Practical hydrological protection for tropical forests: the Malaysian experience

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Synergies between hydrological research and certification of natural forest management in the humid tropics give rise to water protection standards that are also partially applicable to forest plantations and agroforestry systems.

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Stream-gauging structure within the buffer zone of the selectively logged Baru experimental watershed, East Malaysia

Water resources are essential for people, ecology and economic development in both forested and non-forested areas. As most tropical natural forests escape contamination by artificial chemicals such as those in urban landscapes or leached from intensive agriculture, the quality of their water is often the least hazardous to human health. Paradoxically because of the inherent quality of the natural forest environment, standards of environmental protection in selectively managed natural forests, including hydrological requirements, are often far tougher than those applied in non-forest lands.

Guidelines for hydrological protection during forestry operations are plentiful in the global forestry and hydrology literature (e.g. Megahan, 1977; Cassells, Gilmour and Bonell, 1984; FAO, 1996, 1999; Sabah Forestry Department, 1998; Hamilton, 2004; Thang and Chappell, 2004). They include measures to protect soil water and nutrient status, the recharge of major aquifers, microclimate and evaporation, and river resources. Some of the published guidelines, however, lack a credible scientific basis, some are contradictory, some are not viable economically, some are only directly applicable in temperate environments, some are so complex that they require a Ph.D. in hydrology to apply, and some even have negative impacts on certain aspects of the hydrological system.

This article reviews the hydrological basis of standards set within the system of Malaysian Criteria and Indicators for Forest Management Certification (MC&I), which has been used to certify forestry practices in 4.7 million hectares of permanent reserved forests in four states of Peninsular Malaysia: Selangor, Pahang, Terengganu and Negeri Sembilan. The inclusion of hydrologi-

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cal standards in the certification system ensures their universal application in all certified forest management units. The article identifies what the authors consider to be the single most important hydrological standard – the watercourse buffer zone – and considers its application outside certified natural forests, which is important because many tropical natural forests are being converted with no certified hydrological standards to agriculture, agroforestry and urban landscapes. The lessons learned in Malaysia's relatively well-developed forestry sector, particularly those supported by primary hydrological research, may be useful for wider application in other tropical countries.

STANDARDS FOR HYDROLOGICAL PROTECTION

The Malaysian Criteria and Indictors for Forest Management Certification (Thang, 1996; MTCC, 2001, 2004) contain standards of performance or verifiers used to benefit the hydrological system through protection of the forest canopy and the ground (soil and water). Some of the standards are directly aimed at hydrological protection, while others, notably those related to minimizing collateral canopy damage, have an indirect impact on hydrological phenomena. For example, canopy disturbance caused by the opening of forest roads and subsequent selective harvesting can be minimized by reduced-impact logging (Pinard, Putz and Tay, 2000) to reduce damage to the remaining stand, especially the younger stems, and to biodiversity (Thang, 1987). This has the indirect hydrological benefit of reducing the change in the forest microclimate, minimizing declines in evapotranspiration (Nik and Harding, 1992; Chappell *et al*., 2004b), while also reducing biomass loss and its impact on nutrient and carbon leakage (Yusop, 1989).

Quantitatively, river sediment load and turbidity are the hydrological features most affected by commercial harvesting in tropical natural forests, as shown by a recent review (Chappell *et al*., 2004b). Recent research, primarily in Malaysia, has shown that erosion, collapse of hollow-log culverts (along feeder roads and secondary haul roads) and landslides can increase river sediment loads 5- to 50-fold directly after selective harvesting (Chappell *et al*., 2004a,b). The elevated sediment loads impair fish habitat, heighten flood risk downstream, increase the costs of treatment for potable water supplies and lead to the inundation of offshore coral beds.

Forestry measures that can reduce these changes and promote rapid recovery are consequently the most important standards for hydrological protection. In production forests of Malaysian permanent reserved forests, erosion, log-culvert collapse and landslides are primarily related to ground disturbance along skid trails (i.e. routes used by tracked skidders in log yarding) and haul roads (i.e. engineered roads used by timber lorries) by blade cutting, compaction, slope cutting and stream crossings. Canopy opening is only a secondary factor (Chappell *et al*., 2004a). While the Malaysian criteria and indicators encourage minimization of the number of skid trails and haul roads, the relationship between the density of road or trail networks and river sediment inputs is complex, since much of the road and trail network is disconnected from permanent watercourses (streams and rivers) (Sidle *et al*., 2004). However, where sediments reach permanent watercourses, sediment problems are easily transferred downstream over great distances.

The most hydrologically sensitive parts of the landscape are the watercourses with perennial flows and the road or trail crossing points (Chappell *et al*., 2007). To comply with the criteria and indicators for Peninsular Malaysia, along all permanent watercourses it is necessary to demarcate a buffer zone 10 m wide (5 m either side of the channel) in which vehicle access and tree cutting are restricted only to stream or river crossings with bridges or culverts.

