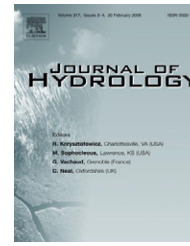
Journal of Hydrology (2007) **337**, 52–67

available at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/jhydrol



Hydrological consequences of landscape fragmentation in mountainous northern Vietnam: Buffering of Hortonian overland flow

Alan D. Ziegler [a,*], Thomas W. Giambelluca [a], Don Plondke [a], Stephen Leisz [b], Liem T. Tran [c], Jefferson Fox [d], Michael A. Nullet [a], John B. Vogler [d], Dao Minh Troung [e], Tran Duc Vien [f]

[a] *Geography Department, University of Hawaii, 2424 Maile Way SSB 445, Honolulu, HI 96822, USA*
[b] *Institute of Geography, University of Copenhagen/Hanoi Agricultural University, Hanoi, Viet Nam*
[c] *Department of Geography and Geology, Florida Atlantic University, Boca Raton, FL, USA*
[d] *Environmental Studies Program, East-West Center, Honolulu, HI 96848, USA*
[e] *Center for Natural Resources and Environmental Studies (CRES) of the Vietnam National University, Hanoi, Viet Nam*
[f] *Center for Agricultural Research and Ecological Studies, Hanoi Agricultural University, Gia Lam, Viet Nam*

Received 22 February 2006; received in revised form 27 December 2006; accepted 10 January 2007

KEYWORDS
Land-cover conversion;
Deforestation;
KINEROS2;
Swidden agriculture;
Tropical watershed hydrology;
SE Asia;
Runoff generation;
Filter strips

Summary We use a hydrology-based fragmentation index to explore the influence of land-cover distribution on the generation and buffering of Hortonian overland flow (HOF) in two disturbed upland basins in northern Vietnam (Tan Minh). Both the current degree of fragmentation in Tan Minh and the current spatial arrangement of buffers (relative to HOF source areas) provide only limited opportunities for infiltrating surface runoff from upslope source areas, in part because of the high connectivity of swidden fields on long hillslopes. The intentional placement of buffers below HOF sources and the reduction of the down-slope lengths of swidden fields could reduce the occurrence of HOF on individual hillslopes. Reduction of the total watershed total depth of HOF would require maintaining a sufficient area of buffering land covers; and this may necessitate the use of longer fallow periods. These measures are, however, counter to the land-practice trends witnessed in the last several decades (i.e., no buffers, cultivation of long slopes, and increasingly shorter fallow periods). The two most likely scenarios of future land-cover change in Tan Minh–one representing increased fragmentation, the other decreased–both lead to an increase in HOF because of reduced buffering potential. The unlikely scenario of abandonment of agriculture and subsequent regeneration of forest, leads to both less

* Corresponding author. Tel.: +1 808 956 8465; fax: +1 808 956 3512.
E-mail address: adz@hawaii.edu (A.D. Ziegler).
URL: webdata.soc.hawaii.edu/hydrology/ (A.D. Ziegler).

0022-1694/$ - see front matter
doi:10.1016/j.jhydrol.2007.01.031

fragmentation and less HOF. The study highlights the hydrological impacts associated with fragmentation at Tan Minh, which is the product of decades of local and regional forcing factors that have dictated the degree and timing of timber removal and swiddening at the site.

Introduction

Tropical upland forests in SE Asia, South America, and Africa have increasingly become supplanted by fragmented landscapes (Skole and Tucker, 1993; Fox et al., 1995; Laurance and Bierregaard, 1997). Fragmentation is a form of land-cover conversion for which large forest tracts are replaced by irregular-sized, asymmetrical patches of remnant forest and various replacement covers (Laurance and Bierregaard, 1997). Fragmentation has often been shown to affect ecological phenomena directly (e.g., Turner, 1996; Laurance et al., 1997, 1998; Williams-Linera et al., 1998). Relatively few studies, however, have investigated the consequences of fragmentation on hydrological and climatological processes at any scale (Avissar and Peilke, 1989; Kapos, 1989; Giambelluca et al., 2003; Laurance, 2004; Ziegler et al., 2004b).

