HYDROLOGICAL IMPACTS OF FOREST, AGROFORESTRY AND UPLAND CROPPING AS A BASIS FOR REWARDING ENVIRONMENTAL SERVICE PROVIDERS IN INDONESIA



Fahmuddin Agus, Farida and Meine van Noordwijk (Editors)

Proceedings of a workshop in Padang/Singkarak, West Sumatra, Indonesia, 25-28 February 2004

WORLD AGROFORESTRY CENTRE



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Pictures of front cover: Durian- (*Durio zibethinus*) base agroforestry in Maninjau; Singkarak Lake and its special fish ('ikan bilih'); outflowing water from Singkarak Lake to Ombilin River and water wheel as a traditional irrigation system for paddy farming.

Photographs by Meine van Noordwijk

Design/lay out by Dwiati Novita Rini

Executive Summary

Watershed functions and the way they are affected by 'development' are much debated and are nearly everybody's concern…..

When natural forests are logged or cleared by slash-and-burn methods for establishing tree crop plantations or upland food crops…,

when roads are built on forested slopes and induce landslides and rapid pathways for mudstreams to reach the rivers…,

when people start to live in upper watersheds and pollute streams by domestic use, livestock or use of agrochemicals…,

when the demand for water increases because of greater use for lowland irrigation, industry or cities…,

when fast-growing trees that use more water than other vegetation are planted,

when government agencies claim control and impose their solutions on the local community,…

when the floodplains and wetlands that used to provide storage and buffer capacity are drained for 'development'…or

when villages are built in places that are prone to flooding and mudslides…

….the end result is 'problems with watershed functions' that affect all of us one way or another.

but there are many ways in which specific problems can be solved through combinations of forests, agroforestry and upland cropping…..

The standard solution to 'rehabilitation of watersheds' is to plant trees in the hope of re-creating the benign conditions of a natural forest. Natural forests, however, provide livelihood options only at low population densities, so it cannot really solve current pressures on the land in areas with high population densities. Tree planting as such may actually increase the problem (fast-growing trees with high water use will reduce dry-season flows of streams and rivers), while mixed multi-strata systems can protect the soil and maintain water quantity and quality as well as providing livelihood to resource-poor local community.

once we have a common perception (criteria and indicators) of what exactly is the problem to be addressed.

Because there are many potential 'solutions' we need to be clear and specific about what the problem is and whether the selected solutions really address the problems. A list of three criteria for water quantity (Transmit water, Buffer peak flows, Release water gradually), water quality (Reduce sediment loads and other pollutants, Maintain aquatic biodiversity) and integrity of the land surface (Control landslides, Reduce loss of fertile topsoil through erosion), needs to be combined with criteria that relate to biodiversity conservation and to the social and economic welfare of the people living in watershed areas. Once seen against these criteria, many 'solutions' are in fact causing new problems. The different stakeholder may in fact have opposite interests, and a broad process of negotiation is needed to establish integrated natural resource management.

For example the way the GNRHL tries to achieve environmental protection goal may miss opportunities to build on local participations ….

Indonesia's current national program for reforestation and land rehabilitation is aimed at addressing widespread concern over degradation of watersheds, through a program targeted at planting X million trees per year on 500,000 ha of 'critical lands'. Assumptions that are yet to be met for the program's success are:

1. Convergence in stakeholders' perception on underlying knowledge of what the trees can actually provide to the environment and the community
2. Suitability and synergy of the supplied tree seedlings with existing local agro-ecosystems
3. Guarantee for acceptance by the local community and maintenance after planting to ensure tree survival
4. Guarantee for non-disruption of local livelihood because of changes in land use systems
5. Community education since early stage, starting from primary schools, on science based, rather than myths, of the relationship between land uses and the environments as well as socio-economic conditions
6. Institutional strengthening at the local/farmers level

7. Application of participatory approach (as opposed to a 'project' approach) with 'pendampingan' ('facilitation') of NGOs and researchers, including empowerment of local community in accessing and utilizing local land and tree resources.

to support the various ways in which proper land management with trees can provide local as well as national (environmental) benefits,

Indonesia is rich in examples of landscapes where farmers have combined the use of trees for productive purposes with elements of the natural forest that provide environmental services and areas that are used for intensive food crop production. These 'agroforestry mosaic' landscapes can be seen as 'Kebun Lindung' ('protective gardens') that offer great opportunity for combining economic and environment targets. Yet, there are obstacles in the recognition of these systems, as they may not meet the legal definitions of 'forest' or be in conflict with the existing land use regulation system and policies - even though it could pass the test when functional criteria and indicators of forest would be used.

while ensuring that outside stakeholders provide recognition and rewards in ways that are transparent, effective and pro-poor.

New ways to build 'hulu-hilir' (upstream-downstream) relationships that can satisfy everybody's needs, will require ways to share the benefits that lowland community enjoy from the effectively protected water resources, ways to enhance recognition and respect for upstream communities and their ability to monitor and solve problems, and means to reduce rural poverty. A combination of public and private rewards and payments is most likely to be successful in watershed management. Test sites for this new approach include the Singkarak and Sumberjaya (West Lampung District) action research sites of the RUPES (Rewarding the Upland Poor for the Environmental Services They Provide) program.

Our overall message is:

We need to rebuild effective communication between local, scientific and public/policy perceptions and knowledge of the problems that development can cause to 'watershed functions' and try to find solutions that build on local opportunities rather than blue-print standardized solutions.

Table of contents

Executive Summary **i**

Basic Relationships Between Forests and Watershed Functions **1**
Introduction 1
The hydrological cycle of humid tropical forests 2
What are the impacts of deforestation? 9
Response of total streamflow: greater water yields *11*
Response of total streamflow: less buffered flows *12*
What is the response of deforestation to dry season flow? *13*
Effects on soil loss *14*
Land use effects on soil nutrients *18*
Conclusions 20

Role of Agroforestry in Maintenance of Hydrological Functions in Water Catchment Areas **21**
Introduction 22
Development of forest and water concepts in Indonesia 23
Criteria and indicators 27
Hydrological functions in relation to tree cover 31
'Kebun Lindung' or 'protective garden' 32
Negotiation support 33
Discussion and conclusions 34

Environmental Services of Agriculture and Farmers' Practices Worth Rewarding **37**
Introduction 38
Environmental services of agriculture 39
Erosion and sedimentation under different land management systems *39*
The role of trees and grass strips *40*
Paddy field as a sediment filter *44*
Water retention 44
Carbon sequestration and biodiversity *46*
Practices worth rewarding and mechanism for technology selection 46
Conclusions and policy implications 49

Criteria and Indicators of Watershed Management Used for the National Movement for Land and Forest Rehabilitation (GNRHL) in Indonesia **51**
Introduction 52
Criteria and indicators of watershed management 53
Land management *53*
Water management *54*
Human resources management in correlation with the natural resources *55*
Evaluation standards *56*
Criteria and indicators of forest management 57
The proportion of forest and spatial distribution in a watershed *59*
Matching tree species and forest types with the environment *60*
Forest and land rehabilitation 61
Forest and land rehabilitation activities *61*
How do the forest and land rehabilitation movement improve watershed conditions? *62*
Conclusions 64

Recognizing and Rewarding the Provision of Watershed Services **65**
Ensuring an adequate supply of clean water 66
But can markets help? 67
The value of water and watershed services 68
Using market mechanisms - opportunities and pitfalls 70
Different types of market mechanisms 72
Self-organized private deals *72*
Public payment schemes *73*
Open trading schemes *74*
What's needed to make market mechanisms work for watershed protection 75
Watershed services - separating the fact from the fiction *75*
Providers *76*
Users *77*
Supporting institutions and policies *78*
Markets for watershed services in Indonesia 79
Stages in developing watershed markets *79*
Case studies in Indonesia 80
Annual fee paid by PT INALUM to the North Sumatra District Government for Conservation of land around Lake Toba *81*

Land lease of state land to the local community for providing watershed functions in the upper Way Besay watershed of Sumberjaya, Lampung 81
Preserving natural spring water through cultivating local varieties plants 83
Action-learning to develop and test upstream-downstream transactions for watershed protection services: a diagnostic report from Segara River Basin, Indonesia 84
Conclusion 85

Institutional Development of Water Resource Management for the Ombilin-Singkarak Sub Basin in West Sumatra, Indonesia: A Study on Role Sharing for River Basin Management **87**
Introduction 88
Overview of the region of Inderagiri Subbasin 89
Demography and employment 90
The subbasin and its area 90
Climate 91
Issues on water resource management 91
Interbasin Water Transfer 93
Impacts of the Singkarak Hydroelectric Power Plant 93
Increased Operation and Maintenance Costs of Waterwheel Irrigation Systems 94
Unreliability of irrigation water and decline in rice yield 94
Decreased Performance of Irrigated Agriculture 94
Impacts on industry and domestic water supply 95
Issues on role-sharing in water management 95
The institutional development for the ombilin-singkarak subbasin management 96
Linkage among stakeholders in water management 98
Rationalization the role of Balai PSDA 99
The concept of role sharing in water resource management 100
Agenda for Further Studies 101
Acknowledgements 101

Challenges and Opportunities to Implement RUPES Program at Singkarak Catchment **103**
Introduction 104
The Catchment and Lake Setting 105
The People and Institutions 106

Environmental Issues 107
Possible Mitigating Interventions 108
Proposed Mechanism of Reward 110
RUPES Project at Singkarak 113
Conclusions 114

Working group brief reports 115
1. Criteria and indicators of watershed problems from a policy and research perspectives 115
2. Farmers' environmentally benign practices and local ecological knowledge 118
3. Mechanisms and pitfalls for rewarding farmers for actual hydrological services 120
4. Final discussion 122

Field visit to Lake Singkarak and Lake Maninjau 125

References 133

List of participants 143

Basic relationships between forests and watershed functions

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If forests are converted into other land uses, the soil, vegetation and consequently the cycle of water will be subject to changes. This chapter aims to discuss some of the consequences of the conversion of moist tropical forest to agricultural land, especially the response of water yield and soil loss. Soil conservation strategies will be discussed as well, as this is the main key to restore appropriate land use and an attempt to increase the production of small farmers in rainfed agricultural uplands.

