

Role of agroforestry in maintenance of hydrological functions in water catchment areas

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After a century of attention for 'watershed management, there is still a remarkable lack of clear criteria and indicators of the hydrological functions that society expects to be met from water catchment areas. The lack of realistic expectations leads to large public investments in 'reforestation' that are unlikely to achieve value for the money spent. Hydrological functions of watersheds, given the rainfall that the area receives, include the capacity to 1. Transmit water, 2. Buffer peak rain events, 3. Release water gradually, 4. Maintain water quality and 5. Reduce mass wasting (such as landslides).

The relation between full ('forest') and partial ('agroforestry') tree cover and hydrological functions in this sense involves changes at different time scales, and tradeoffs between total water yield and the degree of buffering of peak river flows relative to peak rainfall events. The role of land use can be analyzed in terms of changes in evapotranspiration linked to the presence of trees, infiltration linked to conditions of the soil and the rate of drainage linked to the drain network in the landscape. Models that link the dynamics of macropores in the soil and the space-time characteristics of rainfall to the dynamics of river flow can fairly well reproduce the time series of data from intensively studied (sub)catchments. We may thus have some confidence in their use for extrapolation to future land use change scenarios. A major lesson from the intensive studies is that forms of farmer-managed agroforestry can maintain the hydrological functions that society expects from 'protection forest' ('hutan

lindung'), while providing income for rural population densities in the range 50 - 100 persons km⁻². These 'kebun lindung' forms of land use lack recognition, so far, and conflicts over access to and stewardship of state forest lands remain a major obstacle. If the multi-stakeholder negotiation of the use and management of upper watersheds could become more based on functional criteria and transparent indicators, these 'kebun lindung' forms of land use could reduce the perception of an unavoidable environment - development conflict.

Introduction

The concept of watershed management to secure a steady supply of water of good quality is probably as old as irrigation agriculture. Yet, there is still a remarkable lack of clear criteria and indicators that represent realistic expectations based on well-established cause-effect relationships and the multiple interests of stakeholders involved. Watershed management is, in the public debate, often directly linked to the degree of 'forest cover' with the assumption that 'reforestation' can, in essence, undo the negative impacts of deforestation. There is still considerable confusion over and lack of reference to empirical data sets on the question whether river flow at an annual basis and specifically in the dry season will increase or decrease after forest conversion or reforestation.

The term 'sustainable management' has become a cliché that does not recognize the need for farmers to keep adjusting their enterprise to the changing opportunities in markets and does not provide a method to monitor progress and success in achieving the environmental objectives. Realities of rural population densities and their livelihood needs and expectations are often left out of discussions on desirable land cover forms, contributing to large discrepancies between the colours on the planners' land use maps and the situation on the ground.

In this contribution we propose a set of criteria and indicators for the hydrological functions of catchment areas that can be used to evaluate options for sustainable management of such area, and focus on the potential of agroforestry to reconcile productive land use with the protection of these hydrological functions.

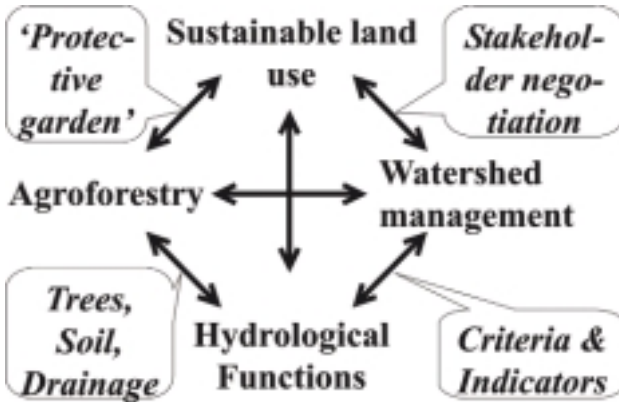


Figure 1. Relationships between sustainable management of water catchment areas, hydrological functions and agroforestry discussed in this contribution.

