6. An Overview of Water and Related Hazard Issues in Southeast Asia

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Introduction

Headwater streams emanating from forests and agricultural lands supply much of the potable water for tropical regions of Southeast Asia. The quality, quantity, and timing of water from these headwater catchments are strongly influenced by land use (e.g., Baharuddin and Abdul Rahim 1994; Douglas et al. 1992; Ziegler et al. 2000). In turn, the distribution and timing of water routing in these headwaters greatly influences natural hazards such as river flooding, severe surface erosion and landslides (Sidle et al., 1985; Inamura and Dang 1997; Sidle et al., 2003).

The interactions of land use with water pathways and storm runoff, as well as with natural hazards, have not been extensively studied in tropical ecosystems of Southeast Asia. Relative anthropogenic impacts may also be strongly associated with the spatial and temporal attributes of land uses (Sidle and Hornbeck, 1991; Maita et al., 1998). Without understanding the controls on materials transported through and stored in headwaters, it is difficult to develop prudent long-term management plans for larger catchments (Walling, 1983). The issue is further polarized by effective but largely unsubstantiated opinions tabled by certain environmental groups that view any industrial management practice (particularly forestry) as unacceptable and unsustainable. Land management agencies and water users are therefore left to decide on acceptable activities based on poor scientific information and the biased perspectives of both environmental groups and the industrial sector. While planning and decision processes related to integrated catchment management must consider socio-economic and political objectives as well as public opinion, it must be remembered that *hydrologic response* is the primary driver in these systems.

Land Use Issues that Affect Water and Related Resources

Land use activities in the tropics of Southeast Asia can have a substantial impact on the occurrence and severity of floods, landslides, debris flows, and severe soil erosion. In addition to generating widespread sedimentation and damage to streams and riparian habitat, these hazards pose significant risks to humans, infrastructures, and property in the runout

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zone (Swanston and Schuster, 1989; ESCAP, 1999). The probability and severity of these natural hazards can increase related to timber harvesting, road building, vegetation conversion, urbanization, and recreation (e.g., Sidle et al., 1985). While the media has been quick to blame 'so-called' deforestation for the recent flood disasters in Southeast Asia, a more pragmatic look at the actual factors contributing to the flooding process is needed – e.g., spatial distribution of soil compaction, alteration of flow paths, sealing of soil surfaces, and changes in evapotranspiration. These and other factors (e.g., overloaded slopes, reduced root strength) must be considered in assessing the effects of land use on landslide initiation and the onset of severe surface erosion.

Nowhere in the world are natural resources more at risk than in developing rural regions of Southeast Asia. Government policies in the region that promote high cash value crop production and transmigration together with the apparent needs of subsistence farmers to generate additional sources of income from the land have placed increasing stresses on soil and water resources. Additionally, export of timber and associated forest products from this region to developed nations worldwide has exacerbated these stresses. Along with the development of extensive agricultural and forest land are the methods employed for land clearance (e.g., fire, logging, mechanical clearing) and the transportation corridors (ranging from foot paths to roads).

