Field observation and modeling for the effects of forest thinning on runoff generation in headwater catchments

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1. INTRODUCTION

Forest thinning is an important part of the silvicultural treatments that is currently recommended for higher timber product in forested watersheds in Japan (Dung et al., 2011). Based on the summarized information of the previous studies, Dung et al. (2012) showed that annual runoff tented to be increased with increases in logged area (thinned area). Hence, mechanisms for changes in runoff due to forest thinning and associated management practices are not examined. Hydrological modeling can useful for understanding changes in flow paths at given catchments. *Objective of this study is to examine effects of forest thinning on internal hydrological flow path in headwater catchments using field observation and modeling.*

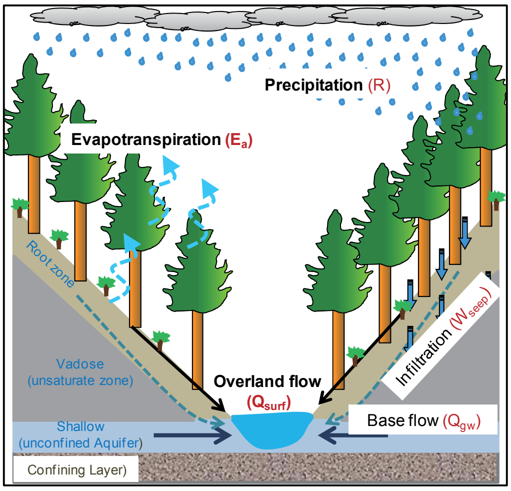


Figure 1. Schematic illustration of SWAT modeling application in hydrology processes

2. MODEL STRUCTURE

We used Soil and Water Assessment Tool (SWAT) model. SWAT is physically-based, spatially-distributed model which can simulate the effects of soil, vegetation, and topography on the movement of water at and near the land surface with the variety of processes, such as evapotranspiration, infiltration, surface, and subsurface runoff. SWAT divides sub-catchments into hydrological response units (HRUs), which are unique combinations of soil and land cover (Fig. 1 and Table 1; Neitsch et al., 2005). The hydrologic simulation is primary based on the following water balance equation,

$$SW_t = SW_0 + \sum_{i=1}^{t}(R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw})$$

where SW_t is Final soil water content (mm), SW_0 is Initial soil water content (mm), R_{day} is Amount of precipitation (mm), Q_{surf} is Amount of surface runoff (mm); E_a is Amount of evapotranspiration (mm), W_{seep} is Amount of water entering the vadose zone from the soil profile (mm), and Q_{gw} is Amount of return flow (mm). Simulation was conducted daily time steps.

Table 1. SWAT parameters and investigation methods

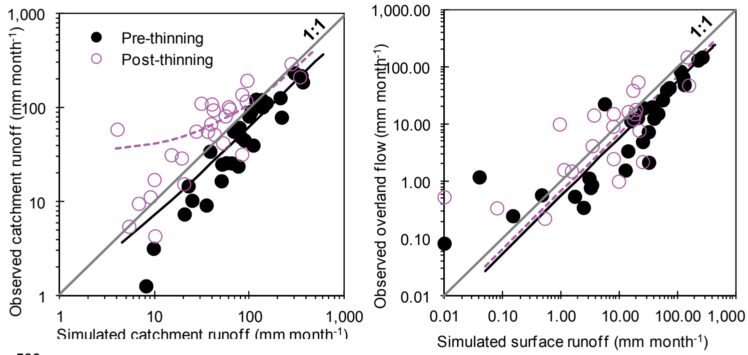
SWAT PARAMETERS	DAILY INTERVAL
SURFACE RUNOFF	Curve number: $Q_{surf} = (R_{day} - I_a)^2 / (R_{day} - I_a + S)$ *R_{day} is the rainfall depth (mm), I_a is the initial abstractions which include surface storage, interception and infiltration prior to runoff (mm), and S is the retention parameter (mm).*
SOIL WATER CONTENT	$WP_{ly} = 0.4 * m_c \rho_b / 100$ *m_c: percentage clay content of the layer (%) and ρ_b is the bulk density for the soil layer (Mg m^{-3})*
GROUNDWATER	$Q_{gw} = \frac{8000 . K_{sat}}{L_{gw}} . h_{wtbl}$ *K_{sat} is the hydraulic conductivity of the aquifer (mm/day), L_{gw} is the distance from the ridge or subbasin divide for the groundwater system to the main channel (m) and h_{wtbl} is the water table height (m)*
EVAPOTRANSPIRATION	Hargreaves method: $\lambda E_0 = 0.0023 . H_0 . (T_{mx} - T_{mn})^{0.5} . (\overline{T}_{av} + 17.8)$ *λ is the latent heat of vaporization (MJ kg^{-1}), E_0 is the potential evapotranspiration (mm day^{-1}), H_0 is the extraterrestrial radiation (MJ m^{-2} day^{-1}), T_{mx} is the maximum air temperature for a given day (^{0}C), T_{mn} is the minimum air temperature day (^{0}C), and $\overline{T}_{av}$ is the mean air temperature (^{0}C).*

3. MODEL APPLICATION

3.1. Study site and method

This study was conducted in two headwater catchments (0.19ha: M4 and 0.35ha: M5) in Mie Prefecture (34°21′ N, 136°25′ E). The M5 was covered by Japanese cypress with 3500 stems/ha in pre-thinning and was removed 58.3% of the stems, while M4 remained untreated as the control catchment. We monitored stream runoff at catchment outlets over a two-year pre- and a two-year post-thinning periods. We also monitored overland flow in two hillslope plots (Dung et al., 2011, and 2012). Runoff responses to thinning were then evaluated through paired-catchment analysis and SWAT model approaches. Coefficient of determination (R^2) and Nash-Sutcliffe efficiency (NSE) were applied for examining the reliability of prediction.