Development of forest and water concepts in Indonesia

The general public and policy perception of 'watershed protection' specifies a desirable condition ('forest') for the upper watershed and associates any flooding event to a loss of forest cover in the hills and mountains, with tree planting as the knee-jerk rehabilitation measure. An 'ecohydrology' approach involves more than a focus on the degree of forest cover in the upper watersheds, as the quantity, timing and quality of water flows is determined by the land cover and land use in the whole landscape. In Indonesia it seems that the public and policy debate has not progressed much since De Haan (1936) wrote in his 'contemplations on the issue of forest reserves':

"There has been too much emphasis on the contrast between **"forest"** and **"non-forest"**. One often supposed that as long as a certain percentage of an area was reserved as 'protection forest', agriculturalists outside of that area could do as they wished. Nothing is further from the truth. The difference in hydrological behaviour between a montane forest and for example a rubber garden is certainly much smaller than that between this rubber garden and the cropped fields of a smallholder."

Kartasubrata (1981) summarized the development of ideas about forest and water in Indonesia, as they were reflected in debates during

the colonial era. As the debate still resonates today, it may be interesting to see the arguments as phrased at that time. The debate heated up with a statement of Heringa (1939) who pleaded for a substantial increase of forest cover on Java, both for the production of timber, resin, turpentine and tannin, as well as for the hydrological significance of forests. On the island of Java with its high volcanoes the rivers have such a strong fall that in the west monsoon the rainwater flows rapidly into the sea in its force transporting much fertile soil and mud from the fields and from the riverbeds to be deposited into the sea. Heringa formulated a theory that stirred up much of the debate, when he said:

"The forest works as a sponge; it sucks up the water from the soil in the wet season, to release it gradually in the dry monsoon at the time when there is shortage of irrigation water. Decrease of forest cover therefore will bring about decrease of discharge during the East monsoon ('dry season') and cause shortage of the needed irrigation water. Therefore, a balance is needed between forest condition and output of agricultural lands (rice fields). Consequently one has to determine a minimum forest percentage for every catchment area".

Roessel (1939) applauded the idea of extension of industrial forests, however, he criticized the use of hydrological arguments to justify reforestation. He posed the 'infiltration theory' that emphasized that percolation of water through the subsoil produces spring water, not the forests as such. Coster (1938) working at the Forest Research Institute in Bogor provided quantitative data and suggested a synthesis: vegetation determines recharge to the 'sponge', but most water is held in the subsoil, not in the forest as such.

In much of the current debate the more synthetic viewpoints of Coster (1938), with both positive and negative impacts of trees on river flow have not yet been understood, and existing public perceptions and policies are based on Heringa's point of view. The concept that a '**Kebun lindung**' can be as functional in terms of infiltration and hydrological impact as a '**Hutan lindung**' still appears to be novel today, as the dichotomy between forests and all non-forest land use persists in the regulatory frameworks as well as general perceptions. The recent Chambéry Declaration on "Forests & Water" in the context of the International Year of Fresh Water 2003 appears, yet again, to imply that 'non-forests' cannot meet any of the 'forest watershed functions'.

Table 1. Three perspectives on the relationship between forest cover and watershed functions (modified from Kartasubrata, 1981).