The effects of roads and trails on hydrologic processes and sediment transport are significant in tropical catchments (Baharuddin et al., 1995; Ziegler et al., 2000; Sidle et al., 2003). All roads and trails modify site hydrology by decreasing the hydraulic conductivity and infiltration capacity of the traveling surface, redirecting incoming rainfall and water as Hortonian overland flow, and concentrating this runoff into various parts of the catchment. In many regions of Southeast Asia, secondary roads and trails (including forest roads and skid trails) are not built to suitable engineering standards, are not surfaced with rock, and drainage systems often do not exist; thus, surface runoff simply follows the natural contour of the road and discharges onto the slopes or into channels at topographic low points or discharge nodes (Sidle et al., 2003). Where the roadbed is erodible, the lack of drainage systems can have catastrophic consequences for sediment production, particularly in steep terrain. Baharuddin et al. (1995) measured surface erosion losses in the range of 10-13 t $ha^{-1}yr^{-1}$ from plots on logging roads and skid trails in a Peninsular Malaysian rainforest during the first year after logging (Table 1). In the second year after logging, losses declined to 2-3 t $ha^{-1}yr^{-1}$. Using field evidence of cumulative soil loss, Sidle et al. (2003) estimated that surface erosion from logging roads and skid trails was about 275 t $ha^{-1}yr^{-1}$ in a selectively logged catchment in Malaysia (Table 1). Erosion from road surfaces as well as headcutting of channels contribute to sedimentation of streams. Roads cut into hillsides may intercept subsurface water and reroute it into drainage systems or along the road surface, thereby enhancing peak flows (Sidle et al., 2003). Mass wasting from roads occurs episodically, with little soil loss in many years and much erosion during years with large storms; while such episodic inputs can be missed in short-term monitoring, they may be dominant sediment inputs (Douglas et al., 1999).

Issues related to urbanization are more spatially restricted and constitute a major concern related to water supplies, pollution and flooding because of the high density of inhabitants concentrated in the ever growing cities of Southeast Asia. Water-related hazards are a particular concern due to the demographics. A recent example is the extensive flooding that occurred in Jakarta in early 2002, partly exacerbated by poor urban drainage systems. Health issues arise during flooding in many Southeast Asian cities because storm drains are not separated from sewage lines; thus, when these systems are overloaded, contaminated water is widely distributed overland. High temperatures in the region promote the spread of infectious water-transmitted diseases.

The conversion of tropical forests to oil palm plantations has been undoubtedly the most widespread land use change in Malaysia and Indonesia during the past several decades (e.g., McMorrow and Abdul Talip, 2001). At the turn of last century, more than 55% of Malaysia's forest was reported as oil palm plantations. The recent rate of conversion of native forests to oil palm plantations in Indonesia is even greater and this, when added to the impacts of illegal logging, are drastically reducing tropical forests. Few studies have been published in the scientific literature on the effects of conversion of tropical forests to oil palm plantations; based on field observations, the impacts on soil and water resources are much greater in terrain steeper than 20%. Most of the impacts appear to occur during the land clearing process and in the initial 2-3 years following plantation establishment, with much rapid storm runoff and sediment produced on roads and connected disturbed areas (e.g., terrace cuts) within the plantation. Additionally, the clearing of native forests by fire, a common practice in Indonesia, has contributed substantially to the recent haze problems in equatorial Southeast Asia.

The conversion of native forests to permanent agriculture and other plantations (e.g., coffee, rubber, fruit trees) has also created problems for soil and water conservation (Table 1). Forest conversion to coffee plantations is occurring throughout much of Southeast Asia, particularly in Vietnam and Indonesia, while tea and fruit plantations, as well as a variety of high cash value crops are grown on steep hillsides throughout the region. Much of the forested landscape in northern Thailand was converted to agricultural land between 1954 and 1976; more recently, forest cover has been relatively stable, but dynamic cultivation changes have occurred on the converted land related to a shift from subsistence to cash crops (Fox et al., 1995). Where crops are grown as monoculture, soils are typically more susceptible to erosion compared to forest cover.

An apparent compromise to such land conversions is the application of agroforestry. These practices are believed to offer a combination of both short-term economic returns to farmers (i.e., crop production) together with longer-term investments and soil and water conservation benefits (i.e., trees) (e.g., Fischer and Vasser, 2000). The effectiveness of agroforestry depends strongly on the adaptation of the practice with the local environment and culture as well as the effectiveness of restoring some of the water, sediment, and nutrient pathways inherent in the former natural forest environment. The incorporation of a cover crop within a plantation of trees, or between rows of trees or shrubs, has been shown to be an effective control on surface erosion in Peninsular Malaysia (Hashim et al., 1995), Philippines (Tacio, 1993), and Sumarta (Rosadi et al., 1999) (Table 1). Coffee and cocao trees grown on moderate slopes experience high rates of erosion (11-70 t $ha^{-1}yr^{-1}$), but rates declined to 0.15-3.4 t $ha^{-1}yr^{-1}$ when cover crops are incorporated (Hashim et al., 1995; Rosadi et al., 1999) (Table 1). The sustainability of various agroforestry practices in Southeast Asia has yet to be evaluated at the watershed scale.