3.2. Results and discussion



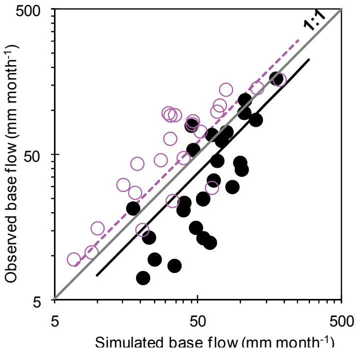


Figure 3. The relationship between observed and simulated monthly runoff components of M5 during the pre- and post-thinning periods

Runoff responses to precipitation for both observed and simulated values are similar (Fig. 2). Paired analysis between observed and simulated data revealed significant increases of both catchment runoff, and base flow, but not overland flow (Fig. 3 and Table 2). Because forest thinning caused increase infiltration and decrease evapotranspiration. Soil water availability affects the base flow components (Table 2).

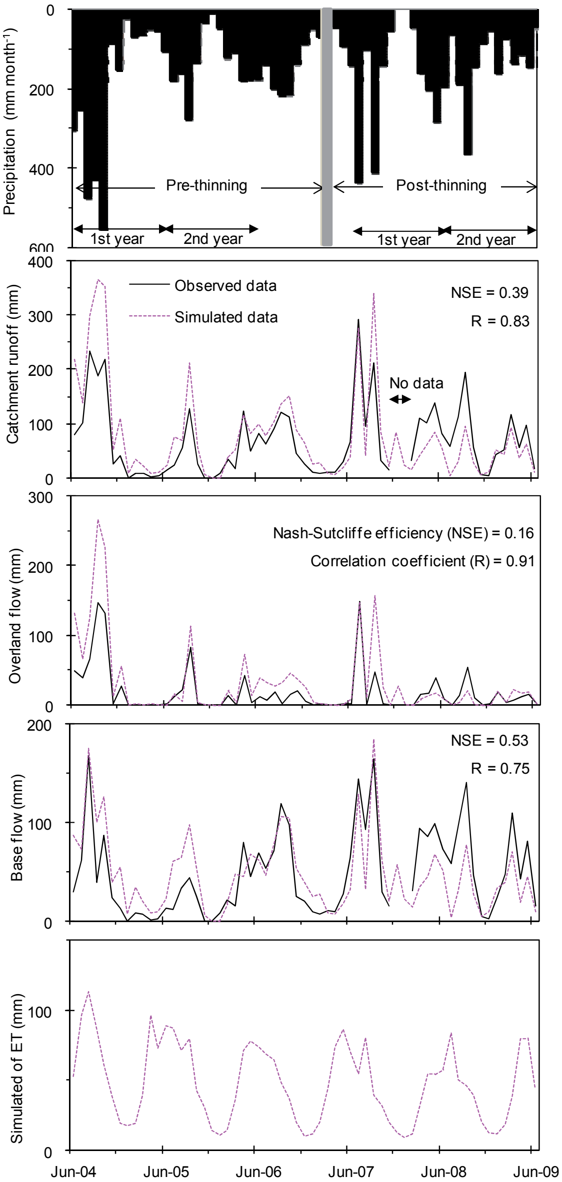


Figure 2. Characteristics of observed and simulated monthly runoff components during the pre- and post-thinning periods

4. CONCLUSION

SWAT model was able to simulate runoff components. Simulated results can be useful for analyzing of runoff responses to thinning with high reliable by comparing observation and simulation data. Hence, runoff components were estimated by model was greater than that based on field observation (except ET values) (Fig. 4 and Table 2). Such differences may occur due to the assumption of water pathway and storage in soil. Model simulation was conducted under homogeneity condition of soil, topography and vegetation while the study site is actual heterogeneity that impacted on distribution and runoff pathway resultant causing smaller runoff component comparing to simulation.

Table 2. Annual water balance estimated by field observation and SWAT model

Periods	Methods	Annual rainfall (mm)	Water yield (mm)	Overland flow (mm)	Base flow (mm)	ET (mm)	Soil water storage (mm)
Pre-thinning	*Observation*	1987	*655*	*331*	*325*	*735**	*602***
	SWAT		1173	555	610	669	158
Post-thinning	*Observation*	1829	*978*	*212*	*767*	*581**	*270***
	SWAT		811	265	560	505	514

Notes: * indicates applied by Kosugi et al. (2007) and Kolb et al. (2009); ** indicates estimation based on water budget; Parameters of SWAT (post-thinning period) was assumed as pre-thinning condition.

References

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