Aspect	Forests as sponge theory (Heringa, 1939)	Infiltration theory (Roessel, 1939)	Synthesis and quantification (Coster, 1938)
Dry season river flow	Depends on forest cover	Depends on geological formation	Vegetation determines soil permeability
Required forest area for hydrological functions	A minimum required fraction can be calculated from the area of rice fields to be irrigated with dry season flow	There is no minimum forest cover	Discharge of springs depends on the amount of water that percolates into the soil <i>minus</i> the loss of water because of evaporation.
What to do if forest target is not met?	Farm land of farmers and agricultural estates has to be purchased and reforested	Reforestation is only carried out if certain soil types expose susceptibility to erosion, but then after other measures, such as terracing, catching holes and soil cover have proved insufficient	Depends on elevation . Lysimeter measurements indicated that the evaporation of a free soil surface 1200, 900 and 600 mm per year at locations with an elevation of 250, 1500 and 1750 m a.s.l., respectively
Forests or ground cover?	All soil types are equal; afforestation with industrial wood species has the same hydrological effect as natural forest and is (always) better than agricultural estates	An agricultural estate which succeeds to ban superficial run off by terracing etc. or soil cover, is hydrologically more valuable than an industrial timber plantation, where surface run off can still take place, for example, because of steep slopes, poor undergrowth or poor humus formation	Measurements by the Forest Research Institute showed that well maintained tea, coffee, rubber and kina plantations are from a hydrological point of view nearly the same as forests (planted or natural) but superior to agricultural fields. Fires in the grass wilderness in the mountains stimulate water run off and erosion.
Scope of reforestation	All problems with 'watershed functions' can be cured with reforestation	Recovery by reforestation can only be expected in cases where superficial run off and erosion can be controlled with good forests. Forests without undergrowth and without good humus formation are usually not sufficient. A soil cover with grass, dense herbaceous or shrubby vegetation, however, will do.	It is probable that afforestation in low lands may decrease the discharge (including that in the dry season), because of the high evaporation rate from the forest; in the mountains the increased infiltration of abundant rain into the soil more than offsets the increased water use by trees.

As explored by Grove (1995), perceptions on the relationships between deforestation, subsequent changes in rainfall, land degradation and siltation of rivers date back to experiences in the Mediterranean region, with the Greek philosopher Theophrastos as one of the earliest written sources documenting these perceptions. The European colonial expansion into the tropics and particularly their experiences in small islands such as Mauritius strengthened perceptions that forests generate rainfall. Yet, hard evidence of a change in documented rainfall as a consequence of deforestation still hardly exists, and the causality of the association between forests and rainfall (rainfall => forest) is generally the reverse of what is perceived (forest => rainfall). A recent re-analysis of rainfall patterns for Indonesia (Kaimuddin, 2000; Rizaldi Boer, pers. comm.), for example, indicates shifts in the isohyets (zones of equal rainfall) in Indonesia, that are not obviously related to local land cover change: some areas that lost forest cover became wetter, other areas that lost forest cover became drier; for Indonesia as a whole average rainfall did not change, despite the considerable loss of forest cover, but there may have been a change in the overall circulation pattern that affects local rainfall. Although at local scale real changes in rainfall may have coincided with real changes in forest cover, there is no convincing evidence to support hypotheses about causal relationships. The way a landscape 'processes' the incoming rainfall, however, does directly depend on the land cover, and the total amount of water, the regularity of the flow and the quality of the water in the streams can be directly affected by changes in cover.

A final quote on this historical section: "Formerly the view was generally accepted, that forests had the tendency to increase rainfall to a large extent. Nowadays this view is combated by many investigators, who deny any appreciable influence; others support the view that the distribution is changed by the forest, and not the total amount of rainfall...." Braak (1929).

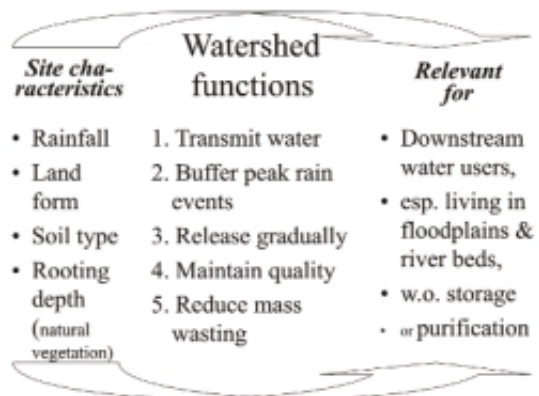
Widely held perceptions of the overriding importance of forest cover for the maintenance of watershed functions in source areas have been questioned over the last decades in hydrological research, and rather than using a 'forest' <=> 'non-forest' dichotomy, have lead to the recognition that the types of land use that follow after forest conversion can make a lot of difference. Land use (including but not restricted to the protection of existing forest cover) in such source areas thus has local as well as external stakeholders and beneficiaries, and increasing demands for

water in the lowlands have often lead to an increased sense of conflict over what happens in the source areas. Yet, upper watersheds in much of the tropics provide a living for large numbers of farmers and rural communities, who have often remained outside of the main stream of development. The consequences of this is an 'upland' - 'lowland' distinction with a strong perception of a conflict of interest: people living in the upper watershed are perceived to 'destroy the watershed functions', where in fact there is no recognition or reward mechanisms for all those situations where their land use protects water resources.

