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Catchment processes in Southeast Asia: Atmospheric, hydrologic, erosion, nutrient cycling, and management effects

Roy C. Sidle [a,*], Makoto Tani [b], Alan D. Ziegler [c]

[a] *Disaster Prevention Research Institute, Kyoto University, Uji, Kyoto 611-0011, Japan*
[b] *Graduate School of Agriculture, Kyoto University, Kyoto 606-8502, Japan*
[c] *Geography Department, University of Hawaii, Honolulu, HI 96822, USA*

Abstract

Recognizing the importance of catchment processes related to the long-term sustainability of rapidly developing forested and formerly forested landscapes in tropical Asia, two scientific meetings were recently hosted to highlight current research advances in this region. Here we have compiled 18 papers that address various catchment processes in tropical Asia, including atmospheric fluxes, hydrologic and geomorphic processes, and carbon and nutrient cycling, as well as related land management effects. Sustainable management options related to catchment processes in Southeast Asia are discussed herein, along with research and technology transfer needs. A conceptual model is presented for assessing the interactions of anthropogenic factors on catchment processes across various temporal and spatial scales.

Keywords: Forest management; Sustainable development; Forest conversion; Research priorities; Sediment; Water; Models; Socio-economic issues; Tropics

Forested catchments in the tropics provide important benefits related to water production, biodiversity, carbon and nutrient sequestration, soil conservation, and other downstream services (e.g., Härdter et al., 1997; Greer, 1998; Lefroy et al., 2000; Ashton et al., 2001). Quantitative studies related to various catchment processes are, however, few. In Southeast and East Asia, the sustainability of management practices in tropical forests is increasingly coming into question (e.g., Laurance, 1999; Cramb et al., 2000; Tomich et al., 2004). Of particular concern are the environmental effects of widespread forest land conversion to agricultural production with associated problems of soil erosion, downstream pollution and sedimentation, nutrient losses, altered runoff patterns, and decreased biodiversity (Härdter et al., 1997; Islam et al., 2001; Rasul and Thapa, 2003; Bruijnzeel, 2004).

The interactions among ecosystem processes with local climate, geography, and socio-economic conditions in Southeast Asia are critically important to understanding issues related to sustainable management of tropical headwater catchments. Although hydrologic, geomorphic, biologic and geochemical processes from temperate areas in Asia have been extensively reported in international scientific journals, these processes and their interrelations tend to be more poorly documented in the tropics and sub-tropics. Important issues such as scale related to these processes have not been adequately addressed—often studies have focused on fluxes or processes at the plot-scale, which although important to individual landowners, may not be representative of the broader off-site and downstream concerns. At the other extreme are studies in larger drainage basins that estimate fluxes, but do not articulate specific catchment or hillslope processes. While these investigations quantify material export, they do not improve our understanding of how various land uses interact with different spatially and temporally distributed processes; therefore, are of limited utility in formulating best management practices. Furthermore, the publication of reputable process-based work by regional researchers in international journals has not been facilitated nor has it received a high priority, and many 'local' research reports within the region are not readily accessible to scientists and land managers worldwide. Information based on investigations in Southeast Asia must be shared with scientists, managers, and government officials because rapid economic development with concurrent population increases greatly affect hydrologic processes. Because of these demographic and developmental changes, as well as disparities in economies, the issues of highest importance to the region may differ from research perspectives and agendas of scientists and agencies from outside (Thapa, 2001). For example, the most important

* Corresponding author. Tel.: +81 774 38 4116; fax: +81 774 38 4118.
E-mail address: sidle@slope.dpri.kyoto-u.ac.jp (R.C. Sidle).

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cultural and management issues in developing regions may be more focused on potable water supplies, site productivity, food security, and natural disaster prevention rather than other environmental topics. Whatever the particular regional environmental issues and concerns, it is clear that without understanding the controls on water, biota, and materials transported into and through smaller catchments, it is difficult to develop prudent long-term forest management plans at the larger ecosystem scale (e.g., Gomi et al., 2002). Of similar importance is the impact of these fluxes on aquatic and terrestrial habitat. Additionally, parts of Asia are recognized as being vulnerable to plausible climate change, but few studies are available to forecast the severity of the impacts (Ramakrishnan, 1998).

In recognition of the importance of forest catchments in Southeast Asia to regional and global environmental conditions as well as economies, two scientific meetings were recently hosted: a special session on ''Tropical Catchment Processes'' at the Fall 2003 American Geophysical Union meetings and a IUFRO (International Union of Forestry Research Organizations) Forest Hydrology Workshop in Kota Kinabalu, Sabah, Malaysia, in July 2004 on ''Forests and Water in Warm, Humid Asia''. In particular, this latter IUFRO workshop provided a venue for many local and some outside scientists to exchange and disseminate research ideas and information related to fundamental and applied aspects of forest ecosystem processes in Southeast and East Asia. Participants in these two sessions were invited to submit papers for consideration in this special issue of *Forest Ecology and Management*.

