（様式５）(Style5)

学位論文全文に代わる要約
Extended Summary in Lieu of Dissertation

氏名：　Sanz Grifrio Limin
Name

学位論文題目：　Influences of plantation forests on hydrological processes in mountainous watersheds
Title of Dissertation　（山地流域におけるプランテーション林が水循環過程に及ぼす影響）

学位論文要約：
Dissertation Summary

1. Introduction

The management of watershed should consider the occurrence of every change in two factors such as climate, land-use. Land-use is the only manageable factor that could affect the flow and the quality of the water resource; conversely the development of water resources affects the land-use. As a result, it is essential that watersheds and water resources development should be managed in concert with one another. Land-use composition and land-use changes at the upstream area would affect the water availability both for surface water and groundwater at the downstream area of the watershed. Land-use activities that alter the type or extent of vegetative cover on a watershed would frequently change water yields and, in some cases, maximum and minimum streamflows. Current condition of land-use conversion is occurring now in Saba watershed, Bali where 35 % of paddy field in upstream and middle stream area of this river basin had been converted to clove plantation in last two decades. Therefore, infuence of the land-uses type and portion to water resources condition in a watershed is an important issue that should be investigated. Hydrological modeling would be an instrument to estimate the influences of land-uses to the hydrological processes. It is widely acknowledged that a hydrological model is a tool for conceptualization of hydrological phenomena.

Aim of this study is to investigate the influences of plantation forests on hydrological processes in mountainous watershed by using hydrological model. This study would focus on interception of plantation forests, in this case in clove and coffee, and its effect to the streamflow discharge. Because the rainfall is the main input for the hydrological model, estimation of areal rainfall is also a subject in this study.

In chapter 1, the importance of this study and objective was introduced. Chapter 3 would be contained explanation about research area in this study. In chapter 3, previous researches that related to this study were reviewed. In chapter 4, determination of areal average rainfall was investigated through case study in Kamo River watershed, Japan. Areal average rainfall estimation was also done in upstream Saba watershed. Rainfall partitioning in plantation forests was discussed in chapter 5 and then hydrologic model about river discharge was discussed in chapter 6.

2. Previous Researches

Previous researches have contained three popular methods of determining Areal Average Rainfall (AAR) that are the arithmetic mean, the Thiessen polygon and the isohyet. Another method to estimate areal average rainfall by co-Kriging interpolation method (Hevesi, 1992 and Martinez-Cob, 1996) has lead to conclusion that rainfall observations at some points of extreme rainfall for predicting rainfall in a mountainous area and evaluated that the presented method could predict annual rainfall at any point successfully.

Previous researches about rainfall partitioning had been reviewed. The results of Asdak *et al* (1998) experiment generally suggest that interception loss in an undisturbed tropical rainforest decreases following logging because logging practices create a discontinuous canopy. Other researches by Dietz *et al.* (2006) concluded that LAI alone did not correlate significantly with the pattern of rainfall partitioning, the throughfall percentage increased significantly with decreasing tree height. A possible reason for height-LAI-throughfall relationship was that under the conditions prevailing in the study region where canopy might not completely dry up between subsequent rainfall events.

3. Research Area and Description

First research area is the Kamo River watershed which is located in the eastern part of Ehime Prefecture, Japan. This area is classified as humid subtropical climate *Cfa* of Köppen climate classification with significant amounts of precipitation in all seasons. The Kamo River watershed area is 196.6 km^2 and mostly consists of mountainous area with the elevation ranges from 120 to 1920 m The area, whose slope is larger than 20 %, accounts for about 89 % of total area.

Second research area is Saba watershed that is located in Indonesia, between 114°56’33” to 115°06’30’E, and 8°14’38”S to 8°20’14” S, where altitude range is 0 - 2270 m and the area is 152.8 km^2. Area of Saba watershed reaches two districts in Bali Province, i.e., District of Buleleng (78%) and District of Tabanan (22%). From District of Buleleng, four sub-districts are in the Saba watershed, i.e., Sub-district of Banjar, Sub-district of Busungbiu, Sub-district of Seririt and Sub-district of Sukasada; while District of Tabanan comprises only Sub-district of Pupuan.