Soil loss from conventional hillslope agriculture practices in Southeast Asia are generally high, although rates are have typically been assessed only for surface erosion at the field plot scale (Table 1). Such rates are generally higher than at the catchment scale because there is little opportunity for deposition and storage of sediment on uniform gradient plots. For vegetable crops grown on moderate to steep hillsides, the highest levels of soil loss (38-140 t $ha^{-1}yr^{-1}$) occurred when cultivation was oriented up and down the hillslope, a typical practice in the region (Paningbatan et al., 1995; Presbitero et al., 1995; Sombatpunit et al., 1995; Poudel et al., 1999). Cultivation along the hillslope contour together with the use of agricultural hedgerows reduced erosion by half or more (Table 1). Modest erosion rates were reported from rice paddy fields in northwest Thailand (Nishimura et al., 1997). Midmore et al. (1996) note that preparation and maintenance of terraces cut into hillsides are major sources of erosion in tea plantations in the Cameron Highlands, Malaysia (Table 1).

No studies have quantitatively addressed the impacts of forest conversion on landslides in tropical Southeast Asia. Terraces built on steep slopes can increase landslide potential by both concentrating water on the terraces (especially if back-sloped) and by oversteepening the terrace face. Aside from terracing, the major effect of agricultural conversion on slope stability can be attributed to a more or less permanent loss in rooting strength compared to forest or brush vegetation. Shallow rooted agronomic species have negligible rooting strength compared to deeper-rooted trees and shrubs (Sidle and Dhakal, 2002). This long-term reduction in root strength can be translated into in increasing probability of land sliding (e.g., Sidle 1992).

Shifting cultivation is still common in the region and involves leaving intensively cropped land fallow to restore soil fertility, however, it can increase both surface and landslide erosion if practiced on steep hillsides. Intensive cultivation may decrease the infiltration capacity of soils, thereby increasing runoff and surface erosion during storms (e.g., Roose and Ndayizigiye, 1997). Additionally, mass wasting may increase due reductions in rooting strength (Sidle et al., 1985). Because shifting cultivation clears forested hillsides for long periods and because reforestation on abandoned, nutrient-depleted agricultural fields is very slow, the impact of this practice is longer-lived compared to timber harvesting with regeneration. When fire is used to clear forested sites (i.e., slash and burn), additional erosion may occur.

Few studies have assessed the direct effects of recreation on hydrologic and erosion processes in tropical Asia, although inferences have been made to such impacts. In Pulau Penang, Malaysia, a mountainous island that has undergone rapid urbanization, results from a one-year catchment study provide some insights into the magnitudes of cumulative effects of recreational pressures on sediment losses (Wan Ruslan, 1997) (Table 1). Erosion loss from the upper catchment that was cleared for crops and orchards (with roads) was 9.1 t $ha^{-1}yr^{-1}$

Table 1. Soil erosion from various land uses in Southeast Asia and similar environments