This issue contains one of the first collections of refereed papers related to catchment processes in Southeast Asia. Three papers focus on atmospheric processes: the first two on energy fluxes (Klemm et al., 2006) and fog deposition (Chang et al., 2006) in a *Chamaecyparis* cloud forest in Taiwan; the third on the effects of complex tropical forest canopies in Peninsular Malaysia on rainfall distribution (Konishi et al., 2006). Zulkifli et al. (2006) reported nutrient export from logged and unlogged catchments in Peninsular Malaysia in stream water, suspended particulates, and bedload sediment. The paper by Hairiah et al. (2006) examines how forest conversion to coffee agroforestry systems in Sumatra influenced litter, soil organic carbon and earthworm populations. Four papers apply modeling approaches to understand hydrologic processes at various scales. A ''Data Based Mechanistic'' model is presented that examines relationships within rainfall-streamflow data and the component water pathways of overland flow, subsurface flow, and transpiration, and how these are altered by logging activities in the tropics (Chappell et al., 2006a). Cuo et al. (2006) apply the distributed-hydrology-soil-vegetation model (DHSVM, i.e., Wigmosta et al., 1994) to a catchment in northern Thailand to assess the effects of mountain roads on soil moisture levels and stream discharge. Chandler (2006) utilizes a water budget approach to partition precipitation in cropland, pasture and forested headwaters in karst terrain in the Philippines amongst overland flow, evapotranspiration, bedrock storage, and baseflow. Ziegler et al. (2006) estimate effective vegetated slope lengths for buffering overland flow on hillslopes in two fragmented basins of northern Vietnam. Eight papers focus on erosion, sedimentation and hydrogeomorphic processes in tropical forests of Asia. An investigation in a tropical rain forest of Sabah, Malaysia, details the role of soil pipeflow on runoff generation and sediment supply processes (Sayer et al., 2006). Two papers derive indices based on topography to draw inferences about physical processes in headwater catchments of northern Thailand and east Malaysia (Chappell et al., 2006b; McNamara et al., 2006). Lai and Detphachanh (2006) found that even during dry years, bedload sediment constituted greater than one-third of the total sediment flux from a moderate sized catchment in Peninsular Malaysia. Two studies in logged catchments of Peninsular Malaysia examined the effects of riparian condition and woody debris in headwater streams on sediment storage (Gomi et al., 2006), and the role played by ferns colonizing a disturbed logging road on reducing sediment loss and increasing base cation fluxes (Negishi et al., 2006). A study in southern India found that more than half of the suspended sediment load in both the Bhadra River and Bhadra Reservoir originated from mining activities occupying $<1\%$ of the catchment area (Krishnaswamy et al., 2006). This issue concludes with a summary paper that details the effects of various land management practices in tropical forests of Southeast Asia on both surface erosion and mass wasting (Sidle et al., 2006).

During discussions held at both meetings a number of research themes were generally acknowledged to be of high priority related to catchment processes in tropical forests of Southeast Asia. Some of the more general topics that were deemed important include:

- Monitoring energy and gas fluxes from various land uses, such as plantation forests, oil palm and coffee plantations, and urbanized areas to quantify anthropogenic impacts.
- Upscaling of basic information on energy and gas fluxes to assess of land-atmosphere interactions over wide areas.
- Determining the most appropriate approaches needed to model catchments (and catchment processes) in the tropics where input data are sparse.
- Linking the development of new hydrological models with field investigations in tropical Asia.
- Issues of regional hydrology related to flooding and sedimentation—influences of land cover change and changing or variable climatic inputs.
- Determining the best methods of assessing regional flooding and sediment hazards.

Of the more specific research needs discussed, the following were perceived as very important:

- Determining the best methods for quantifying and characterizing important hydrological properties (e.g., hydraulic conductivity, infiltration capacity) related to hillslope and catchment scale fluxes, and how to best include such parameters in different types of models.
- Application of new techniques (e.g., isotope chemistry, geochemical techniques, advanced hydrometric approaches, sediment fingerprinting) to elucidate hydrogeomorphic processes in tropical Asia.

- Better understanding of both the terminology and function of preferential flow pathways in tropical forest soils.
- Better definition of fog forests as well as their spatial relevance in the tropics of Asia.
- Specific effects of roads (and other small-scale, but intense disturbances) on water, sediment, and nutrient routing.
- The importance of nutrient/chemical fluxes related to sediment loss.

Finally, two technology transfer needs related to catchment processes in the tropics of Southeast Asia were identified:

- Determine the most effective methods for generating and utilizing decision making tools in tropical catchment management—i.e., how to incorporate the appropriate level of 'good science' with socio-economic issues and constraints.
- Develop appropriate management perspectives in the tropics—i.e., rehabilitation versus 'best management' or more sustainable planning. We need to focus on best management practices and recognize the institutional and scientific obstacles that must be overcome.