4. Determination of Areal Average Rainfall in Mountainous Watersheds

For estimating AAR in this mountainous watershed area, (i) the arithmetic mean, (ii) the Thiessen polygon, (iii) the elevation regression and (iv) the combination of (ii) and (iii) were applied. We also applied newly developed method, combination method (iv) that combines the contribution of elevation regression method and Thiessen method into a single method.

As an main input for hydrological model, areal average rainfall is a necessary to be estimated. Application of linear relation between elevation and monthly rainfall was led by the necessity of predicting rainfall at high elevation area in the mountainous Kamo River watershed. By comparing between measured and predicted monthly rainfalls, linear relationship was evaluated to be applicable for predicting rainfall even at a high elevation and very helpful for predicting AAR in a mountainous watershed. This relationship between elevation and monthly rainfall would be the principle to the some AAR estimation methods Meanwhile, in Saba watershed, the relation between elevation and monthly rainfall has shown that in some months, higher elevation would give lower monthly rainfall amount. As a result, elevation regression was applied to predict areal rainfall in upstream Saba watershed. due to elevation range of the watershed.

5. Rainfall Partitioning in Plantation Forests

Next discussion would be about mechanisms of rainfall interception processes; throughfall and stemflow and revealed differences of the partitioning of gross rainfall to throughfall and stemflow and factors influenced on them in the clove and the coffee plantation forests in the upstream Saba river basin. Comparison among results of throughfall and stemflow measurement led to a conclusion that the canopy in managed clove plantation would intercept more rainwater than the canopy in natural forest. Although clove plantation canopy would intercept more rainwater, the difference in land cultivation method would cause different value of soil infiltration and evaporation from the soil. In clove plantation, the fallen leaves of clove are collected and then utilized for essential oil extraction. The collecting of clove leaves causes thin litter layer on the topsoil. On the contrary, there is relatively thick litter layer on the topsoil in a natural forest. More litter layer on the topsoil would increase the rain amount that can be retained in the soil. The litter layer also limits the evaporation from the soil Another difference is in plant spacing between managed clove plantation and natural forest Managed clove plantation was monoculture cultivated with relatively low density of tree with uniform plant spacing. On the other hand, a natural forest is established naturally with varied tree species, random tree spacing, and relatively dense. This condition resulted in relatively dense rooting zone within the natural forest. The dense rooting zone in the natural forest would lead more porous soil structure that can infiltrate and hold more water in the soil layer.

Consideration about canopy interception capacity, litter containment, and soil water retention would be able to answer the question about hydrologic role of managed plantation and natural forest in this river basin. Cultivation method in clove plantation, which also considers the capacity of litter containment and soil water retention, will be required to give hydrologic services in maintaining water resource as natural forest does.

6. Evaluating Influences Of Plantation Forests In Upstream Saba Watershed

Evaluating the influences of plantation forests in upstream Saba Watershed was done by application of hydrological runoff model that considers each land-use role in the model. First model applied is lumped tank model. Application of tank model to upstream Saba watershed consisted of several sub-models such as evaporation model, infiltration model, canopy interception model, and areal rainfall model. Groundwater outflow coefficient for each land-use is determined by observing the dry season hydrograph to find the recession coefficient. Determination of groundwater coefficient would reduce the variable parameters that should be optimized. Result of lumped tank model is shown in the Figure 1. Three major land-uses that were considered is clove plantation, coffee plantation, and natural forest. Based on the optimized parameters in the lumped tank model, clove plantation would generate the largest surface flow among the three major land-uses. Meanwhile natural forest would generate smallest surface flow in the upstream Saba watershed.