Introduction

With their unique diversity of plant and animal life, tropical forests represent an immense source of food, fibre, timber, medicines and fuel for local farmers, hunters and gatherers and (indirectly) city dwellers elsewhere. Forests are also of concern to the world community as a whole, in the way they constitute a significant element in the global carbon budget and harbour a large share of global biodiversity.

Nowadays, forests are being cleared in order to expand the area of productive agricultural land. Thus the unique properties of the forest are lost to humankind. Fortunately, in both tropical and temperate countries conservationists and more and more citizens are concerned with the wellbeing of indigenous people and the negative environmental effects of forest destruction. It matters a great deal what conversion method is used to derive agricultural lands from forest. It also matters a lot how agricultural lands are managed - some of the 'forest functions' can be maintained in agricultural landscapes, while others (especially the biodiversity) may significantly loss due to forest conversion.

There are ways in which forest in the humid tropics can be used, with consequences in productivity, biodiversity, and environmental services:

- Maintain the forest with little or no disturbance by man, for protection purposes,
- Sustained management of the forest for continuous production of wood and other commodities and services such as soil and water conservation, wildlife and recreation,
- Clear forest areas for temporary food crops and planting of commercial tree crops, but allow for a regrowth of forest species in an 'agroforest' context
- Clear forest and use the land for permanent farming and grazing, plantation forestry or agroforestry.



Figure 1: Forest with epiphytes that only thrive in moist air. (*Source: Hamilton and Bruijnzeel, 2000*)

The consequences for water yield and soil loss of these options can be understood from the basic hydrology of forest areas. This overview relies heavily on a recent review by Bruijnzeel (2004), the interpretation, however, is that of the authors.

The hydrological cycle of humid tropical forests

This section explains how the interaction between forest vegetation, soils and atmosphere persists. This interaction process between various factors in an ecosystem is called the hydrological cycle and based on this we can gain insight in what will happen if a forest is converted to another type of land use.

The hydrological cycle contains several factors, which influence the cycle of water through a system. These factors are:

- Precipitation (rainfall)
- Interception by tree canopies, other vegetation or surface litter
- Throughfall and stemflow reaching the soil

- Infiltration or overland flow
- Evapotranspiration (evaporation and transpiration)

Precipitation

Rain is the main precipitation input to forests in the humid tropics. A small part reaches the forest floor directly as 'throughfall' without touching the canopy.

Interception

Of the rain that strikes the vegetation a substantial portion is intercepted by the canopy and evaporates back into the atmosphere during and immediately after the storm.

Stemflow and throughfall

The remainder of the rain reaches the forest floor as crown drip and via branches and trunks as stemflow after the respective storage capacity of the canopy and the trunks has been filled. The sum of direct throughfall, crown drip and stemflow is commonly called net precipitation.

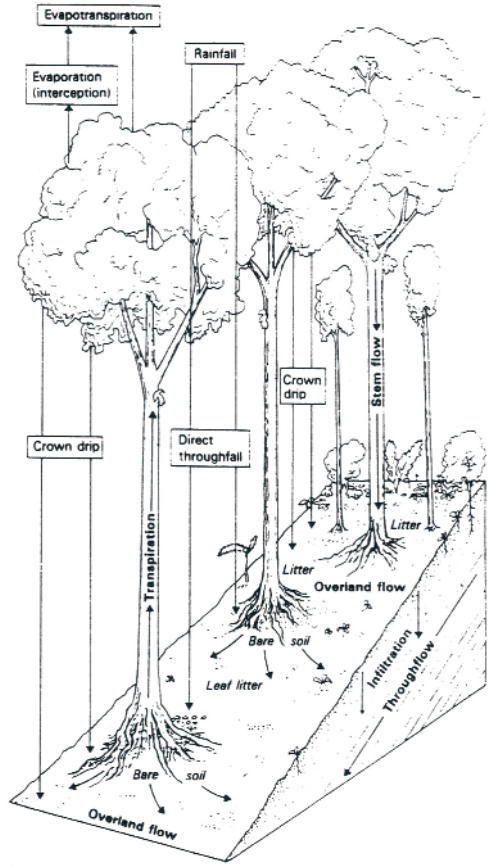


Figure 2: Hydrological cycle for a forested ecosystem. (*Source: Critchley and Bruijnzeel, 1994*)

The rainfall arriving at the soil surface encounters a filter that determines the path to reach the stream channel. The water in various pathways may leach amounts of nutrients from the rhizosphere system.

Evapotranspiration

Water evaporates from the soil surface and returns to the atmosphere. Soil moisture content and water table depth play an important role in the amount of evaporation. Also water is returned to the atmosphere by transpiration via plant leaves. This process is dependent on climatic, soil properties and physiological characteristics of the vegetation. The evaporation from the soil and the transpiration losses via vegetation are

often difficult to measure separately and therefore are combined in the term 'evapotranspiration' which is usually calculated by empirical formulas in combination with measurements as air temperature, relative humidity, daylight hours, sunshine hours and wind velocity.

Forest can influence the evapotranspiration by their effect on wind turbulence, high humidity in the forest, interception of rain water and their root-system. In general forests return more water to the atmosphere than do other vegetation types or bare soil due to the great transpiration and evaporation of intercepted water.

What is the influence of a forest on infiltration and soil moisture content?

In general the infiltration rate in forests is higher than on other land, because of the many biopores in the soil caused by the activity of soil fauna, roots and high organic matter content. Leaf litter protects the soil against clogging. As a consequence forests soils have high storage capacities.

Wet or dry sponges

The complexity of forest soils, roots and litter has often been described as a sponge soaking up water during rainy events and releasing it gradually during dry periods. If a sponge is wet, however, it cannot take up further water and this is what may happen during heavy rainfall or consecutive days of moderate rainfall. The rate at which water can leave the sponge is an interesting subject of discussion. Although forest soils generally have higher infiltration and storage capacities than soils with less organic matter, most of this water is consumed again by the forest rather than used to sustain streamflow.

What is the influence of a forest on run off and streamflow?

If rainfall intensities below the forest exceed the infiltration capacity of the soil, the unabsorbed excess runs off as "Hortonian" or "infiltration excess" overland flow. The remainder infiltrates into the soil and, depending on vertical and lateral hydraulic conductivities, local soil moisture and slope steepness, may take one of several routes to the main stream channel. Forests have good storage and infiltration capacities of the soil and therefore overland flow hardly occurs. If it occurs, it is restricted to very small areas where soil is disturbed due to, for example,

burning. Due to the high amounts of pores in the soil a substantial part of the water flows off as quick subsurface flow which can give storm flow in a river.

Because of the great infiltration capacity of the forest soil, the accessibility to the groundwater system is relatively high with a result that a lot of water is stored in the groundwater reservoir and released again gradually as base flow in rivers. Because of high evapotranspiration capacity in general, forests have a lower total stream discharge in relation to other forms of land-use.

Cloud forests

Cloud belts on tropical mountains, where amounts of water reaching the soil surface, are strongly influenced by the presence of trees. In these so-called 'cloud forests', 'elfin forests' or 'mossy forests' a significant portion of the incoming precipitation is stripped by the vegetation from low clouds and fog, blown through the forest canopy.

Cloud forests are usually short-statured, twisted, epiphyte-laden, dense canopied forests of hard-leafed species. They are usually found in a relatively narrow altitude range, but their actual position varies widely from tropics to temperate zones. Cloud forests have developed as low as 500 m above sea level on small islands in humid equatorial locations such as Fiji, but also in semi-arid small islands in oceans at the leeward side of the mountain, in contradiction to humid climates where the most developed dwarf-forests with epiphytes and lichens usually are situated at the windward side of the mountain. More often they are found in large mountain ranges between 2000 and 3500 m such as the Andes. From the movement of saturated air masses these trees, with their epiphytes, lichens and mosses, are able to condense the



Figure 3: Cloud forest. (*Source: Hamilton and Bruijnzeel, 2000*)

cloud or fog which then drips or runs to the ground and is added to the water budget of the area. Contributions by such fog stripping may reach several hundreds of mm yr^{-1} and even embodies the only input of moisture during an otherwise dry season.