Criteria and indicators

Major aspects of river flow (the total annual water yield, the regularity of flow, frequency of flooding of wetlands, alluvial plains and other areas along the course of the river and availability of water in the dry season) are dominated by rainfall, rather than by the way watersheds operate hydrologically. In order to focus more clearly on the role of the watershed functions per se, we need to tease apart what the contributions of rainfall and terrain (and other site characteristics that are not directly influenced by land use change) are, and what role land cover (that is under direct human influence) plays. We propose a set of criteria for watershed functions that expresses 'outcomes' of measurable properties of rivers relative to inputs of rainfall. The criteria thus focus on 'watershed functions' as modifiable by land cover and land use, given the site characteristics and rainfall pattern that differ from location to location and from year to year, but are not likely to respond to human decisions and actions. The functional relevance of these criteria to stakeholders will vary with their location, role and perspective (Fig. 2). Quantitative indicators of the various criteria can

Figure 2. Five criteria for watershed functions that relate site characteristics to aspects of river discharge that are relevant to specific groups of downstream stakeholders



help inform the stakeholder negotiation process, but not directly lead to a selection of the 'most desirable' or 'least undesirable' scenario.

The criteria can be directly linked to a quantitative understanding of the way the precipitation P is partitioned over river discharge Q and evapotranspiration E in the water balance (Fig. 3). This coupling helps in understanding the logical relationships and inherent tradeoffs between changes in transmittance, buffer and gradual release functions.

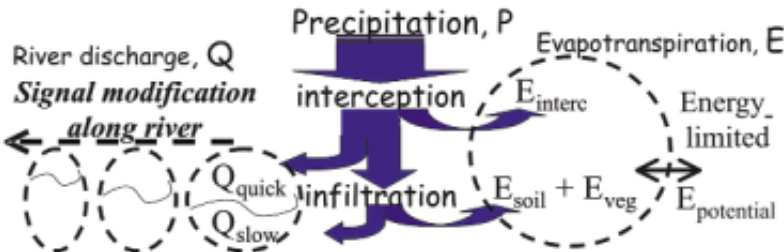


Figure 3. Schematic representation of the partitioning of precipitation in its passage through the canopy, when it reaches the soil surface and after infiltration into the soil

By analyzing the various controls that land cover exerts on the process of canopy interception of incoming rainfall, infiltration of the soil surface and use of water temporarily stored in the soil for evapotranspiration at the soil surface or transpiration by plants, we can understand the outcomes at the level of annual water budgets (Fig. 4).

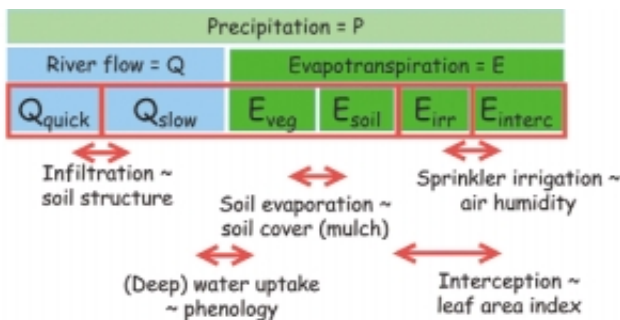


Figure 4. Five controls exerted by land cover and land use on the partitioning of precipitation over river discharge and evapotranspiration

A set of quantitative indicators was developed for the first three criteria (Table 2), that can make use of long term records of rainfall and river flow, and/or be used to summarize results of simulation models. The application of these indicators to data for the Sumberjaya area in Lampung is discussed by Farida and van Noordwijk (2004).

