were due to antecedent rainfall amount, ion washout from canopy by net rainfall and ion adsorption or leaching through soil. Thus, the rainfall and soil water can be considered to end members including throughfall and groundwater. These components have been selected as the end members in many studies (Hooper 2001; Kim and Jeong 2002).

On the basis of the selected components, three-component mixing diagrams were represented in Figure 6 and 7 using anions (Cl^-, NO_3^-, SO_4^{2-}) and cations (Na^+, K^+, Mg^{2+}, Ca^{2+}) assumed to be tracers in the stream

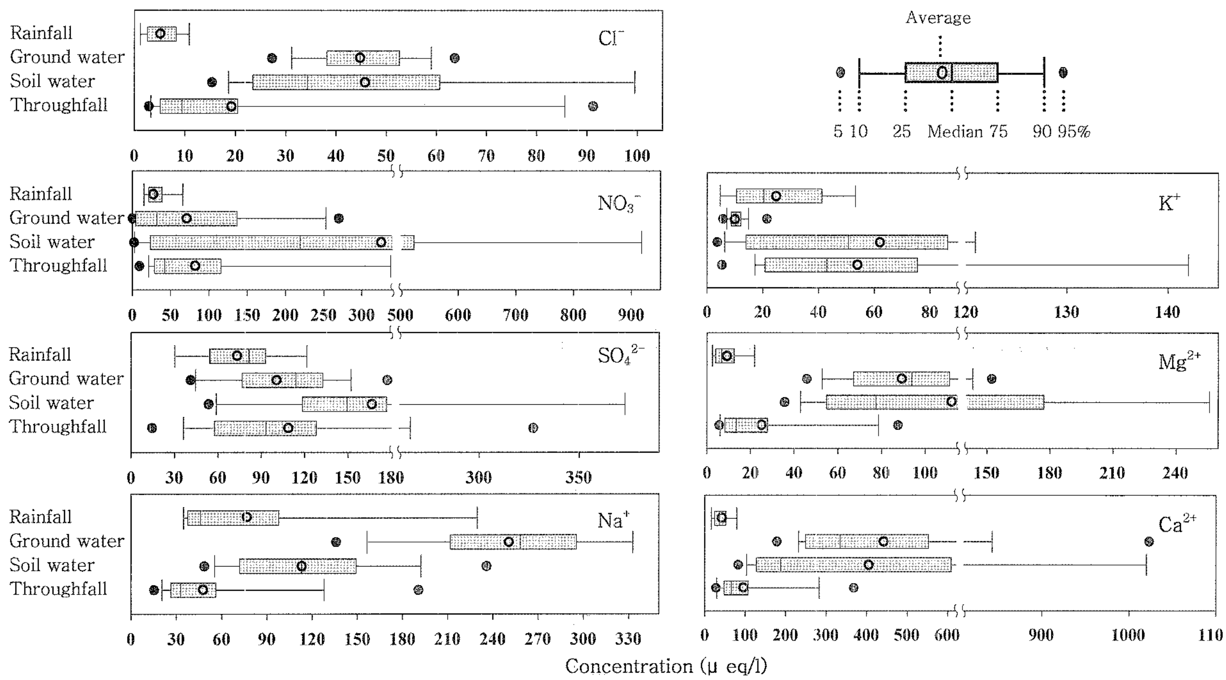

Figure 5. The spatial variations in the concentrations of anions and cations of throughfall, soil water, ground water and rainfall during the period from June to July 2005.

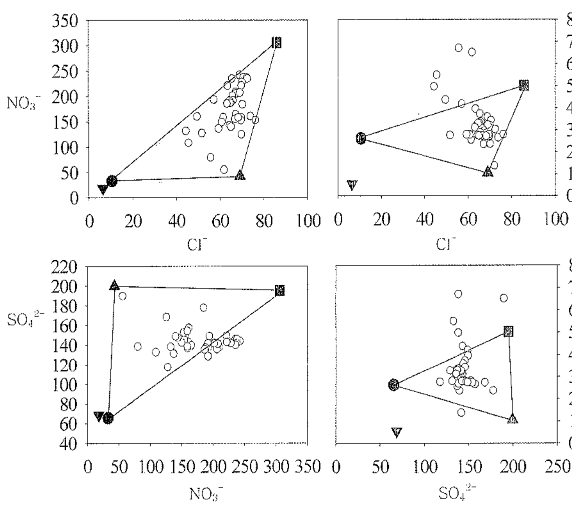

Figure 6. Mixing diagram of the event 1 for throughfall (●), soil water (■), ground water (▲), rainfall (▼), stream water (○) from June 26 to 30, 2005. Concentrations are in micro-equivalents per liter.

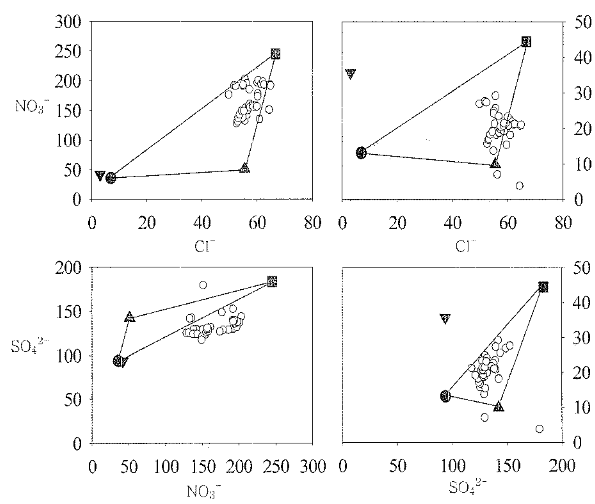

Figure 7. Mixing diagram of the event 2 for throughfall (●), soil water (■), ground water (▲), rainfall (▼), stream water (○) from July 1 to 5, 2005. Concentrations are in micro-equivalents per liter.

water.

In the event 1, each component and stream samples formed the suitable mixing diagram in case of chloride-nitrate ion and nitrate-sulfate ion. Especially, chloride-nitrate ion was found to be the most suitable tracers for EMMA model in the two events. Whereas mixing diagrams using nitrate, sulfate and potassium ion were represented by different tendency. This does not agree with the results of Hopper *et al.* (1990) using sulfate and calcium ion as tracers but could be a consequence of each end-member's chemical characteristics. In the event 2, chloride-nitrate ion showed stream water quality was closer with soil water than others. The antecedent rainfall within 10 days of the event 2 was larger than that of the event 1. During the event 2 nitrate concentration may increase because soil surface with high concentration of nitrate saturates. On the other hand potassium-chloride resulted that stream water quality moved a little toward groundwater. This is caused by potassium containing much in ground water.

Conclusion

This study was conducted to choose end-members and tracers for application of End Member Mixing Analysis (EMMA) model at the coniferous forest catchment, Gwangneung, Gyeonggi-do nearby Seoul, South Korea. In the spatial variations of ion concentrations, we selected groundwater, soilwater, and throughfall as the end members that contribute to the stream runoff. Each component and stream samples in the two events formed the suitable mixing diagram in case of chloride-nitrate ion and sulfate-potassium ion. Especially, chloride-nitrate ion were found to be the most suitable tracers.

As considered above results, it was considered that runoff quantity and quality were due to mixing groundwater, soil water and throughfall on runoff process in this catchment. Selected end-members and tracers could be adopted to EMMA and used to runoff separation for the event 1 and 2.

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