7.2 Appendix 2 Terminology used for watershed functions

The broad category of 'watershed functions' may well be the first 'environmental service functions' that has been recognized as such, and it continues to be the one with the largest immediate relevance for people, especially for poor people who don't have the opportunities of the better-off to shield themselves from the impact of droughts, floods and poor quality of water. With strongly increasing demand for water and a constant supply, the prediction that conflicts over water are likely to increase is easily justified.

A simple way to explore the overall concept of 'watershed functions' is first of all to look at the hydrological 'outcomes', in this case the flow of water coming out of an area in rivers, and sometimes in subsurface groundwater flows. We can distinguish (see ASB lecture note 7) between the

- Quantity or total water yield
- Evenness of flow, which implies high flows in the 'dry' season and an absence of strong peak flows in the set season
- Quality of water, with respect to its use as drinking water, other domestic uses, industrial use, irrigation or as habitat for fish and other water organisms

These three aspects are influenced by land use to different degrees, and this has consequence for possible 'reward' mechanisms.

7.2.1 Total water yield

Rainfall varies between different parts of the earth, from approximately 0 to over 10 m of rainfall per year (that means that if rainfall would not infiltrate the soil or runoff laterally a lake of 10 m depth could be formed in a year, in the absence of evaporation at the surface of the lake). Rainfall is usually expressed in mm rather than m, and is broadly linked to the type of natural vegetation: evergreen tropical forest usually requires rainfall amounts of more than 1500 mm $year^{-1}$, deciduous (= shedding leaves in an 'off' season) forest and savanna may grow in the 800 – 1500 mm $year^{-1}$ range, and various forms of scrub or open vegetation in the 300 – 800 mm $year^{-1}$ range. Below 300 mm $year^{-1}$ very few crops can be grown without irrigation, and the natural vegetation will consist of short grass or desert specialists. As forests are associated with high rainfall, it may come as no surprise that the cause-effect relation has been confused: do forests cause rainfall? Or does rainfall allow forests to grow?. The perspective that deforestation will lead to a reduction of rainfall has a long history (elegantly reviewed by Williams in his book 'Deforesting the Earth'), but remarkably little hard evidence in its support, despite the large scale at which the 'experiment' of deforestation has been implemented, first in Europe, than in north America and currently in the tropics.

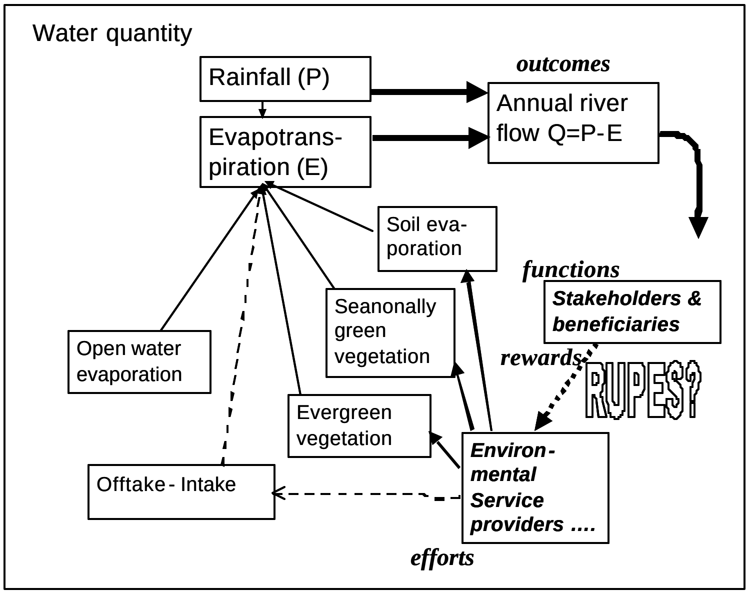

Figure App2.1. Schematic relations of 'water quantity' as landscape outcome

Current evidence points to clear relations at global scale, with atmospheric circulation and thus rainfall zones shifting even if the total may stay the same. Some places definitely have become wetter, others drier, and future changes may add to variability, even if the direction of change for specific locations is not clear yet. These real changes in climate have coincided in many parts of the tropics with real changes in forest cover – even though the causal link is indirect, via global climate change. The continued perception of a direct link is thus understandable, but a real effects is unlikely to be large, if it exists at all. If we take for granted that effects of local land use on total annual rainfall are small, the main effect on total water yield of a catchment area is a change in the rate of evapotranspiration, or the return flow of water molecules to the atmosphere. In a simple equation: Q = P – E, or the total water yield (surface rivers+ groundwater flows) equals precipitation (rainfall plus snow and ice, which in most parts of the tropic can be ignored) minus evapotranspiration. That leads to the scheme in figure App2.1.