Unit hydrograph – what happens to an ‘average’ drop of rainfall?

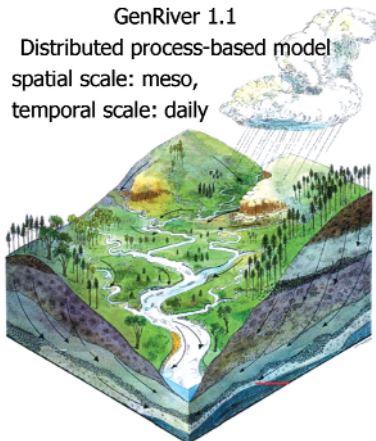
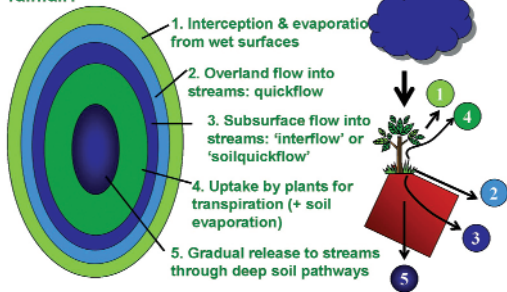


Figure 5. Basic processes represented in the GenRiver model developed at ICRAF and available from www.cgiar.icraf.org/sea

Table 2. Criteria and indicators of hydrological functions as developed by the ASB consortium for assessments in the (sub)humid tropical forest domain.

Criteria	Indicators	Stakeholder relevance	Empirical data P = rainfall, Q = river flow	Water balance model
1. Transmit water	Total water yield (discharge) per unit rainfall	All water users, esp. below reservoirs	daily P & Q	√
2. Buffer peak rain events	2.1a Buffering indicator for peak flows given peak rain events	People living in & depending on river beds and flood-plains	daily P & Q	√
	2.1b Relative buffering indicator, adjusted for relative water yield		daily P & Q	√
	2.1c Buffering peak event		daily P & Q	√
	2.2 Highest of monthly river discharge totals relative to mean monthly rainfall		(hydrograph segregation) (pathway tracers)	√
	2.3 Fraction of total river discharge (1.1) derived from a. overland flow (same day as rain event) b. soil quick flow (1 day after rain event) (compare 3.2)			√ √

Criteria	Indicators	Stakeholder relevance	Empirical data P = rainfall, Q = river flow	Water balance model
3. Release gradually	3.1 Lowest of monthly river discharge totals relative to mean monthly rainfall 3.2 Fraction of discharge (1.1) derived from slow flow (> 1 day after rain event) (compare 2.3a&b)	People depending on water flows in dry season	daily P & Q (hydrograph segregation, tracers)	√ √
4. Maintain water quality	4.1 River water suitability for a. untreated drinking water (incl. bacterial (Escherichia coli) counts, absence of pollutants) b. other domestic use c. industrial use d. irrigation water e. as biological habitat (incl. BOD, COD, biological indicators) 4.2 Annual net export per contributing area of a. sediment b. nutrients (N, P) c. heavy metals d. pesticide and derivatives ('active ingredient') 4.3 Difference between mean water temperature and forest baseline	Users of river, subsurface flow or groundwater, esp. those without options for pretreatment		
5. Reduce mass wasting	5.1 Fraction of steep slopes covered by deep-rooted trees ten years ago but cleared since that time and thus subject to loss of root anchoring 5.2 Fraction of annual net sediment export per contributing area (see 4.2a) that is derived from bank erosion and riverbed deposits roadside landslides non-road related landslides current hillslope erosion paddy rice fields in valleys 5.3 Effective width of intact riparian filter vegetation integrated over stream network	People living in or depending on potential path-ways for mud flows & landslides Reservoir life span		