> In the coastal ranges of the arid Pacific areas of Chile, Bolivia and Peru, a persistent fog, the *camanchaca* strikes the uplands between 500 and 1000 m. Artificial nets and screens are erected and trees are planted in order to capture water for potable domestic use.
>
> In the uplands of West-Java, Indonesia, at heights from 800 m and more, tea plantations have been established where in the past the hills where covered with cloud forests. Tea plantations generate a good ground cover but the capacity to capture fog is generally lost.

Another important characteristic of cloud forests is their extremely low water use, which is probably related to their often limited height. The net result is that in combination with the extra water supplied by the fog, it is not unusual for streamflow totals from such areas to be higher than measured amounts of incoming ordinary rainfall. Therefore, catchment headwater areas covered with these forests should be protected if a steady supply of water to the adjacent lowlands is to be guaranteed. In their natural state, because of their unusual environment, these cloud forests structure and species have a great importance for biodiversity. Unfortunately, in many tropical montane areas they are rapidly disappearing. The replacement of trees by any other short crops brings the contribution of water by 'cloud stripping' to an end and may result in a diminished stream flow.

Water yield and soil loss measurements for 'small' and 'large' catchments

Usually during hydrological investigations, the hydrological in- and outputs of an area are measured in a catchment. This can be a catchment of a huge river basin or only a small drainage basin of several hectares.

To study the hydrological response of an area to land conversion, a small catchment is preferred by researchers because when land

conversion takes places, this is usually uniformly be done over the area such that the effects of land use changes on hydrological processes could easily be detected. In the large catchment, land use changes take place on only small parts of the total area. In addition, in a large catchment the land use is more spatially varied and this will complicate the hydrological processes. Therefore, the measurements from small catchments may not simply be extrapolated to a larger area.

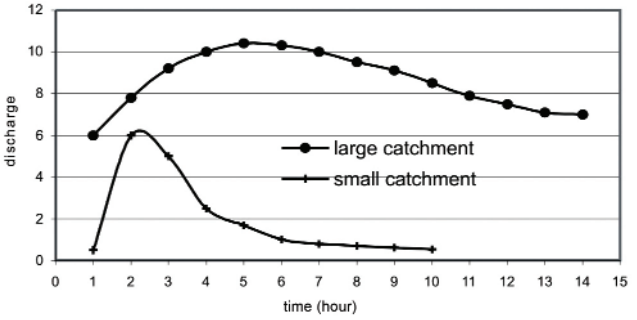


Figure 4: Differences in discharge from small and large catchments.

Small catchment	Large catchment
Uniform rainfall	Pluriform rainfall in time and space
Uniform land use	Pluriform land use
Uniform geology	Pluriform geology

It has been demonstrated that contrasts in catchment response between drainage basins within a small area are primarily the result of catchment characteristics (geology, topography, soil, vegetation characteristics) rather than meteorological inputs. In large catchment areas, there is also a large variation in time and space of the meteorological input (rain, sunshine, wind). Therefore, the discharge of a larger-scale catchment area after rainfall differs from that from a small-scale drainage basin.

In small catchments there is less spatial variation in soil type, drainage situation and vegetation type, but small catchments in headwater areas may be leaky and part of the flow may go unrecorded as deep leakage through rock fissures and fault zones or through the valley fill, thereby producing an underestimate of the hydrologic nutrient losses or misestimates in the factors of the hydrological cycle.

It is also possible to measure water yield and soil losses in very small areas, for example in plots of only a few square meters. Because this area is so small, the influences of groundwater flow can be neglected and also surface properties of the area cannot be compared straightforwardly with larger areas. In a large catchment area almost all watershed functions are available to compute a water balance of the area.

What is a water balance?

The water balance of an area can be made to compute the various in- and outputs of an area. The main input to an area is precipitation. The outputs are: evaporation from the soil, transpiration via trees, stream flow and groundwater flow:

$$P = E_i + E_s + T + Q_s + Q_g + S$$

Where

P = precipitation,

E_s, E_i = evaporation from the soil and water intercepted by canopy surfaces,

T = transpiration by plants,

Q_s, Q_g = stream flow and groundwater flow,

ΔS = change in soil moisture storage.

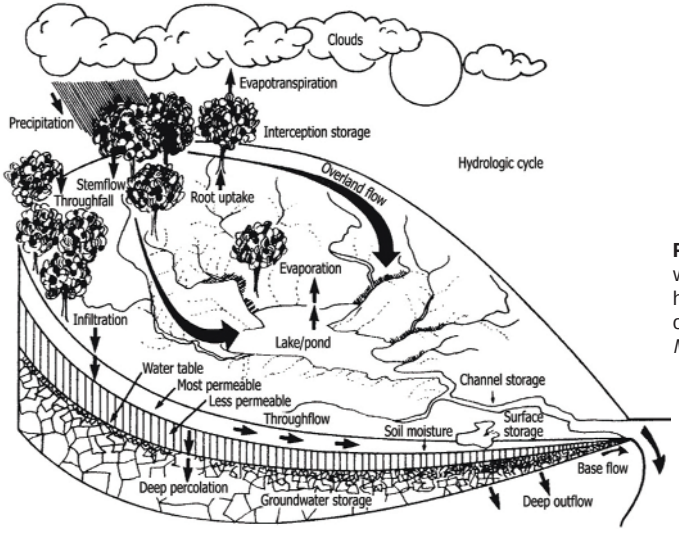


Figure 5: A catchment with its various hydrological inputs and outputs. (*Source: Messerli and Ives, 1997*)

In short we can state that a forest has its own specific hydrological cycle, controlled by the **interaction between** forest **vegetation**, **soil**, **landscape**, **climate**, and **so forth**. If this interaction is disturbed, various factors of the hydrological cycle (evapotranspiration, interception, throughfall, infiltration) will change which leads to another response to rainfall.

What are the impacts of deforestation?

In general, there are three intensity levels of disturbance of a forest that can be distinguished:

- Low: small scale and short-lived events of forest clearing
- Intermediate: selective logging, forest fire, shifting cultivation -- with a chance of recovery of forest vegetation
- High: forest clearing, conversion to pasture, monocultures of tree crops, timber plantations or permanent annual cropping -- with very little chance of recovery of forest vegetation.



Figure 6. Slash-and-burn clearing can be the start of a 'temporary' disturbance of the hydrological cycle and it can also be the start of irreversible conversion. (*Source: Dephutbun, 2000*)

Logging operations of any type cause disturbance to the soil and the vegetation. Yet, the way logging is performed can make a lot of difference. Use of heavy machinery that compacts the soil, pulling logs into streams and rivers for easy transport and careless felling can cause disproportionate levels of damage to watershed functions. As lowlands

already are converted in agricultural lands, loggers turn their attention to steeper terrain and uplands. Where heavy machinery is used to cut and transport the timber, up to 30 % of the soil surface may be laid bare in the forms of roads and tracks. Especially on wet clayey soils the porosity and infiltration capacity are seriously reduced after the use of wheeled machinery.

Hydrological effects of forest conversion

As a result of deforestation the response of the land to rainfall will change depending on the type of deforestation, a region's climate, geological setting, as well as the rainfall during and after the conversion.

The key to the hydrological behavior of a forest is the presence of the canopy and the forest floor, with its leaf litter and concentrated roots. The canopy (through its interception of rainfall and its evaporation loss via transpiration) together with the litter on the ground (through its effects on infiltration) is crucial in the hydrological cycle of the forest. One of the most important factors which will change when deforestation including disturbance of the soil takes place, is a diminished capability of the soil to absorb water; in other words: ***the infiltration capacity of the soil reduces***.

In general after conversion of tropical forest into agricultural land the infiltration capacity of the soil and the water uptake by trees diminish due to the following reasons:

- ***Exposure of bare soil to intensive rainfall***

  If protecting canopy and leaf litter layer is removed, the soil is exposed to the erosive power of rain. Part of the soil pores are sealed and thus give an increase to runoff and erosion. Due to erosion, the fertile and permeable topsoil is removed or compacted, thereby lowering further the infiltration capacity.

- ***Transpiration decrease***

  Conversion of forest land into agricultural lands reduces transpiration because crops do not have a full leaf canopy throughout the year and the leaf area of field crops is much lower compared to that of forest. Agricultural crops tend to have shallower root systems than trees and as a consequence only use soil water in the upper part of the soil. This reduced transpiration means a higher total annual flow to the river.

- ***Compaction of topsoil***

  If tropical forest is converted into man-made areas, like agricultural lands and/or inhabited areas there will be a strong increase in the amount of impervious surfaces like roads, yards and roofs, which will give an extra impact on the amount of surface runoff and consequently will reduce infiltration.

- ***Gradual disappearance of soil faunal activity***

  Most soil fauna (indirectly) depends on the continued inputs of organic material in the form of leaf, fruit or wood litter. Conversion of forest tends to reduce litterfall which also reduces food supplies for the soil fauna. Furthermore the use of fertilizers and pesticides diminishes the soil faunal activity and thus lowering the rate of soil manipulation and natural tillage.