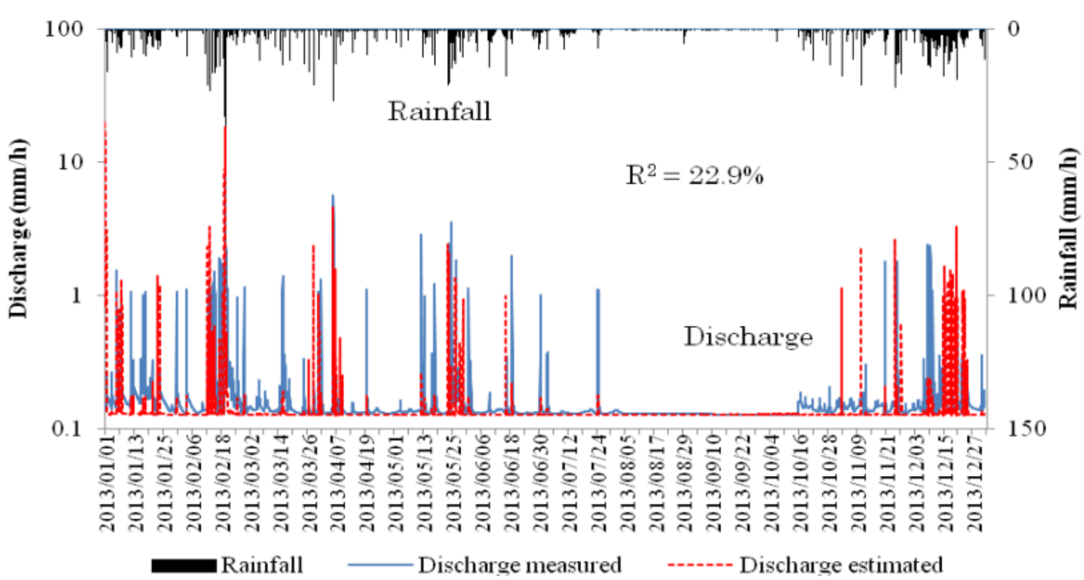

Fig. 1 Measured and modeled hydrograph for lumped tank model in Titab sub-watershed in 2013

Second hydrological model applied for Titab sub-watershed is distributed hydrological model by ICHARM (International Center for Water Hazard and Risk Management) and PWRI (Public Work Research Institute), Japan. This ICHARM/PWRI distributed hydrological model is a runoff analysis model converting rainfall into runoff for a given river basin that can be classified as both conceptual or parametric, and physically based, fully distributed model. Conceptual models are based on assumed physically realistic equations combined with semi-empirical ones to relate rainfall and outflows. The relationships are parametric and parameters have to be estimated. The parameters can be set according to observed rainfall and discharge data, or estimated from similar rivers. Physically based distributed models treat discharge as a migration phenomenon of rainfall in the river basin and represent the migration process by using infiltration and/or non-equilateral flow equations. Titab sub-watershed were divided into 0.5 km x 0.5 km grid in application of this distributed model. Discharge calculation in the river was calculated by Kinematic Wave method, in the other hand, vertical water movement in each grid was calculated by two layers tank model. Parameters were set for three major land-uses; clove plantation, coffee plantation, and natural forest. Result of distributed model is shown in Figure 2.