Hydrological functions in relation to tree cover

Tree cover, whether in the form of natural forest, remnant trees left in land clearing, partial tree cover derived from planting along field boundaries or in blocks of plantation forestry, can influence a number of steps in the pathway of water:

- The tree canopy intercepts part of the rainfall and can store a quantity of water in waterfilms around leaves and stems that will readily evaporate after the rainfall event (the amount of water involved depends on the leaf area index as well as surface properties of the leaves; it can be a considerable fraction of the rainfall in small events, but is usually negligible for large rain events that are the main concern in flooding).
- The ground vegetation and litter layer has a direct protective role in reducing 'splash' effects of raindrops that can lead to a dispersal of clay particles from soil aggregates; depending on soil texture, splash impacts can lead to a sealing of the soil surface, blocking of water entry points to the soil, as well as to the entrainment of soil particles into overland flow; the protective function of surface litter is positively related to its resistance to decomposition.
- Infiltration into the soil depends on soil structure at the surface and in various layers of the soil. Soil structure is influenced by biological activity that depends on plants (surface litter, root exudation and turnover) for their energy source; year round availability of 'food for worms' is thus important in counteracting the natural process of decay and clogging of existing macropores. The structure-enhancing function of surface litter is positively related to its ease of decomposition.
- Water uptake from various soil layers throughout the year, to support the process of transpiration from leaf surfaces. Tree phenology, root distribution and physiological response to partial water stress all influence the quantities of water used. Water uptake between rainfall events influences the amount of water that can be stored in a subsequent rainfall event, and thus feeds back on the infiltration process and influences overland flow. Water uptake in dry periods, especially from deeper soil layers will influence the amount of water available for 'slow flows'.
- Landscape drainage is influenced by surface roughness of the soil, the presence of small depressions that increase the time available for

infiltration into the soil in what otherwise would be rapid surface runoff, and the type of 'channeling' that can occur once overland flows reach a certain magnitude and stream power that allow for a self-enhancing process of soil quick flow. In natural forests animal tracks may be the main starting points for such channeling, but generally stay below the thresholds of self-enhancing effects. Human paths and especially tracks used for wheeled vehicles or pulling of logs tend to have the continuity and intensity that enhances drainage and transfers of sediment to streams. Specific enhancement of drainage to protect crops from water-logging and/or surface water to be a hygienic risk, tend to be associated with land use change after forest conversion. The existence of wetlands and areas that can temporarily store surface water by 'flooding', plays a key role in reducing the likelihood of flooding downstream. Conversely, reducing flooding frequency upstream, increases the risks downstream.

The overall impact of forest conversion and or changes in degree and spatial pattern of tree cover in landscapes can be understood from the combination of and interaction between these processes. A number of available simulation models captures the essence of these processes and allows us to test the predicted overall outcome against empirical data sets. Existing models differ in their spatial and temporal resolution as well as in the detail of land form, soil, climate and vegetation parameters that is needed to start a simulation. Agroforestry options at plot scale can be evaluated with the WaNuLCAS model that operates at a daily time step (Khasanah *et al*, 2004). The effects of land use mosaics at landscape scale are represented in the GenRiver (Farida and van Noordwijk, 2004) and Fallow model (Suyamto *et al*, 2004) at a daily and yearly time step, respectively.

'Kebun Lindung' or 'protective garden'

The Indonesian system for forest land classification recognizes a number of 'forest functions' (conservation, watershed protection and production of wood and non-wood products) as the main reasons for maintaining forests in the landscape. Restrictions to the type of forest use that is allowed vary between these categories.

'Hutan lindung' refers to active protection functions ('melindungi') relative to downstream land areas and water flows. The earlier Dutch term ('schermbos') refers to 'umbrella' functions. The 'buffer' function (criterion 2) is directly linked to this protective function, as it reduces the levels of peak flows. The buffer function can be enhanced at the hill slope scale by water use between rainfall events and maintenance of soil structure, and at landscape scale by wetlands and areas that can receive temporary excess of surface water through 'flooding'.