Figure 7. Water logging and surface runoff due to decreased soil infiltration capacity. (*Source: van Dijk, 2002*)

Erosivity of rainfall in the tropics

In the humid tropics rainfall usually is intense, with a large amount of water received over a short period. Due to these rainfall characteristics in the humid tropics, the raindrops usually have a high kinetic energy and thus have a quite high erosive power.

Response of total streamflow: greater water yields

One of the results of changing land use to agriculture is an increase of annual stream flow out of the area. This is a simple consequence of the water balance: if evaporation of intercepted water and transpiration by

vegetation are reduced, more water will leave the area as stream flow once the storage capacity of the soil is saturated. The overall catchment water yield increases significantly under rainfed agricultural use (typically by 150-450 mm yr^{-1}, depending on rainfall) compared to undisturbed natural forest. The greater 'water yield' may, however, come in the form of 'peak flows' rather than as 'base flow' thus potentially increase the frequency and intensity of floods if the down stream area is flood prone.

Response of total streamflow: less buffered flows

After logging, the forest still keeps a percentage of the ground cover, protecting the soil against erosion. After clearing of the forest floor, however, the protecting layer of leaf litter, branches and trunks are removed, remaining the soil bare. No longer are there trees to intercept rainfall and evaporate it directly back into the atmosphere. Due to high precipitation intensities in the humid tropics the soil pore is clogged and infiltration capacity is diminished dramatically. This will result in a more pronounced catchment response to rainfall and the increase in storm runoff during the rainy season. This increase may become so large as to seriously impair the recharging of the soil and groundwater reserves which normally feed springs and maintain base flow.

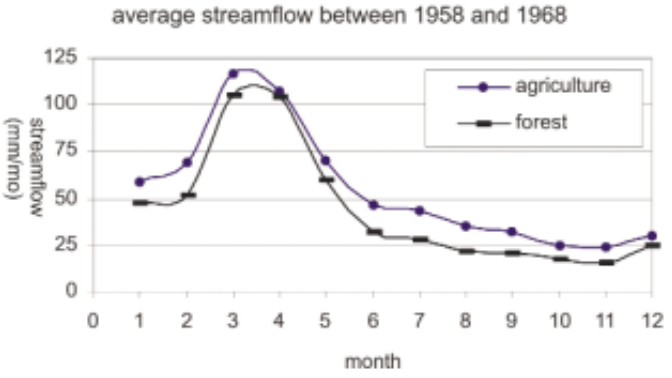


Figure 8. Changes in seasonal distribution of stream flow following changes in land use, in the Mbeya area (Tanzania), where montane forest was replaced by subsistence agriculture; in this case stream flows increased during the dry periods as well as in the peak of the rainy season. (*Source: Critchley and Bruijnzeel, 1996*)

In undisturbed tropical forest, infiltration excess-overland flow makes up less than 1 % of the incoming rainfall but on agricultural fields with no or less conservation practices this may increase to about 30 %. The portion of precipitation that contributes to infiltration excess-overland

flow directly runs off to the nearest channel, instead of infiltrating the soil and subsequently recharging the groundwater supply.

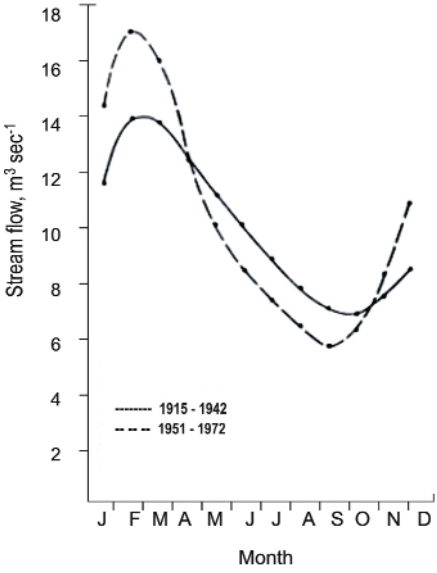


Figure 9. Change in seasonal distribution of streamflow out of the Konto-river basin, Indonesia. In the second period a significant conversion of forest to agricultural land took place. (*Source: Brujinzeel, 1990*)

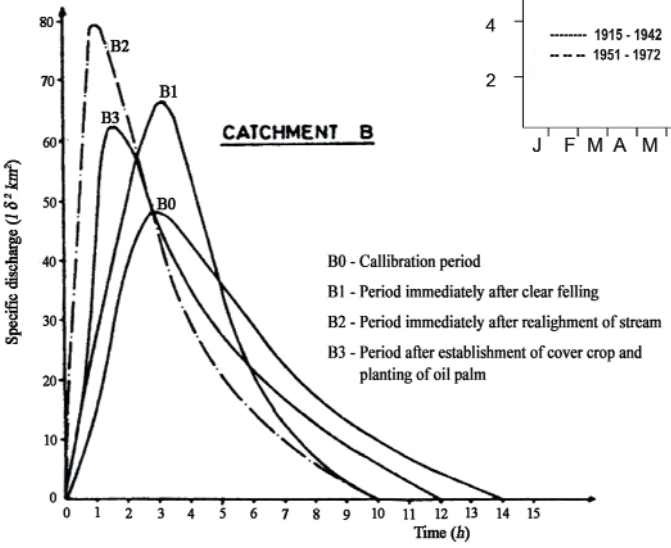


Figure 10. Stream discharge after B1: clear felling, B2: realignment of stream B3: re-establishment of cover crop and planting of oil palm (*Source: Brujinzeel, 1988*).

What is the response of deforestation to dry season flow?

Under undisturbed forest, generally the dry season flow or base flow is maintained. This flow is generated in the rainy season when enough water is able to infiltrate via the highly permeable soil of the forest and infiltrated to deeper soil layers, which drain the area. As a result of disturbance of the forest floor, less water is capable to infiltrate. The remainder is running off over the surface directly during and after a rainfall event.

Decreasing infiltration capacity forces the water to run off overland if the infiltration capacity of the soil is exceeded by the precipitation intensity. This will lead to a direct contribution of runoff water to the storm flow stream instead of a contribution to the deeper soil water.

Under disturbed circumstances of the forest floor or when forest is converted into agricultural land, a larger portion of the incoming rainwater will run off quickly after and during the rainfall event. Less water is left to replenish deeper water bearing layers and so less water is left to maintain a continuous flow during dry seasons.

This could be explained by the fact that agricultural crops almost always use less water than the original forest. For example, total stream flow from forest that has been converted to rubber or cocoa plantation will be permanently about 300-400 mm yr^{-1} higher than when the area is covered by natural forest. After a few years of conversion to plantation the increase of water yield becomes less pronounced as a result of uptake of water by the growing vegetation and the recovery of undergrowth.

Effects on soil loss

Erosion is the process by which soil and rock particles are loosened and broken down and carried or washed away by runoff water or by raindrops (splash erosion). Undisturbed natural forest usually has the lowest surface erosion rates of any form of land use in the humid tropics. The leaf litter, undergrowth and highly permeable topsoil help to keep surface runoff low, and thus erosion to a minimum.

The main factors which control erosion are:

- relief: the steeper and the longer the slope, the higher the velocity of runoff water and thus the more the soil suffers from erosion and the easier is the sediment transported downslope.
- rainfall: high amount and high intensity of rainfall stimulate a higher erosion rate
- soil: soils are usually shallow on steep slopes and in converted forest sites. The shallow soils are more susceptible to erosion.
- plant and soil cover: the cover of the floor will be reduced after conversion.
- management: management systems such as strip cropping, terracing etc. can reduce runoff and erosion.

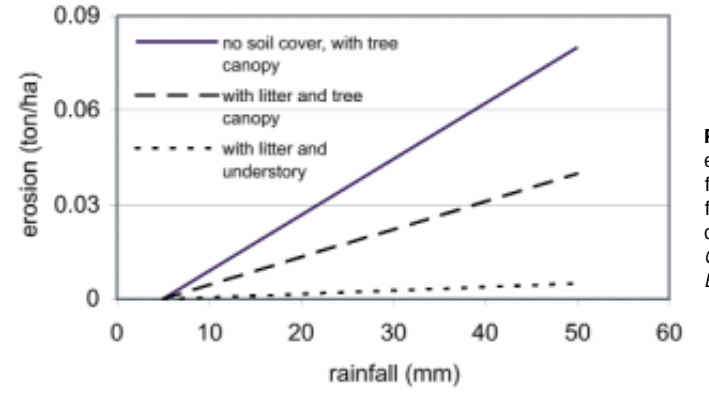


Figure 11. Surface erosion in a young forest plantation as a function of soil surface conditions. (*Source: Critchley and Bruijnzeel, 1996*)

What kind of erosion can be distinguished?

Erosion in disturbed forests can occur in different types:

- surface (sheet) erosion, also known as inter-rill erosion.
- rill erosion, where little streams start to form on the surface
- gully erosion, where new streams are deeply incised in the landscape
- stream erosion
- landslides and mass movements of soil, due to interruption of subsurface flow pathways by roads and / or loss of tree root 'anchoring' of the soil

Surface erosion can be a severe problem in steep agricultural lands, such as in West Java, where soils are degraded and soil particles have a low stability. Stream erosion will occur if runoff rainwater is already came together in a small stream and if flow velocity and thereby erosive energy is high enough to take up soil particles with the flow.