Area	Methods/ Slope	Cover/treatment	Erosion t ha^{-1}yr^{-1}	References
Southeast Asia: Pen. Malaysia, Sabah, Java, & Thailand	Catchment & plot exp. Various slopes	Undisturbed natural and secondary rainforest	0.01 – 3.12	Morgan & Finney 1982; Douglas et al. 1992; Sinun et al. 1992; Baharuddin & A. Rahim 1994; Wan Ruslan 1997
Sabah	Catchment study	Logged lowland dipterocarp rainforest: 1. During and immediately after logging 2. 5 – 6 years after logging, after regeneration	 1. 16 2. 5.9	Chappell et al. (in press)
Peninsular Malaysia	Catchment Plot experi-ments erosion features	Logged tropical rainforest: 1. selective logging 2. logging road (1st year after logging) 3. skid trail (1st year after logging) 4. logging road (first 16 months after logging) 5. skid trail (first 16 months after logging)	 1. 0.3-0.4 2. 13.3 3. 10.1 4. 272 5. 275	Baharuddin & A. Rahim 1994 Baharuddin et al. 1995 Sidle et al. in press
Baybay, Leyete, Philippines	Plots; 50% slopes	1. Bare 2. Up/down slope cultivation: corn, sweet potato 3. same crops + contour cultivation with hedges (no intercropping) 4. same as 3 w/ rotation/intercropping, groundnut	1. 68.7 2. 38.1 3. 18.6 4. 2.7	Presbitero et al. 1995
Laguna, Philippines	Plots; 14-21% slopes	Corn & mungbean with: 1. Up/down slope cultivation 2. Hedgerow alley cropping; contour till 3. same as 2 but with mulch residue 4. Alley cropping + no till + mulching	 1. 140.3 2. 23.0 3. 2.8 4. 1.8	Paningbatan et al. 1995
Northern Mindanao, Philippines	Plots; 35-44% slopes	Cabbage, tomato & corn) with: 1. Up/down slope cultivation 2. Contour planting 3. Strip cropping 4. Contour hedgerows of asparagus, pineapple, pigeon-pea, & lemongrass	 1. 65.3 2. 37.8 3. 43.7 4. 45.4	Poudel et al. 1999
Camaron Highlands Malaysia	Air photo assessment	Mixed vegetables with tea on prepared terraces (large area)	24	Midmore et al. 1996
Khon Kaen, Thailand	Plots; 3.6% slopes	Rozelle (fiber crop) with: 1. Up/down slope cultivation 2. Hedgerow alley cropping; contour till 3. same as 2; residues mulched 4. same as 3 + no till 5. bare soil; no fiber crop	 1. 2.8 2. 3.0 3. 1.5 4. 0.3 5. 48.4	Sombatpunit et al. 1995
Upper Mae Tang River Basin, NW Thailand	Small plot exp. 21.4% slopes	Rice paddy	3.9	Nishimura et al., 1997
Malaysia	Various	Oil palm plantations	7.7 – 8.9	Morgan & Finney 1982
Pulau Pinang, Malaysia	Catchment; Various slopes	1. orchards, agricultural crops + roads 2. urbanization/recreation	1. 9.1 2. 30.9	Wan Ruslan 1997
Sunmberjaya, Sumatra Indonesia	Plots; 27% slopes	"Sun" coffee plantation with: 1. No ground cover 2. *Paspalum* ground cover 3. Natural weed ground cover	 1. 10.7 2. 0.14 3. 1.3	Rosadi et al. 1999; Oki et al. 1999
Southern Minanao, Philippines	Plots; steep slopes	Agroforestry: vegetable crops interplanted between double contoured rows of N-fixing shrubs & trees	3.4	Tacio 1993
East Coast of Peninsular Malaysia, Kemaman (south Terengganu)	Large plots; 17.6% slopes	Agroforestry: Cocoa, shade trees (*Gliricidia*) and 1. Intercropped w/ banana; bare ground 2. same as 1 w/ legume ground cover 3. Monocropping (no banana); bare soil 4. Monocropping; legumes 5. Bare soil; no crops	 1. 69.7 2. 3.4 3. 11.2 4. 1.0 5. 120.7	Hashim et al. 1995

compared to 30.9 t $ha^{-1}yr^{-1}$ in the rapidly urbanizing lower catchment. These losses are particularly notable since they are from catchment studies, not plots. Erosion loss from a nearby undisturbed catchment on the island was 1.02 t $ha^{-1}yr^{-1}$. Effects of such large-scale recreation are difficult to assess because tourism includes a multitude of infrastructures, all of which impact erosion and hydrologic processes to some degree, but which are difficult to separate from other anthropogenic impacts. The Cameron Highlands in Peninsular Malaysia is another example of where development pressures related to tourism (e.g., new roads, hotel development, horticulture) have caused many landslides and severe surface erosion. The scope of outdoor recreation in Southeast Asia has greatly expanded in the past two decades, particularly coastal tourism, which has resulted in the destruction of many coastal and near shore forests. Large coastal sediment plumes detected on satellite images attest to the regional scale of soil loss following land clearance and development (Gupta, 1993).