The 'hill-slope' aspect of this protective function can in fact be provided by many types of vegetation cover, as long as it maintains a surface litter layer, avoids channel formation and uses water in evapotranspiration. Where natural forest vegetation is gradually replaced by trees that are preferred for their productive or other functional properties, the 'protective function' can remain intact. Clear felling of areas larger than the gaps that occur as part of the natural forest regeneration cycle, will endanger the protective function - but most of the gradual transformation of 'forest' into 'agroforest' has historically avoided land clearing at that scale.

The word 'forest' has, in the Indonesian setting, become directly associated with state control and exclusion of farmers from the land. Farmers describe their 'modified forest' or agroforest, generally as a 'kebun' or garden, emphasizing the productive and functional role of the trees present.

Efforts to evaluate such 'kebuns' in terms of the hydrological criteria and indicators, so far suggest that multistrata coffee gardens, jungle rubber, mixed fruit tree homegardens and repong damar systems do (or at least can) meet the essential 'protective' functions at the hillslope scale. They can thus be described as 'kebun lindung' - combining protective and productive functions.

Negotiation support

Seventy percent of Indonesian land area is considered to be 'state forest land', with decisions on land access and land use made by national (especially before the 1998 law on devolution of government) or local (after 1998) levels. The relation between local communities and farmers,

regardless of how long they have been in the area, and this state forest zone has a long history of conflict. Often these conflicts have led to loose-loose outcomes, where both the conditions of the forest and the local livelihoods suffered - while the gains were made elsewhere by the beneficiaries of the legal and illegal logging industry.

The 1997 forest law with its opportunities for a more direct involvement of local communities in forest management and the various events after 'reformasi' and devolution of government, have reduced the de facto authority of the state over the state forest zone and created a situation where multi-stakeholder negotiation is a necessity as well as a major opportunity to improve the track record of land management in water catchment areas.

The case study in Sumberjaya (Pasya *et al.*, 2004) has shown that recognition of forms of 'kebun lindung' is a slow process but all current evidence points at a huge opportunity for reducing conflict and improving outcomes for all parties involved.

Discussion and conclusions

Application of the hydrological criteria and indicators to the Sumberjaya benchmark area is discussed elsewhere (Farida and van Noordwijk, 2004), while the negotiation process is described by Pasya *et al.* (2004). Criteria and indicators can only play a meaningful role in the public debate and negotiation process if they are understood, transparent and open for monitoring by the various stakeholders. The set that we propose here needs to be further tested in that sense. Our current understanding of the local ecological knowledge of soil and water movement (Joshi *et al.*, 2004) suggests that the concept of 'evapotranspiration' or 'water use' by plants does not have a direct equivalent in the local system, but that issues of rainfall, overland flow and response of rivers are understood in a similar way to their representation in the models, at least qualitatively. There is a challenge to move the dialogue with the forestry officials from a focus on 'tree planting' per se, to one that is based on measurable functions. A debate on 'functions' rather than 'control over land' has a clear political undertone that can not be easily resolved - but pragmatic solutions that are acceptable to all can emerge, as the Sumberjaya example shows. An important element in the acceptability of farmer-based solutions is the broadly shared opinion of a failure of the previous

approach. Where quantitative data can help to drive that message home, the debate can make progress.

An interesting challenge to the current HKM agreements is how the results will be monitored. From a 'watershed function' perspective, research suggests that 'presence of a litter layer' is more directly linked to changes in infiltration and erosion, than criteria based on trees per se (Fauzi *et al.*, this volume). Local monitoring of water quality provides another entry point, and has been successfully used in northern Thailand (Thomas *et al.*, 2003) and the Philippines.

Overall our conclusion is a hopeful one: it is likely that recognition of 'kebudayaan' can help resolve current conflict by refocusing the 'watershed management' debate on measurable functions rather than perceptions of an intrinsic need for 'forest cover'. The public debate on this issue needs to be stimulated to gain a broader platform for 'result-based natural resource management', to replace the current focus on unrealistic targets.