These lists are certainly not 'all inclusive', but represent a consensus of some of the important research priorities for forested or formerly forested tropical catchments in Southeast Asia. Such priorities differ from the research and technology transfer needs in more studied temperate forests where a better understanding exists of the linkages between catchment processes and management effects, where best management practices are typically implemented, and where emerging research themes include legacy or cumulative effects of management practices. Additionally, the vast differences in capital assets and levels of development amongst many countries in Southeast Asia would preclude certain national agencies from funding much of the high-cost catchment research; thus, where such studies are deemed essential, resources must come from outside. The recommendations we present could serve as useful guidelines for future funding of both basic and applied research in tropical Southeast Asia by international donors and national scientific funding agencies. Prudently targeted investments in research in Southeast Asia will reap benefits in the long-term by encouraging better soil and water conservation practices, reducing natural disasters, and supporting sustainable development, thus reducing the foreign aid in response to crisis situations. A conceptual outline for an approach to understanding important catchment processes and linking these processes in the context of management and social issues across various spatial scales is shown in Fig. 1. It is important to recognize that certain dominant processes will change with scale and that, while such processes may not be unique to the tropics, certain conditions (e.g., higher decomposition rates, differences in soil development, incident rainfall duration-intensity, soil fauna, weathering processes) and management practices may create

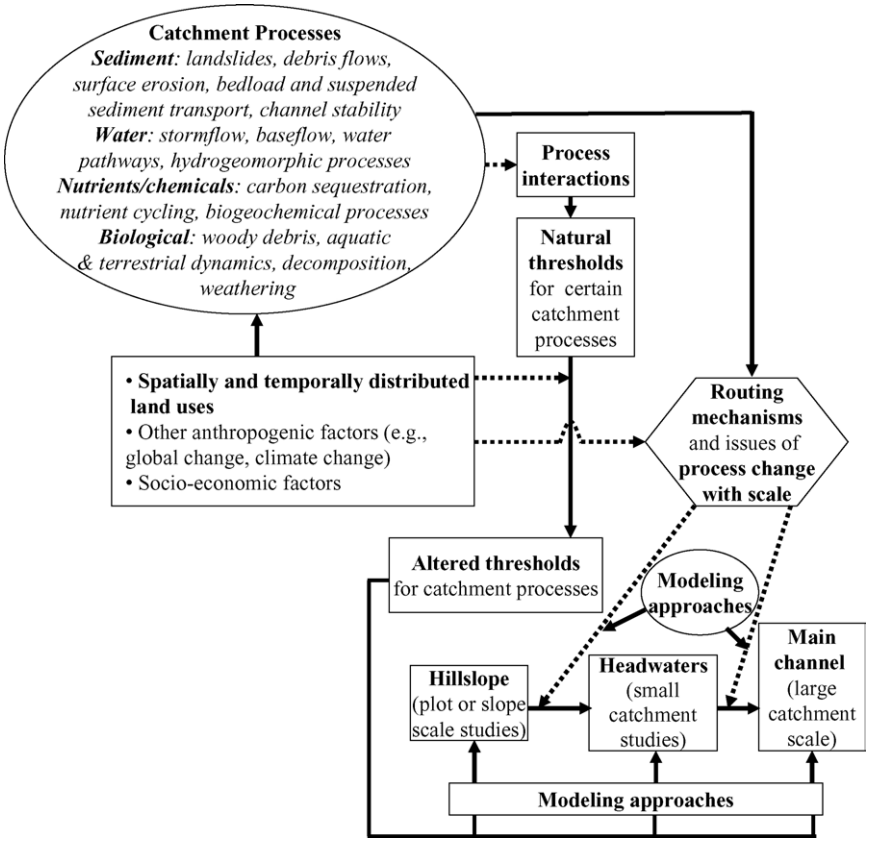

Fig. 1. A conceptual model for assessing the interactions of land use and other external factors on catchment processes across various spatial and temporal scales. Solid arrows represent compartmental connections; broken arrows represent process transfer or routing links.

very different catchment responses compared to temperate forests.

The papers contained in this special issue emphasize the need to investigate processes (not just fluxes) of water, sediment, nutrients and organic materials to fully assess the impacts of distributed forest land uses (Fig. 1). Without such knowledge, cause and effect of distributed land uses are difficult to disentangle. To assess processes like runoff at the catchment scale, distributed modeling techniques have proven useful. Existing hydrology and sediment models need to be modified and applied in the tropics, although it must be recognized that many distributed models are very data intensive. Empirical models are useful in particular regions, but are not transferable to other areas. One major challenge for catchment modeling in all regions is to integrate the closely coupled processes of runoff, erosion, and sediment routing and transport into linked hydrogeomorphic models (Sidle, 2004) (Fig. 1); however, special concerns are evident in tropical Asia because of the lack of widespread distributed data on important parameters. Additionally, related to the long-term productivity and sustainability of forest lands in Southeast Asia, the inclusion of losses and transport of soil nutrients and carbon in catchment models is needed.

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