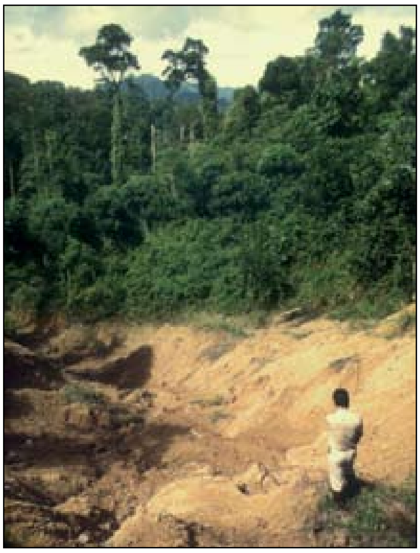
Other criteria and indicator systems differ in the recommended placement and dimensions of such buffer zones. Some foresters have suggested that ephemeral channels, which by definition flow only during storms, should be protected (FAO, 1999; Cassells and Bruijnzeel, 2004), while others suggest that protection is unnecessary for watercourses narrower than 5 m (Sist, Dykstra and Fimbel, 1998). In the humid tropics where drainage density (the length of watercourse with permanent flows per unit watershed area) is very high, if buffer zones were required for ephemeral channels they could take up 40 percent of the landscape (Thang and Chappell, 2004). Moreover, Chappell *et al*. (2004a) have shown that the greatest unit area input of sediments into channels is along first- to third-order channels (i.e. permanent streams to small rivers). This means that it is not critical to protect ephemeral channels, but it is important to buffer all permanent rivers and streams. This research thus endorses the hydrological standard universally applied within the forest reserves of the Malaysian states of Selangor, Pahang, Terengganu and Negeri Sembilan.

Road-initiated landslides in an experimental watershed of Ulu Segama Forest Reserve, East Malaysia, were observed to travel 150 and 500 m (Chappell *et al*., 2004a). Although the haul roads in this area were located and built correctly, they were closer than this to permanent streams (see Table), indicating that sediment generated by major failures of cut-and-fill materials can reach permanent channels.

Mean distance from haul roads to permanent streams, Baru experimental watershed, Ulu Segama Forest Reserve, East Malaysia

Stream type	Distance *(m)*
First-order streams	87
Second-order streams	158
Third-order streams	255

Source: Chappell *et al*., 2004a.



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500 m landslide below a secondary haul road (Baru experimental watershed) shortly after failure

Thus, while the buffer zone may protect water by preventing skidders from using the watercourses as transport routes, it is not expected to trap sediments from upslope. Ziegler *et al.* (2006), working in agricultural landscapes in northern Viet Nam, have similarly questioned the effectiveness of buffer zones, even those up to 50 m wide, in trapping sediments. Bren (2000) and Chappell *et al*. (2006) have implied that prediction of the trap efficiency of buffer zones or the location of disturbance-sensitive streamside soils is currently too uncertain for practical application of variable-width buffer zones in forestry.

While skidders are prevented from using watercourses as routes within reduced-impact logging areas (e.g. Sabah Forestry Department, 1998), where skid trails cross permanent watercourses they have the potential to be significant points of input of sediments to streams and thence to rivers. The criteria and indicators for Peninsular Malaysia recommend various ways of crossing streams using either culverts or bridges. Hydrological research is needed to ensure that the allowed crossings, including the use of hollow logs which may collapse after a few years, are both hydrologically sound and cost effective in the long term. Helicopter and skyline yarding, tested on steep terrain in East Malaysia (Mannan and Awang, 1997), has the potential to reduce significantly the number of tracks in the forest by eliminating skidder use from these areas (FAO, 1996). While reducing the number of stream crossings is expected to decrease river sediment loads, direct evidence of the watershed-scale impact of these different yarding methods in the tropics has yet to be measured. The main haul roads, with concrete stream culverts, engineered bridges and gravel surfaces, are designed in such a way that their impacts on sediments are unlikely to persist long after the construction phase (Forestry Department Peninsular Malaysia, 1999).

Certification within the forest reserves of the states of Selangor, Pahang, Terengganu and Negeri Sembilan has encouraged the use of improved logging practices supported by fundamental hydrological research (Thang and Chappell, 2004). Land managers should ask if the application of these findings could be of value also for hydrological protection during forest clearance or the establishment of tropical timber plantations or agroforestry systems.

PROTECTION IN UNCERTIFIED NATURAL FORESTS AND PLANTATIONS

As described above, for protection against the largest hydrological changes associated with tropical natural forestry, establishing a 10 m wide buffer zone along all permanent streams and rivers during forest harvesting operations is effective. In forests where it would be economically unaffordable to meet all the physical environmental standards required for certification by international assessors, this single standard, if followed strictly, would provide some assurance of water resources protection in natural forests.