High stream flows may cause gully erosion usually as a consequence of improper discharging of runoff from roads, trails and settlements. Water streaming down with a high velocity has, depending on the type of soil, enough energy to take up soil particles and this kind of erosion can attribute to increased gully erosion.

Mass wasting (landslides) can occur in forested areas under conditions of steep topography, tectonic activity (earthquakes) and intense rainfall.



Figure 12. Heavy erosion on a poorly drained road. (*Source: Critchley and Bruijnzeel, 1994*)

Mass wasting and landslides: natural or man-induced process?

Factors controlling mass wasting under natural forest cover are:

- steep slopes
- unstable nature of rocks and unconsolidated soils
- depth and degree of weathering
- high seismicity
- oversteeping of slopes cause by undercutting of rivers
- (over) saturation of soil

In forested areas a distinction can be made between deep-seated and shallow (< 3m) landslides. The deep ones seems not to be influenced by the presence or absence of a well-developed root system, but are more controlled by geologic factors. Shallow landslides are controlled by disturbances of the soil. If the protective root-system in the topsoil, which stabilizes the soil on steep hill sides, is disturbed, landslides occur frequently. Under natural conditions, disturbance of a part of the forest floor can take place by tree fall, fire or heavily flooding.

Non-natural disturbances of a forest soil are removal of the forest for production purposes, cultivation and grazing or construction of roads, canals and housing areas. Irrigation canals in upland areas are frequently associated with slope failures due to the removal of the toe of the slope and the saturation of the weathering layer by seepage and overflow.

What are the on- and off-site effects of erosion?

Erosion not only affects the location where soil loss takes place (on-site) but also downstream (off-site). The on-site effects of erosion include:

- decrease of soil fertility as a result of soil loss
- decline of physical soil properties, due to loss of organic matter
- decrease of infiltration capacity
- reduction of agricultural lands productivity



Figure 13. Sediment-laden river, resulting from adverse land use in Sapi-watershed, Central Java, Indonesia. (*Source: Critchley and Bruijnzeel, 1994*)

Table 1. Surface erosion in tropical forest and tree crop systems (Mg ha^{-1} yr^{-1})

Land use	Erosion		
	Min	median	Max
Natural forest	0.03	0.3	6.2
Shifting cultivation, fallow period	0.05	0.2	7.4
Plantations	0.02	0.6	6.2
Multi-stored tree gardens	0.01	0.1	0.2
Tree crops with cover crop/mulch	0.10	0.8	5.6
Shifting cultivation, cropping	0.40	2.8	70.0
Agricultural intercropping in young forest plantation	0.60	5.2	17.4
Tree crops, clean weeded	1.20	48.0	183.0
Forest plantation, litter removed or burned	5.90	53.0	105.0

Source: Bruijnzeel (1988b)

The downstream, off-site, effects of erosion include:

- lower quality and use value of river water
- sedimentation in the reservoirs and channels

- damaging watercourses, land and properties
- change of the hydrological regime of rivers

Is soil erosion measured upstream the same as the sediment loads measured downstream?

Individual sediment particles undergo a period of transport, deposition and remobilization by water as they travel downstream. The residence time of sediment in various storage locations varies widely depending on the type of deposition site. There can be a great time lag in soil erosion and sediment yield measured off-site. The time lag increases with catchment area because of the increase storage opportunities, decrease gradients and wider range of depositional sites in larger catchments. The ratio between sediment measured at the exit of the catchment and sediment generated on-site is called 'sediment delivery ratio' and it represents the fraction of on-site generated sediment that is stored somewhere in the catchment.

Between different scales of measurements of soil loss (individual terrace units vs. total catchments) there can be a significant difference in the average amount of transported sediment. This is caused by the fact that within an area there will be always some places in which sediment can be deposited. This process of deposition and storage of sediment has a widely spatial and temporal range. Therefore sediment generated upstream does not have to be equal the amount of sediment yield measured downstream.

Land use effects on soil nutrients

Soil formation in the humid tropics is relatively fast due to high temperature, high rate of organic matter production and high rainfall. Tropical forests can produce a huge amount of biomass, even when their soils are very low in fertility. Forests have a relatively 'closed' nutrient cycle: the plant nutrients entering the forest system are being cycled continuously between the canopy and the soil. When a forest system is disturbed, the nutrient cycle is interrupted, leaving the soil with a deficiency of nutrients. Upon tropical forest clearing, nutrients are lost from the ecosystem in various ways, depending on geological and climatic factors:

- Harvesting of stems: the amount of nutrients incorporated in the stem and bark of trees varies for calcium and phosphorous between 10 and

75%, potassium between 20 and 80 % and magnesium 20-65% of the amount available in above and below ground biomass. This amount of nutrient is transported out of the system when the wood is transported.

- Slashing and burning: nitrogen and carbon go up in smoke. Between 25 and 80 % of all calcium, potassium and phosphorous present in slash may be lost, depending on the intensity of fire.
- Nutrients carried away in eroded sediment.
- Nutrient loss through increased leaching and drainage of the soil.

After conversion to agriculture a new nutrient balance will be established. Plantations present the opportunity to establish a system which, with careful management, can provide an accepted alternative to the nutrient cycle of a forest.

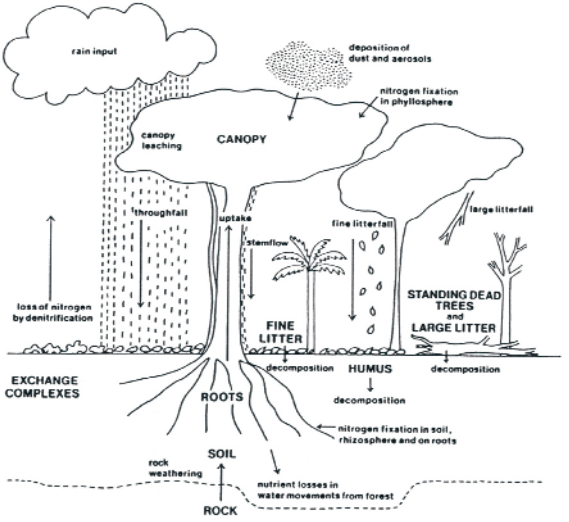


Figure 14: Nutrient cycle in a moist tropical forest. (*Source: van Dijk, 2002*)

The loss of nutrients from a soil can only be compensated by inputs from precipitation (rain and dry deposition), weathering and fertilizing. The loss of nutrients by forest clearing is very hard to equilibrate by a new supply of nutrients through precipitation or rock weathering because of the relatively slow process of rock weathering and the relatively little amounts of nutrient input by precipitation. Therefore, nutrients balances during forest clearing are disturbed when too much biomass is removed or when too little time is given to the land for natural re-growth of the vegetation.

Conclusions

Forests exhibit the most ideal land use in terms of its functions in regulating hydrological processes and in protecting the soil. Deforestation causes the decrease in soil infiltration capacity, with as a consequence of increase runoff and accelerated soil erosion, and more extreme discharge characteristics. The amount of water streaming out of the area increases whereas the difference of water yield between the dry and wet seasons also increases.

Generally, deforestation decreases evaporation (especially from the intercepted rainfall on plant canopy) and transpiration due to lower leaf area and shallower root system of the successive vegetation. Infiltration decreases following deforestation due to combined effects of soil compaction, exposure of soil surface to rain drops and removal of tree litter that otherwise protect the soil surface. These lead to increased runoff and soil loss and subsequently lower productivity of the land. The downstream area could be affected because of the higher wet season flow and lower quality of stream water due to sediment load following deforestation.

What safeguards are needed during forest clearing, and in the development of alternative land use systems, to minimize damage to the environment?

- Well developed ground cover
- Well developed canopy
- Proper lay-out of road system
- No use of heavy machinery
- Maintaining riparian buffer zones
- Selective logging (not too much removal of biomass)

If a piece of land is deforested with care, in other words, if the soil properties are maintained and the infiltration capacity of the soil stays at the same level, then base flow will increase (due to lower evapotranspiration of crops compared to forest).

Forests represent important values over and beyond their hydrological functions. Damage to watershed functions can, however, be avoided by more careful conversion practices and by securing protective land use practices that re-create the essential 'forest functions' in an agriculturally used landscape.

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 *minus* 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

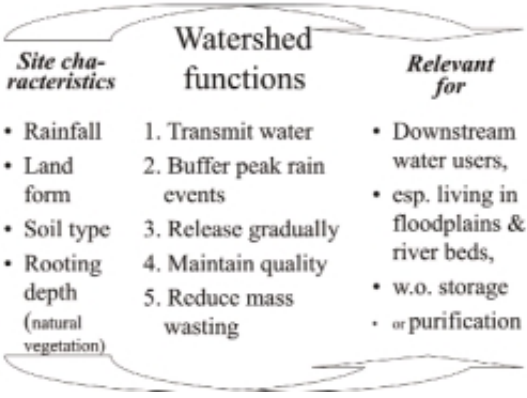


Figure 2. Five criteria for watershed functions that relate site characteristics to aspects of river discharge that are relevant to specific groups of downstream stakeholders

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).