Four classes of land cover can be distinguished from the perspective of evapotranspiration:

- open water bodies, where water loss is determined by the relative humidity of the air and the presence of a stagnant boundary layer of air that reduces the transport of water vapour,
- open soil, which may have a rate of evaporation similar to open water bodies when the surface is wet, but where evaporation may rapidly become limited by the rate of transport to the soil surface; soil cover with a litter layer provides a stagnant air zone, further reducing transport opportunities and mixing with the atmosphere
- seasonally green vegetation: most plants are able to provide their leaves (evaporating surfaces) with the amount of water that is needed for evaporation similar to an open water surface, during most of the rainy season; during periodic

dry spells, plant transpiration is likely to drop below the value of open water, but stay above that of open soil,

- evergeen vegetation such as evergreen trees (e.g. pines, eucalypts, trees such as grevillea), irrigated rice paddies or vegetable crops will have a rate of transpiration equal to that of open water, or higher if lateral flows of dry air drive the evapotranspiration per unit area to higher levels.

Efforts of land users that will reduce evapotranspiration and thus increase total water yield may thus be found in ***not*** planting evergeen trees (especially fast growing ones), or irrigating rice paddies or vegetable crops in the dry season.

The differences in total water use between different types of vegetation (deciduous or evergreen) are often less than 300 mm year^{-1}. In a climate zone with a n annual total of 1500 mm year^{-1}, such a difference is likely to be noticeable (and many villagers complain that reforestation with pine trees or eucalypts reduces dry season flow or total water yield – even though the public and forest service tends to believe that such trees will increase water yield….). In climates with higher rainfall the same absolute difference will be smaller relatively speaking., and may drop below the threshold of what people can notice and care for.

Overall we can say that the total water yield of any 'catchment' area is largely determined by rainfall and thus outside of the control of any local land users. The difference that land cover can make is fairly well bounded (less than 300 mm year^{-1}), and rewards for efforts may have to focus on this difference against baseline, rather than at the total volume that actually comes out of a watershed (unless attributes a greater influence to 'human rainmakers' than most of them would subscribe to themselves).

Total water yield per unit rainfall can be used as indicator, with a value that increases more than proportionally with total rainfall. The potential effect of land use change is likely to decrease more than proportionally with total rainfall.

7.2.2 Evenness of water flow and buffering

Floods alternating with droughts – that is the general picture of 'disturbed watershed'. When we make a comparison across the tropics, however, we see that not only the total amount of rainfall per year varies over more than two orders of magnitude (i.c. from 0.1 – 10 m year^{-1}), but also the variability: the number of dry and wet months can vary quite independently of total rainfall (giving rise to various climate classification schemes that use the number of dry and wet months rather than total rainfall). Evenness of riverflow, in the sense of a continuation of flow during dry months and an absence of high peaks and floods in wet months, may thus be largely attributed to the local climate – and thus to the 'natural capital'. Land cover, and thus the decisions of local 'actors' will influence the degree of 'buffering', but we need to carefully tease out the part that can be influenced, if we want to get a clear basis for 'rewards'.

A straightforward way to define 'buffering' is to compare the total quantity of river flow at above-average rates, with the total quantity of rainfall at above-average rates. Buffering equals 1 – the ratio of these two quantities, both expressed in mm year^{-1}. As daily rainfall data are most widely available, we can take this timestep as a basis for the calculations of what is above average riverflow or rainfall. A fully 'asphalted' watershed where riverflow directly follows rainfall may have a buffering of 0, a watershed that provides constant riverflow regardless of the rainfall pattern has a buffering of 1. Real watershed will be in between these two extremes.