Recent Water-Related Issues in Southeast Asia

In the past few years, there have been a number of flood disasters in Southeast Asia. Most severe were the floods in central Vietnam in 1999 that claimed more than 700 lives and caused the evacuation of more than 25,000 households. Rainstorms in late October and early November of 1999 caused catastrophic flooding in the central Vietnam provinces and, just as relief efforts were underway, new flooding from heavy rainfall in the first week of December occurred. The total property damage likely exceeded 300 million USD.

During 2002, many water-related disasters have occurred in the region. In February, major flooding and associated landslides in Java (including Jakarta) killed more than 125 people, and destroyed about 1200 km^2 of rice fields. These flood losses were at least as high as those ($\approx$ 200 million USD) during the devastating May 1998 floods in Java that caused widespread looting and arson and helped topple the former President Suharto regime. A prolonged drought during the usual rainy season affected many of the southern Cambodia provinces in 2002, with more than half a million people facing food shortages. Simultaneously, the Mekong River reached flood stages along the Cambodian-Laotian border, killing at least 30 and affecting 1.5 million people. Widespread flooding also occurred in Myanmar with more than 4000 km^2 of farmland inundated by floodwaters. Throughout the Philippines, monsoon rains and typhoons during the summer of 2002 caused extensive flooding and landslides, killing at least 15 people and destroying more than 370 km^2 of farmland. The death toll from widespread flooding in northern Thailand reached 170 by the end of August 2002; damage was estimated at $\approx$ 32 million USD. Although many organizations have earmarked ‘deforestation’ as the main culprit for these floods, better causal links between spatially distributed on-site disturbances and hydrologic response need to be developed to better evaluate flooding.

In a region of economically developing nations, Singapore is an enigma as a rather wealthy island state. Most of Singapore’s water is piped in from neighboring Malaysia. A lesser percentage of the water supply (unspecified by the Public Utilities Board) is captured in reservoirs on the island. Thus, Singapore has a vested interest in the important regional issues related to water resources because of its dependence on Malaysia for a sustainable potable water supply (Ong, 1999). Seemingly, Singapore has a responsibility to minimize environmental impacts and foster high standards for land and water stewardship in foreign areas affected by their water withdrawals. Because of the scarcity of land and high population density in Singapore, the current protected catchments in the central part of the island provide a fixed but limited potable water supply (Ong, 1999). However, these reservoirs do not appear to be efficiently managed. During a recent drowning incident (3 people killed) in April 2002 near the outlet of Kranji Reservoir, it was revealed that the Public Utilities Board (PUB) authorizes releases of water stored in the reservoirs to the sea during storms, rather than pumping this water into alternative storage sites when reservoirs are near capacity. While PUB denied any connection between the releases of water at Kranji Reservoir with the off-shore drownings, the practice releasing stored fresh water to the sea and, at the same time, purchasing water from Malaysia is clearly an unsustainable use of this resource. During the past two decades of rapid growth, Singapore has not elected to adopt water conservation measures such as 'gray water' recycling systems in apartment and business complexes. Further puzzling, is the fact that Singapore is considering expensive high-technology solutions (e.g., desalinization, filtration) to their water crisis. It is apparent that Singapore needs to embrace a broader regional perspective on water use to achieve sustainability of this resource.