In many areas where conversion from natural forest to forest plantations, agroforestry or other land uses is planned, it may not be considered logistically feasible to prevent most tree cutting in all permanent streamside zones. However, research has shown that application of the buffer designation used within Peninsular Malaysia's MC&I would restrict forest cutting (except at "well managed" stream crossings) from only 7 percent of the landscape for watercourse protection (Thang and Chappell, 2004) – less than the area of forest reserves normally gazetted for protection of biological and physical resources. Moreover, such a buffer offers some protection for the most hydrologically sensitive small streams (i.e. less than 5 m channel width) which are the most numerous channels in the landscape but are the least protected in most tropical forestry systems (Thang and Chappell, 2004; Chappell *et al*., 2007). If these "fingers" of natural forest cannot be kept, considerable hydrological benefits would still be obtained by minimizing skidder vehicle use within demarcated 10 m wide buffer zones alongside all permanent streams. Maintaining these ribbons of natural forest would also protect the aquatic habitat by reducing disturbances to stream-water temperature regimes associated with forest clearance (Davies and Nelson, 1994). Indeed, draft criteria and indicators for Malaysian forest plantations (MTCC, 2007) call for the 10 m buffer along all streams during conversion and after plantation establishment.

In agroforestry and intensive agricultural systems and in some forest plantation systems, the use of pesticides and artificial fertilizers greatly heightens the need to define and protect watercourses. In saturated streamside zones, where chemicals can reach streams quickly because they are generally carried more rapidly over land than through subsurface flow routes, prohibiting the use of chemicals is the best way to prevent their becoming a human health hazard; here streamside buffer zones with zero direct chemical applications may need to be wider than 5 m to be effective (McKergow *et al*., 2004). The presence of natural forest within these streamside zones also reduces the likelihood of overland flow by enhancing evaporation and infiltration, and enhances the utilization of nutrients leaching from upslope areas, thereby reducing losses of chemicals into channel watercourses (McDowell, 2001).

CONCLUSIONS

The two decades of research on forestry practices and hydrological processes in Malaysia's natural forests that underlie the certification of hydrologically sound forestry practices in forest reserves of the states of Selangor, Pahang, Terengganu and Negeri Sembilan offer findings pertinent to sustainable forest management in other countries in the humid tropics. Reduced-impact logging techniques within several Malaysian states help maintain the hydrological functioning of rivers in natural forests (e.g. Nik and Harding, 1992; Yusop, 1989; Chappell *et al*., 2004b; Thang and Chappell, 2004). These rivers are of considerable importance for potable water supply because they are free from artificial chemical contamination. It is by influencing sediment load, however, that forestry practices have the largest impact on rivers in natural forests maintained for long-term timber production (Chappell *et al*., 2004b). The MC&I hydrological standards of performance for Peninsular Malaysia contain measures to mitigate impacts on sediment load (Thang and Chappell, 2004).

Despite the recent intensification of hydrological research within tropical natural forests (Bonell and Bruijnzeel, 2004), the impact of many forestry practices on tropical hydrological systems remains poorly quantified. Amounts and sources of river sediments in particular are extremely difficult to determine with accuracy because of the episodic nature of sediment delivery, the heterogeneity of the sediment sources and the high technological requirements for such measurements (Douglas *et al*., 1999; Chappell *et al*., 2004a). Despite these uncertainties, it is clear that small permanent streams – because they comprise the greatest length of perennial watercourse (Chappell *et al*., 2007) and receive the greatest sediment inputs per unit watershed area (Chappell *et al*., 2004a) – all need protection. Within certified forestry systems in Peninsular Malaysia, the placement of narrow buffer zones on small permanent streams:

- restricts skidder drivers from using small channels as routes, thereby reducing channel erosion;
- requires culverts or bridges to be placed at all road and trail crossings of permanent streams, reducing channel disturbance and disconnecting some slope sediment pathways from the channels;
- maintains canopy cover and hence microclimate along stream corridors.

These considerable benefits can be gained by limiting cutting and vehicle access from a relatively small area (less than 10 percent) of the landscape.

While few studies have addressed the hydrological impacts of forestry within tropical natural forests and associated mitigation strategies, almost none have addressed river turbidity for tropical plantations (Bonell and Bruijnzeel, 2004; Chappell, Tych and Bonell, 2007). There is an urgent need to extrapolate the findings of turbidity studies from tropical natural forests to watersheds with plantations, and to initiate new watershed-scale studies on river turbidity and water quality within timber or oil-palm plantations. Hydrological research is also needed to compare the value and economic impacts of buffer zones of different sizes within areas being converted to timber plantations and agroforestry systems. ◆

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Buffer zone in the Baru experimental watershed, 17 years after the first phase of selective logging

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