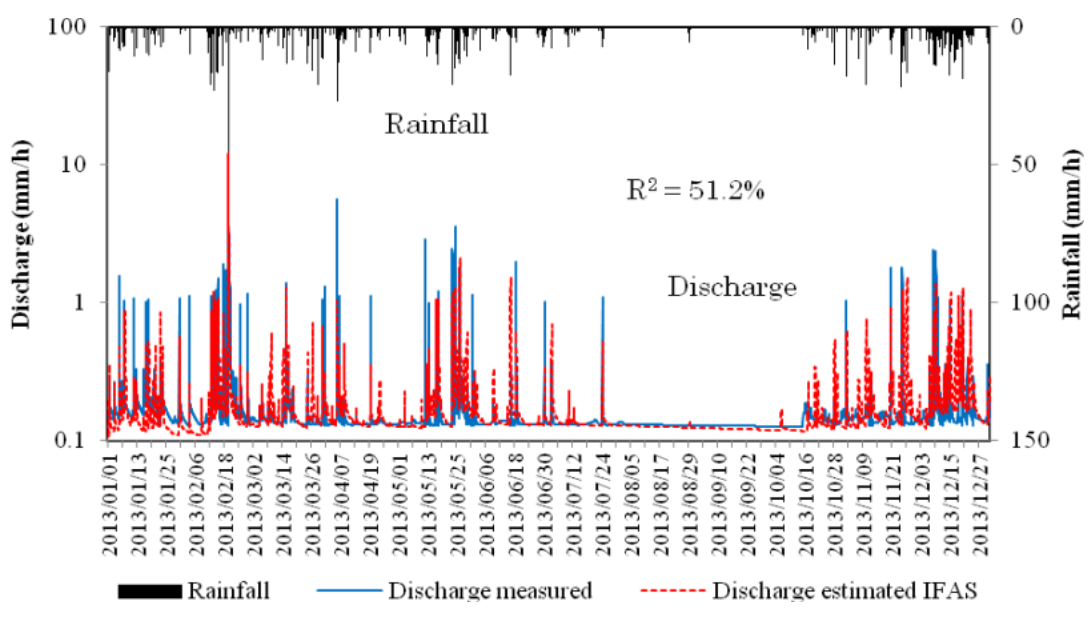

Fig. 2 Measured and modeled hydrograph for ICHARM/PWRI distributed model in Titab sub-watershed in 2013

Based on optimized parameter in ICHARM/PWRI distributed model, clove plantation would generate largest surface flow among the three major land-uses. Meanwhile, coffee plantation and natural forest have given almost similar surface flow parameters.

Comparison between lumped tank model and ICHARM/PWRI distributed model has done by comparing the determination coefficient between the two models. Distributed model would larger determination coefficient rather than lumped model. This difference would be occurred because lumped model did not consider the effect of topography and land-uses distribution that was passed by the flow to the river channel. The lumped model considers only the land-use effect by take the portion of each land-use to the total area of Titab sub-watershed. Meanwhile, distributed model would consider also the land-use distribution, land-use sequence, slope sequences, and slope distribution along the surface flow path. The differences on land-uses sequences and slope along the surface flow path would influence the final discharge in the outlet.

7. Conclusion

Understanding the influence of land-uses on hydrological processes is necessary for management of sustainable water resource in a watershed. Management of the upstream area should get more attention in management of water resources in the watershed. Influence of land-uses on hydrological process in this study was investigated by establishing tank model that represent each land-uses in the watershed. Total discharge generated by all land-uses is a summary of all runoff generated by each land-uses, proportional to the percentage of each land-use portion in the watershed. Lumped model is preferred due to heterogeneity of the watershed and limitation of measurements. In the other hand, distributed model is preferred due to its physical base that can represent the real condition in the watershed.

Regarding the expected hydrological service in a plantation forest; decreasing flood and delaying the response of discharge to rainfall, both plantations could be evaluated to have these functions to some extent, from the viewpoint of the interception process. In detail, coffee was superior to clove from the viewpoint of decreasing the amount of throughfall, and clove was superior to coffee from the viewpoint of delaying the response of throughfall. Around 1.0 % of stemflow rates in the both plantation plots were the same level as those in natural forests in the previous researches. Considered from an areal viewpoint, the contribution of stemflow to the net rainfall within the canopy was quite small, as it is a process just at the points of trees. But, the volume of stemflow, which reached to the base of a single tree, amounted *e.g.* to 18.6 *l* in the clove and 1.7 *l* in the coffee, respectively, with 500 mm gross rainfall. Therefore, stemflow could be evaluated to contribute to retain water effectively in the ground around the base of the tree, where the soil macro-pores are well developed due to the tree's roots and thus water through the stem would be quickly infiltrated.

Application of runoff model in Titab sub-watershed has reveal that clove was superior in generating surface flow rather than coffee plantation and natural forest. Regarding an effect of retaining water in the ground by this process, coffee was evaluated to be superior to clove, because larger planting density of smaller trees of coffee produced smaller volume of stem flow to the base of the tree and could infiltrate water of stem flow more quickly into the ground. In addition, most of fallen leaves of clove have been collected, despite the governmental regulation, and utilized for production, which would be a disadvantage for retaining water in the ground.

(注) 要約の文量は，学位論文の文量の約１０分の１として下さい。図表や写真を含めても構いません。
(Note) The Summary should be about 10% of the entire dissertation and may include illustrations