References

Baharuddin K, Abdul Rahin N. 1994. Suspended sediment yield resulting from selective logging practices in a small watershed in Peninsular Malaysia. *Journal of Tropical Forest Science* 7(2): 286-295.

Baharuddin K, Mokhtaruddin, AM., Nik Muhamad M. 1995. Surface runoff and soil loss from a skid trail and a logging toad in a tropical forest. *Journal of Tropical Forest Science* 7(4): 558-569.

Chappell NA, Douglas I, Hanapi JM, Tych W. 2003. Sources of suspended sediment within a tropical catchment recovering from selective logging. *Hydrological Processes* 17: (in press)

Douglas I, Bidin K, Chappell NA, Sinun W, Walsh RPD. 1999. Role of extreme events in the long-term patterns of erosion from selectively logged tropical forest. *Philosophical Transactions of the Royal Society of London, Series,* B, 354: 1749-1761.

Douglas, I, Spencer, T, Greer, T, Bidin, K, Sinun, W, Wong, WM, 1992. The impact of selective commercial logging on stream hydrology, chemistry and sediment loads in the Ulu Segama rain forest, Sabah, Malaysia. *Philosophical Transactions, Royal Society of London,* B, 335: 397-406.

Economic and Social Commission for Asia and the Pacific (ESCAP). 1999. *Regional cooperation in the twenty-first century on flood control and management in Asia and the Pacific*, ESCAP, United Nations, NY, 216 p.

Fischer A, Vasseur L, 2000. The crisis in shifting cultivation practices and the promise of agroforestry: a review of the Panamanian experience. *Biodiversity and Conservation* 9: 739-756.

Fox, J, Krummel, J, Yarnasarn, S, Ekasingh, M, Podger, N. 1995. Land use and landscape dynamics in northern Thailand: assessing change in three upland watersheds. *Ambio* 24: 328-334.

Gupta A. 1993. Accelerated sediment production and its effects: examples from Southeast Asia. *In*: Environmental Issues in Development and Conservation (C. Briffett & L.L. Sim, eds.), Singapore, pp. 121-129.

Hashim GM, Ciesiolka CAA, Abdullah Yusoff W, Wahab Nafis A, Radzali Mispan M. Rose CW, Coughlan KJ. 1995. Soil erosion processes in sloping land in the east coast of Malaysia. *Soil Technology* 8: 215-233.

Inamura F, Dang VT. 1997. Flood and typhoon disasters in Viet Nam in the half century since 1950. *Natural Hazards* 15: 71-87.

Maita H, Nagai T, Vudhivanich V, Kwanyuen B, Ngernprasertsri S, Tangtham N, Lorsirirat K. 1998. Analysis of suspended sediment yield and watershed characteristics in Mae Klong River Basin. *In*: Proc. of the Workshop on Sustainable Development of Agricultural Infrastructure and Organizational Management of Chao Phraya and Mae Klong Basins, pp. 38-56, Faculty of Engr., Kasetsart Univ., Bangkok, Thailand.

McMorrow J, Abdul Talip M. 2001. Decline of forest area in Sabah, Malaysia: relationship to state policies, land code and land capability. *Global Environmental Change* 11: 217-230.

Midmore DJ, Jansen HGP, Dumsday RG. 1996. Soil erosion and environmental impact of vegetable production in the Cameron Highlands, Malaysia. *Agriculture, Ecosystems and Environment* 60: 29-46.

Morgan, R.P.C., Finney, H.J., 1982. Stability of agricultural ecosystems: validation of a simple model for soil erosion assessment, International Institute for Applied Systems Analysis Collaborative Paper CP-82-76.

Nishimura K, Shimada, T, Yamada T, Ishikawa Y, Sukapunnaphan T. 1997. Hydrological characteristics influenced by deforestation in tropical areas: the Mae Tang River basin, Thailand. *IAHS Publication no. 245*: 125-134.