Following land-cover conversion, the physical characteristics of the replacement vegetation differ from forest at least initially (e.g., root mass/depth/turnover, total biomass, canopy characteristics including leaf area index, leaf morphology). The mechanisms and pathways that partition rainwater (viz. canopy interception, infiltration, and water ponding) on replacement land covers therefore differ from those of the undisturbed forest (Bruijnzeel, 2000, 2004; Giambelluca, 2002; Zimmermann et al., 2006). Reduced soil infiltrability, for example, is often reported on converted lands in montane areas of SE Asia (Hurni, 1982; Lal, 1987; Malmer and Gripp, 1990; Bruijnzeel and Critchley, 1994; Douglas et al., 1995; Ziegler and Giambelluca, 1997; Douglas, 1999; Sidle et al., 2006). One consequence of reduced infiltrability is an increase in Hortonian overland flow (HOF, caused when rainfall rate exceeds infiltrability and surface storage; Horton, 1933). If the spatial extent of disturbance is great enough, hydrological response is altered from that prior to land-cover conversion (cf. Bruijnzeel, 1990, 2004).

In two fragmented basins near Tan Minh Village in northern Vietnam, we found evidence that land-cover conversion increased Hortonian overland flow generation (Ziegler et al., 2004b). Saturated hydraulic conductivity (K_s) on most replacement land covers was less than that for forest. Forests in Tan Minh occupy only about 2% of the total area; and mean patch size is less than 1 ha. The remaining 2100 ha is a mosaic of more than 500 patches of various land covers differing in K_s-and therefore, differing in the propensity to generate HOF. Because of the high degree of spatial heterogeneity in land cover, some portion of HOF generated on upslope areas of low K_s is infiltrated on downslope surfaces of high K_s, before entering the stream network. The extent to which 'buffering' occurs depends, in part, on the frequency that buffers are located below upslope source areas, which is inherently a function of the degree of fragmentation that has been changing over time and space in response to both local and external factors (e.g., conservation policies, subsistence needs, market economy).

Heretofore, we have had no way of judging the potential for buffering overland flow within the fragmented landscape at Tan Minh now, nor in the past and future. In this work, we develop an index of basin-wide HOF occurrence to compare the buffering that occurs under the current degree of fragmentation with that of different scenarios of projected and historic land-cover distribution.

Study area

Tan Minh

Tan Minh (roughly 19:00°N, 104:45°E) is located west-southwest of Hanoi, in Da Bac District of Hoa Binh Province, in northern Vietnam (Fig. 1). The study area is described in more detail elsewhere (Ziegler et al., 2004b). Two watersheds comprise the study area (Fig. 2): Watershed 1 (910 ha) is located on the west side of the study area; and the larger watershed 2 (1228 ha) on the east side. Elevation range is 200–1000 m above sea level. Slopes are steep, typically 0.5–1.7 m m^{-1}; and they extend to the valley floor and/or stream channel. Bedrock is largely sandstone and schist, with some mica-bearing granite. Soils are predominantly Ultisols

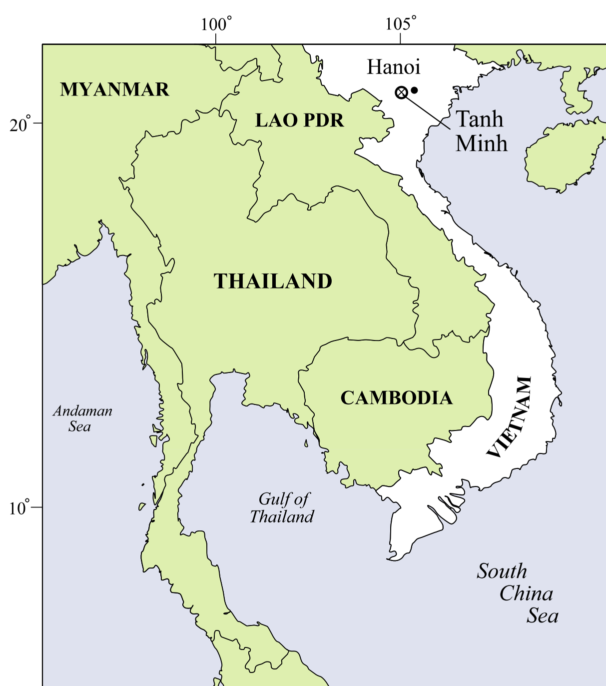


Figure 1 Location of the Tan Minh study area in northern Vietnam.