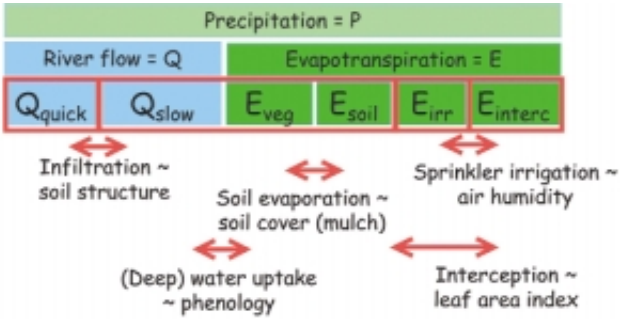


Figure 4. Five controls exerted by land cover and land use on the partitioning of precipitation over river discharge and evapotranspiration

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).

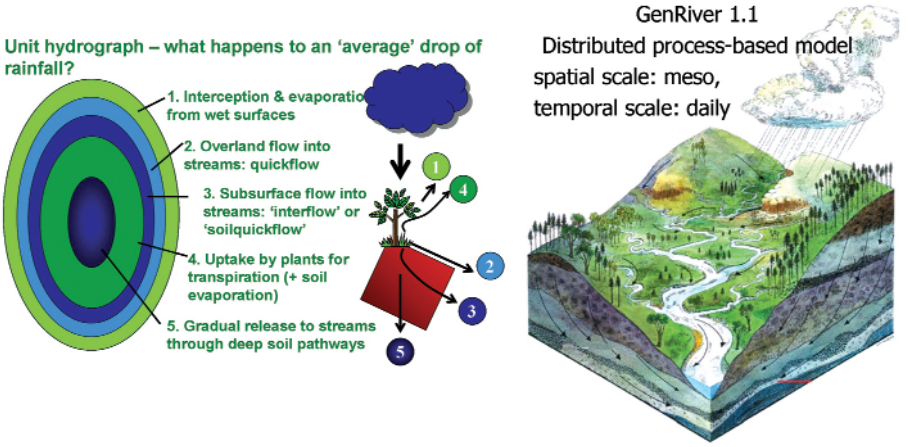


Figure 5. Basic processes represented in the GenRiver model developed at ICRAF and available from www.cgiar.icraf.org/sea

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	Stake-holder 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 daily P & Q	√
	2.1b Relative buffering indicator, adjusted for relative water yield		daily P & Q daily P & Q	√ √
	2.1c Buffering peak event		(hydrograph segregation)	√
	2.2 Highest of monthly river discharge totals relative to mean monthly rainfall		(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	Stake-holder 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 of 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 ion 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 lat 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 lead 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 Pashya *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 'kebun lindung' 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.

Environmental Services of Agriculture and Farmers' Practices Worth Rewarding

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Agricultural functions in producing food, timber, fiber, and various other marketable products have long been known by policy makers and the population at large. Other functions of the agricultural landscape, however, such as environmental services, food security, employment of about 40% of the 99 million labor force in Indonesia, buffer of the country's economy at times of crisis, and maintenance of rural amenities get less recognition than they deserve. This paper reviews environmental services as part of the multifunctionality of agriculture and discusses whether rewarding farmers for those services is justifiable. Discussion is focused on the major agricultural systems including lowland rice, annual upland farming, smallholder plantation, and monoculture estate, as well as on conservation practices within the systems. The main indicators discussed include soil erosion and sedimentation, flood mitigation, carbon sequestration, and biodiversity. As forest is converted to agricultural lands, some of its environmental services disappear. The nature of the succeeding agricultural systems determine the degree of recovery of the services. Further conversion of agriculture to industrial and settlement areas, results in subsequent and mostly irreversible disappearance of agricultural environmental services. Lowland rice fields can filter sediment from the surface flows in a landscape and contribute to flood mitigation; two important functions in areas upstream of flood-prone areas. Smallholder plantations, characterized by complex agroforestry systems, sustain various positive functions including erosion control, flood mitigation, carbon sequestration, and biodiversity. Monoculture tree-based systems are low in biological diversity but they can still contribute in sequestering carbon, flood mitigation and erosion control. Annual crop-based farming systems

have relatively low erosion control, flood mitigation, biodiversity and carbon stock. Intensive vegetable farming, being mostly distributed on steep slopes with high chemical inputs, threatens water quality in the area downstream and may contribute to sedimentation depending on the overall filter functions of the catchment. With the high and increasing population pressure, the demands for using the lands, including the less suitable ones for agriculture as well as for settlement and industry, also increase and the environment is more and more threatened. Therefore, the environmental services become scarcer and more precious. Farmers' services in the forms of practicing environmentally benign farming systems and implementation of conservation practices such as life fences, grass strip, and modification of micro relief (sediment pits, terraces, furrow-ridging) within a fragile environment deserve recognition and rewards from the beneficiaries. Furthermore, the government can increase effectiveness of incentives for two-pronged (economic and environment) practices, for example, by realignment of the funds of national land rehabilitation movement.

Introduction

Beyond its primary function of supplying food, fiber and other marketable products, agricultural activity can also shape the landscape, provide environmental benefits such as land conservation and preservation of biodiversity, contribute to food security and maintain amenities of rural areas (OECD, 2001; Agus and Manikmas, 2003). Agriculture is a safety net for employment and source of income of about 40% of 99 million Indonesian workforce (BPS, 2004). These additional functions (multifunctionality) are not recognized in the current market system and mostly remain external to government policy decisions. Intensification (the use of more labour, energy and agricultural inputs per unit of land to achieve higher outputs per unit area) and extensification (the use of a larger area) of Indonesian agriculture has been able to increase the production of food and fiber although the total production has not met the demands of the entire ever-increasing population, and thus import is inevitable to fill the deficits.

Agriculture produces positive environmental functions - at least in many cases environmental degradation is not as severe as it might be,

although these positive aspects are usually not recognized and rewarded as such. Policies in natural resource management systems that enhance the positive and minimize the negative functions are the key to the sustainable use of natural resources.

Environmental services and other functions are essentially contributions made to society at large free-of-charge by farmers, the majority of whom still remain among the poorest and marginalized communities. There are many disincentives in farming in the forms of recurrent market failures, policies biased towards non-agriculture, unavailability or unaffordability of agricultural inputs, and problems with infrastructure and marketing. Farmers also face hardships because of unpredictable weather and pests and disease problems.

So far, there has been limited documentation on environmental functions of agriculture in Indonesia. Deeper and more convincing research-based knowledge is necessary to increase awareness among policy makers as well as the entire communities on the multifunctionality of agriculture. Comprehensive study and policy papers on the improvement of positive functions and reduction of negative externalities will hopefully lead to a more judicious and unbiased policy formulation, i.e. the policies that can promote practices for both economic and environmental improvements. This paper discusses environmental services of different agricultural systems and practices and systems that deserve rewards.

Environmental services of agriculture

There are many kinds of environmental services that agriculture can provide. These include the functions of erosion control, flood mitigation, water preservation, heat mitigation (Agus *et al*., 2001), preservation of biodiversity, and carbon sequestration. The following section will discuss selected functions.

Erosion and sedimentation under different land management systems

Sutono *et al*. (2003) used the universal soil loss equation (USLE) to calculate annual soil loss under different land use systems in the Citarum River Basin (Table 1). Please note that the results of this equation apply to

a particular scale of measurement and cannot be directly used to estimate net soil loss from larger areas, as landscape-level deposition in 'filter' areas can reduce the net soil loss per unit area. The plot-level prediction used primary and secondary available data in the river basin area and as such, not only land use and management systems (soil cover and management systems, the C and P factors) differed but also other factors such as slope, rainfall erosivity, and soil erodibility depending on the spatial variation of the latter properties. In general, it was shown that the annual upland crop system has the highest soil loss, followed by intercropping of annual upland crops with trees.

The annual upland crop system in general is a rotation or a relay planting of food crops such as cassava, maize, peanuts, soybean and upland rice or intensive vegetable farming systems that usually coincides with steep slopes. Because of minimum soil protection by crops most of the year, these annual upland farming systems are very prone to erosion. Tea plantation gives rather high soil loss because of incomplete soil cover which lead to a high crop factor, the 'C' factor, apart from the fact that it is also usually found on steep slope areas. Paddy fields and forest have the lowest soil loss because of terrace and dike systems of the former and the thick and multi-storeyed vegetation of the latter.

Van Dijk (2002) reviewed literature data on catchment scale erosion research (Table 2) that show a general agreement with the predicted values in Table 1. In general, forest catchments have the lowest sediment yield except for teak forest (with almost clean understorey). Vegetable based system have the highest sediment yield. The systems associated with intensive annual cropping on steep slopes also contribute to a high bed load in the streams and rivers due to a limited filter function of the catchment.

The role of trees and grass strips

Under similar rainfall amount and pattern (the research catchments were within 1 km radius), Agus *et al*. (2002) derived sediment yield data from Tegalan (a 1.1 ha catchment dominated by annual upland crops), Rambutan (a 0.9 ha catchment covered by 10 year old Rambutan, Nephelium lappaceum trees), and Kalisidi (a 13 ha catchment also covered by rambutan but with some annual crop planting on the lower part of the catchment) (Figure 1). The total sediment yield for Tegalan, Rambutan, and Kalisidi catchments were 20, 1.7, and 2.9 Mg ha^{-1} under

annual rainfall of 3800 mm indicating that orchard farming can substantially reduce soil loss.