Ong HS. 1999. An overview of Singapore's water supply. *In*: Sustainable Cities in the 21st Century (A.F. Foo & B. Yuen, eds.), pp. 9-12, Faculty of Architecture, Bldg. & Real Est., Nat. Univ. of Singapore, Singapore.

Paningbatan, E.P., Ciesiolka, C.A., Coughlan, K.J., Rose, C.W., 1995. Alley cropping for managing soil erosion of hilly lands in the Philippines. Soil Technology 8, 193-204.

Poudel, D.D., Midmore, D.J., West, L.T., 1999. Erosion and productivity of vegetable systems on sloping volcanic ash-derived Philippine soils. Soil Science Society of America Journal 63, 1366-1376.

Presbitero, A.L., Escalante, M.C., Rose, C.W., Coughlan, K.J., Ciesiolka, C.A., 1995. Erodibility evaluation and the effects of land management practices on soil erosion from steep slopes in Leyte, the Philippines. Soil Technology 8, 205-213.

Roose E, Ndayizigiye F. 1997. Agroforestry, water and soil fertility management to fight erosion in tropical mountains of Rwanda. *Soil Technology* 11: 109-119.

Rosadi B, Afandi, Manik TK, Senge M, Oki Y, Adachi T. 1999. Evaluation of crop factor in coffee plantation with different cover crops. *In*: Toward Sustainable Agriculture in Humid Tropics Facing 21st Century, Proc. of an Intl. Symp., Bandar Lampung, Indonesia, September 27-28, 1999, pp. 381-386.

Sidle RC. 1992. A theoretical model of the effects of timber harvesting on slope stability. *Water Resources Research* 28: 1897-1910.

Sidle RC, Dhakal AS. 2002. Potential Effects of Environmental Change on Landslide Hazards in Forest Environments. In: *Environmental Change and Geomorphic Hazards in Forests* (R.C. Sidle, ed.), IUFRO Research Series, vol. 9: 123-165, CAB International Press, Oxen, UK.

Sidle RC, Hornbeck JW. 1991. Cumulative effects: A broader approach to water quality research. *Journal of Soil and Water Conservation* 46: 268-271.

Sidle RC, Pearce AJ, O'Loughlin CL. 1985. *Hillslope stability and land use*, Water Resources Monograph, Vol. 11, American Geophysical Union, Washington, DC, 140 pp.

Sidle RC, Sasaki S, Otsuki M,Noguchi S, Abdul Rahim N. 2003. Sediment pathways in a tropical forest: effects of logging roads and skid trails. *Hydrological Processes* 17: (in press).

Sinun, W., Wong, W.M., Douglas, I., Spencer, T., 1992. Throughfall, stemflow, overland flow and throughflow in the Ula Segama rain forest, Sabah, Malaysia. Philosophical Transactions, Royal Society of London, B, 335, 389-395.

Sombatpanit, S., Rose, C.W., Ciesiolka, C.A., Coughlan, K.J., 1995. Soil and nutrient loss under rozelle (*Hibiscus subdariffa* L. var, *altissima*) at Khon Kaen, Thailand. Soil Technology 8, 235-241.

Swanston DN, Schuster RL. 1989. Long-term landslide hazard mitigation programs: structure and experience from other countries. *Bulletin of the Association of Engineering Geologists* 26: 109-133.

Tacio HD. 1993. Sloping Agricultural Land Technology (SALT): a sustainable agroforestry scheme for the uplands. *Agroforestry Systems* 22: 145-152.

Walling DE. 1983. The sediment delivery problem. *Journal of Hydrology* 65: 209-237.

Wan Ruslan, I., 1997. The impact of hill land clearance and urbanization on runoff and sediment yield of small catchments in Pulau Pinang, Malaysia. *IAHS Publication No. 245*: 91-100.

Ziegler AD, Sutherland RA, Giambelluca TW. 2000. Runoff generation and sediment production on unpaved roads, footpaths and agricultural land surfaces in northern Thailand. *Earth Surface Processes & Landforms* 25(5): 519-534.