Because of the high sediment yield under intensive annual upland crop the use of fodder grass in conjunction with cattle fattening activity was introduced in December 2001 and the result shows a reduction of sediment yield for Tegalan in 2002 compared to 2001 (Figure 1). Total annual rainfall was slightly lower in 2002 than 2001 (3100 mm vs 3800 mm). As the grass cover develops, its effectiveness in controlling erosion is increasing. On the other hand, cassava planting on the part of the floor of Rambutan orchard in Kalisidi catchment (because of encroachment by local villagers) loosens soil aggregates and exposed it to rain and canopy drops and thus contributed to the increase in sediment yield.

Similar to the case of Rambutan, coffee also contribute in decreasing soil loss. Based on plot-scale experiments, Pujiyanto *et al.* (2001) showed that soil loss was very high for plots without any conservation measures in the first two years after coffee planting because the canopy cover is relatively limited. During the first two year period, conservation practices such as bench terrace and hedgerows were effective in reducing erosion. Beginning in the third year, however, soil loss became negligible due to effective canopy closure and conservation measures did not give any effect whatsoever (Table 3).

Table 1. Predicted soil loss of different land use systems in Citarum River Basin.

Land use	Catchment		
	Saguling (uppermost) Mg ha^{-1} yr^{-1}	Cirata (upper)	Jatiluhur (lower)
Forest	0.1	0.2	0.1
Intercropping of annual crops with trees	8.4	15.4	36.9
Rubber plantation	-	8.8	11.4
Paddy field	0.3	0.4	1.4
Shrub	1.1	1.6	0.5
Annual upland crops	22.0	61.3	40.1
Tea plantation	23.1	26.9	9.6

Table 2. Runoff coefficient (RC), Sediment yield (SY) and bed load percentage observed from different catchments in Indonesia as cited by van Dijk (2002) from several references.

Land use	Catchment Size	Period of measure-ment	RC (%)	SY Mg $ha^{-1}yr^{-1}$	Bed load %
Forested					
Rainforest	45 km^2	3 years	-	7	-
Rainforest	1-45 km^2	-	-	4-7	-
Rainforest	-	-	-	4	-
Mixed plantation forest	3-12 km^2	3 years	2-6%	0.4-4	1-10%
Pine plantation	18 ha	-	-	0.4-2	-
Agathis plantation forest	20 ha	-	-	4	10%
Teak forest	79 km^2	1 year	-	73	-
Other land uses					
Vegetables on steep terraces	10 ha	3 years	17%	42-75	-
Vegetables on steep terraces	3 ha	4 months	12%	87	5-10%
Logged pine plantation forest	32 ha	-	-	34	-
Logged rainforest	-	-	-	51	-
Mixed (agriculture, forest)	12-22 k km^2	3 years	3-10%	10-12	8%
Agriculture on bench terraces	8-20 ha	1 year	3-9%	19-25	5%
Agriculture on bench terraces	18 ha	-	-	12-14	74-80%
Agriculture on bench terraces	0.1-125 ha	6 years	6%	40	30%

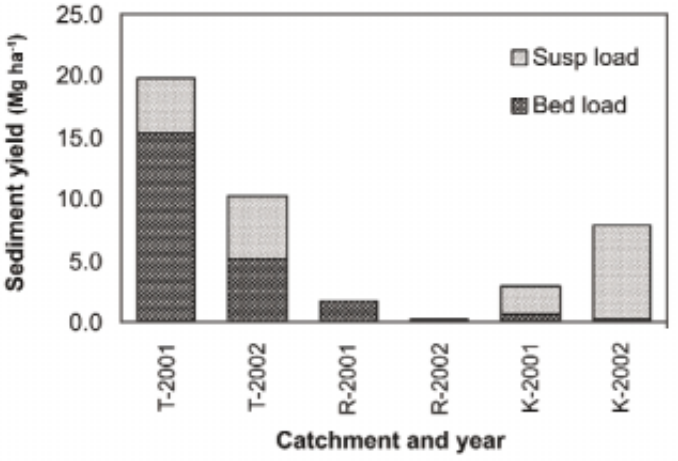


Figure 1. Suspended load and bed load yielded in 2000/2001 (denoted as 2001) and 2001/2002 (denoted as 2002) rainy seasons for Tegalan, T (annual upland catchment); Rambutan, R (rambutan orchard catchment); and Kalisidi, K (rambutan orchard catchment with some cassava on the floor). (Agus *et al*., 2003).

Table 3. Effects of bench terrace and hedgerow planted along terrace lips on soil loss at coffee farm in Jember, East Java on land with slope of 31% and annual rainfall of 2,768 mm during the first four years after coffee planting).

Treatment	Soil loss (Mg ha^{-1} $year^{-1}$)			
	Year 1	Year 2	Year 3	Year 4
Control (no terrace)	25.80 ab)	17.75 a	0.55 a	0.88 a
Bench terrace	1.51 b	1.17 b	0.35 a	0.82 a
Terrace + L. leucocephala	3.03 b	1.19 b	0.28 a	0.82 a
Terrace + V. zizonioides	1.90 b	0.61 b	0.28 a	0.83 a
Terrace + M. macrophylla	0.33 b	0.88 b	0.21 a	0.83 a

a) Source: Pujiyanto *et al.* (2001).
b) In one column, numbers followed by common letter are not significantly different as tested using the Tukey test at the 5% significance level.

Widianto *et al.* (2002) based on erosion measurement in Sumberjaya, West Lampung, evaluated soil loss under forest and different stages of coffee development. This plot-scale measurement was conducted at scattered location and therefore, the effect on soil loss is not only determined by land use and coffee growth stages, but could also be by variation in rainfall amount and soil properties. Nevertheless, the trend in soil loss as found by Widianto *et al.* (2004) is in agreement with that of Pujianto *et al.* (2001) (Table 3).

In Sumberjaya sub district, Lampung, Dariah *et al.* (2004) recorded similarly negligible (less than 2 Mg ha^{-1} yr^{-1}) soil loss under 3 year coffee cover and annual rainfall amount of 2400 mm and the slopes of 50-60%. As such, different conservation techniques they tested did not give significant effects. Earlier on, Gintings (1982) measured soil loss at the same sub district for six month period with the rainfall of 1338 mm on slopes reaching 60%. The author found that soil losses for the six month period were 1.9, 1.6, 1.3, and 0.3 Mg ha^{-1} respectively for land covered by 1, 2, and 16 year old coffee and by virgin forest. The whole year soil loss is expected to be no more than twice as much since average annual rainfall is about 2400 mm.

These research findings consistently show that tree-based systems is an effective erosion control measure. Coffee and rambutan cases, above, exemplify the systems that are not only environmentally save, but also relatively profitable.

Paddy Field as a sediment filter

Soil loss measurement from terraced paddy field system in Ungaran, Central Java, on land with major slope of about 25% revealed that sediment leaving the paddy system is very small (<1.5 Mg ha^{-1} $season^{-1}$) and more than 50% of the erosion occurred during and shortly after tillage operation (Table 4). During the erosion observation, mud (particles and aggregates suspended during tillage) transported to only a few terraces downward and this means that particles reaching the stream originate from only a few series of plots / terraces above the streams. Water flow only occur when the water level in the plot exceed the normal water level of 5 cm during the vegetative stage of rice plant. If water level during and shortly after tillage operation can be controlled such that no or only little outflow of water is allowed, erosion from paddy field could further be minimized. Table 4 also shows a net sediment deposit in the paddy field. This means that paddy field can function as a landscape filter.

Table 4. Amount of sediment entering and leaving a series of 18 terraced paddy fields (ranging in size between 12 to 358 m^2, with a total area of 2515 m^2 in two rice seasons (first season was 31 October 2001 to 31 January 2002 and second season from 16 March to 1 July 2002).

Variable	Rice season	
	First	Second
Duration of observation (day)	62	69
Sediment budget:		
Total sediment entering the system from irrigation canal (Mg ha^2)	3.4	6.2
Total sediment leaving the system (Mg ha^2)	1.4	0.8
Total sediment leaving the system during tillage operation (Mg ha^2)	0.7	0.6
Net sediment deposition (Mg ha^2)	2	5.4

Source: Adapted from Kundarto *et al.* (2002).

Water retention

Agus *et al.* (2001) estimated water retention capacity of several land use systems in Citarum watershed in West Java and Agus *et al.* (2003) evaluated the flood mitigation role of paddy farming for the same case study area using the replacement cost method and the travel cost method.

Water retention capacity (Buffering capacity, BP) is the watersheds capacity to absorb and hold (rain) water. Only rainfall in excess of this water retention capacity will flow as runoff water during and shortly after every rainfall event (Nishio, 1999). The water retention capacity includes water that can be absorbed by soil pores, water that can be stored by ponding on the soil surface, additional water that can be stored by paddy fields, dams, etc. and water intercepted by plants. In essence, this property indicates the flood mitigation capacity of each land use systems. Agus *et al.* (2003) found that tree-based farming systems maintain most of the flood mitigation capacity exerted by forest. Paddy fields, with their terrace and dike system behave like small dams in collecting and ponding water and thus have similar water retention capacity as tree-based agricultural systems (Figure 2).

Furthermore, Agus at al. (2003) discussed that the marketable products of the 157,000 ha paddy field within the 696,000 ha total area of the watershed represented a total value of around $181 million annually and the value of flood mitigation role accounted for about 10% of this amount (about $18 million per year). The total values of flood mitigation, conservation of water resources, soil erosion control, organic waste disposal, rural amenities, and heat mitigation accounted for about 51% of the marketable rice value (about $92 million per year). The current market system only recognizes rice as the product of agriculture and ignores the by-products (externalities).

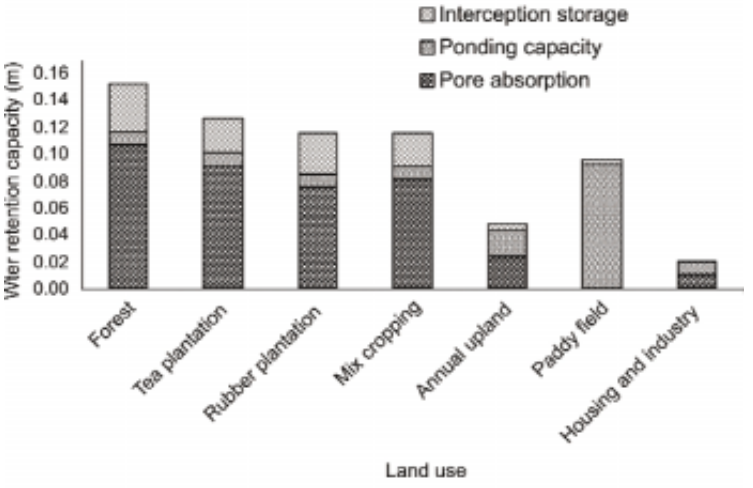


Figure 2. Water retention capacity (capacity of the system to hold water temporarily before runoff occur) of different land use systems in Citarum River Basin (Agus *et al.*, 2003).

Carbon sequestration and biodiversity

The main source of CO_2 in Indonesia is forest conversion which, in many cases, involves burning (Ministry of Environment, 1999). CO_2 emission from forest conversion is much higher than from fossil fuel combustion.

Among agricultural land uses, tree-based farming systems have the highest while annual food crop system have the lowest carbon stock (Table 5). Efforts to maximize carbon storage include diversification of food crops with trees or the adoption of agroforestry system. For coffee system in Lampung Sumatra, the mean annual increment of C-stock of mixed coffee systems is about 1.9 Mg ha^{-1} yr^{-1} during a typical production cycle, and that of a monoculture coffee system was about 1.0 Mg ha^{-1} yr^{-1} (Tomich *et al*., 2001; van Noordwijk *et al*., 2002). Combination of various crops in complex agroforestry systems are common under smallholder farmers not only in Sumatra and Kalimantan where the so called "rubber agroforest" or "rubber jungle" is common, but also in Java where the annual food crop are planted in association with various species of perennial tree crops.

In the forest margin of Sumatra, plots of traditional agroforestry systems can inhabit plant species approximating the number of species in forest. As agriculture intensifies it is dominated by monoculture farming system that, in many cases, have negative impacts in sustaining biodiversity (Table 5).

Practices worth rewarding and mechanism for technology selection

Land us systems differ in the environmental services they provide, depending on the specific management practices used. Practices that deserve rewards are those producing services needed by the community. For example, if flood is the recurrent and growing problems in the downstream, then every practices for increasing or at least maintaining the water retention function of the landscape, deserve rewards. In this case, linking the problems with the farmers' practices that can maintain or increase services to solve such problems is an essential process. This process include identification of watershed-specific problems, identification of interventions that have been or could be done by the farming community to solve or alleviate the problems, selection of most

do-able practices and provision of guidance and incentives for implementing new practices. Location-specific solutions developed by farmers themselves, with or without external support, are superior to the conventional blanket recommendations. The 'extension' challenge is to facilitate and speed up the process of local learning.

Table 5. Carbon sequestration and biodiversity for the Forest Margins of Sumatra

Land use	Carbon sequestration	Biodiversity
	Time averaged C stock (Mg ha^{-1})	Plant species / standard plot
Natural forest	254	120
Community- based forest management	176	100
Commercial logging	150	90
Rubber agroforest	116	90
Rubber agroforest w/ clonal planting material	103	60
Rubber monoculture	97	25
Oil palm monoculture	91	25
Upland rice / bush fallow rotation	74	45
Continuous cassava degrading to Imperata	39	15

(adapted from Murdiyarso *et al*., 2002)

Participatory rural appraisal - a survey technique in which farmers and extension workers communicate iteratively about the local farming systems, including the prospects and constraints - has officially become a standard procedure in the technology-selection process of development projects in Indonesia. However, in practice, recommendations found in many demonstration units or development projects have not reflected the diverse biophysical and socio-economic backgrounds of farmers but appear to be still dominated by standard recommendations. For example, slope gradient has been regarded as the main criterion for determining the number of trees per unit area. Lands with slopes gentler than 25%, between 25 and 40%, and steeper than 40% are 'reinforced' with 100, 200 and 400 trees ha^{-1} to give 25%, 50% and 100% tree canopy cover, respectively (unpublished 1996 Regreening and Reforestation Guidelines issued by the Central Guidance Team of Regreening and Reforestation). Wider issues, such as existing tree stands, subsistence mode of farming, insecure land tenure that forces farmers to invest in activities with fast returns, and inaccessibility to markets, have not been fully considered in technology selection. Tree planting is acceptable to farmers as long as it

does not distort existing annual crop based farming. For those with insecure land tenure, however, getting a fast return on their investment is a lot more important than any other consideration (Agus, 2001).

Management options should address the main issue at stake, and thus start from thorough analysis of cause-effect relations, but should also be viewed from their effect on farmers' basic necessities. Thus, it's very important to have an open and transparent dialogue or negotiation among stakeholders to analyze the problems, possible causes, and problem-solving or alleviating options (van Noordwijk at al., 2004; this volume). Examples of links between watershed problems, causes and management options are given in Table 6. Some of the causes of the problems are natural. These include untypical long dought or excessive

Table 6. Selected watershed problems, causes and management options

Problems	Possible Causes	Problem solving or alleviating options
Significant reduction of water volume (subsidence of water level) in lakes	Long drought	Implementation of drought mitigation measures
	Artificial increase of volume of water output from the lake, such as through dredging of river bed or tunneling water out of lake for hydroelectricity, industry and irrigation.	Increasing inflow into the lake by reducing evapotranspiration in the lake catcment. Sparing water use
Decreased capacity of lakes and dams	Erosion (including stream bank erosion) from the watershed, followed by sedimentation.	Improving plant cover in the catchment Grass strips Establishment of riparian zone Protection of unstable stream bank
Flood	Excessive rainfall	Construction of flood mitigation structures such as dam and flood canal
	Reduced water retaining capacity, reduced infiltration capacity	Enhancement of infiltration and percolation through construction of water retardation ponds and pits Increasing water consumption in the catchment, for example, by tree planting Protection of soil aggregate breakage by mulching, plant cover, and maintenance of plant litter on soil surface
	Clogging of or insufficient drainage system	Maintenance and construction of new drainage system.
	Sedimentation	Improvement of landscape filter through plant cover, life fences, agroforestry, paddy field systems, etc.

rainfall. Some causes are anthropogenic, including improper land use, artifical intervention of ecosystem balances such as by channelling water out of lake.

Conclusions and policy implications

With a high population pressure and growth of 1.6% per year, there is a strong pressure for intensifying agricultural systems and for extending agriculture even to unsuitable steep slopes and marginal lands for producing enough food, wood and fiber and for providing income opportunities. At the same time, land is also needed for settlement, industrial and infrastructural developments. As land from forest is converted to agriculture and agricultural lands are converted to other non agricultural uses, many environmental services tend to disappear and thus the services will become more precious necessities.

Different agricultural systems provide also different environmental services. Smallholder plantations, characterized by complex agroforestry systems, sustain various positive functions including erosion control, flood mitigation, carbon sequestration, and biodiversity. Monoculture tree-based systems lose numbers of species although it can still contribute in sequestering significant amount of carbon, mitigate flood, and control erosion. Intensive paddy farming system has been able to control erosion to a level as low as that of forest. Monoculture annual crop-based farming systems have a low erosion control, low biodiversity and carbon stock but techniques to develop the systems into a more environmentally-benign practices are available, although are not necessarily affordable by farmers.

Traditional agricultural systems and practices maintain significant services, but farming faces lots of disincentives related to supplies, marketing and infrastructures. Since the needs for agricultural products and environmental services are increasing and both are not mutually exclusive, rewarding the farmers, as the environmental service providers, is indeed justifiable. The beneficiaries of the services and government should participate in this endeavor. Government support could be realized through realigning of the current budget of land rehabilitation and conservation to a more problem solving and people oriented approach such that it can contribute in increasing environmental services while providing a better livelihood for farming communities.