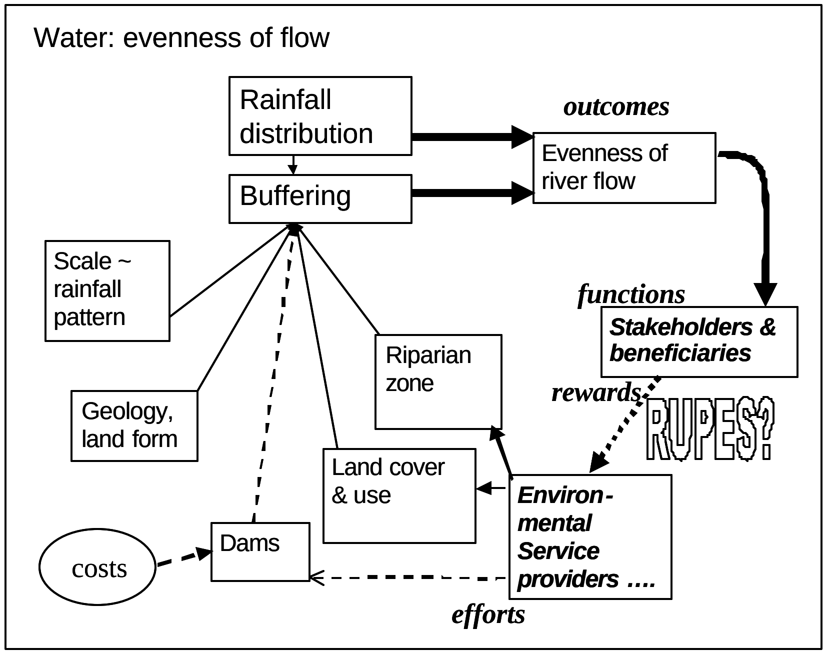

Figure App2.2. As figure App2.1, but specific to the 'evenness of water flow' function

With this definition of buffering, we can further analyze a range of influences. Land cover is important, especially where it influences the rate of infiltration of rain into the soil, by maintaining a good soil structure (one can argue whether it is the earthworms that do this, the trees that feed the earthworms, or the farmers that plant the trees, but that is another story). But the basic make-up of the landscape, the depth of soil over bed-rock, the slopes, and the type of soil (soil texture, specific soil horizons that don't allow water to penetrate all influence the degree of 'buffering'. A further influence on 'buffering' is the degree of spatial correlation of rainfall: where rainfall is dominated by 'fronts' large areas may receive rainfall on the same day; where (convective) thunderstorms dominate, a strong 'patchiness' of rainfall may cause different streams to carry water at different days and a river that integrates across these streams to be relatively stable – even without forest cover. Buffering, according to our definition, will thus depend on the location of the observer relative to the watershed. The further away, the more even the river will tend to be, and the less obvious effects of land use change may be. Current research is trying to quantify these relations, but empirically good evidence for changes of land use on evenness of flow exists for catchments up to 100 km^2 and little or none for catchments of more than 1000 km^2.

With current hydrological models it is possible to determine which part of the overall degree of 'buffering' that an observer at a certain distance from a 'catchment area' will perceive can be directly related to the land use in the catchment, with a specific role for the riparian vegetation in and around the riverbed. Slow transmission of water, linked to trees and dead wood in the channel, may cause local flooding, but increases the evenness of flow of a downstream observer (again clarifying that we need to be explicit about the point of observation or the location of the stakeholders before we can quantify 'evenness of flow').

An efficient way of presenting the input and output of a watershed area in a single graph, is to look at the exceedance probabilities for daily rainfall, daily evapotranspiration and daily riverflow. If a sufficiently long time period is considered (at least 1 year), changes in storage in soil, groundwater and surface water may be negligible and the areas to the left of the curves for rainfall and evapotranspiration + riverflow should be approximately equal. The point of intersection has to have an X-value that equals the mean daily rainfall. The intersection would be at an exceedance probability of 0.5 if rainfall distribution were symmetrical and there would be no dry days – in reality skewness of rainfall distribution plus the fraction of days without rain cause the point of intersection to have a value on the Y-axis that is above 0.5.

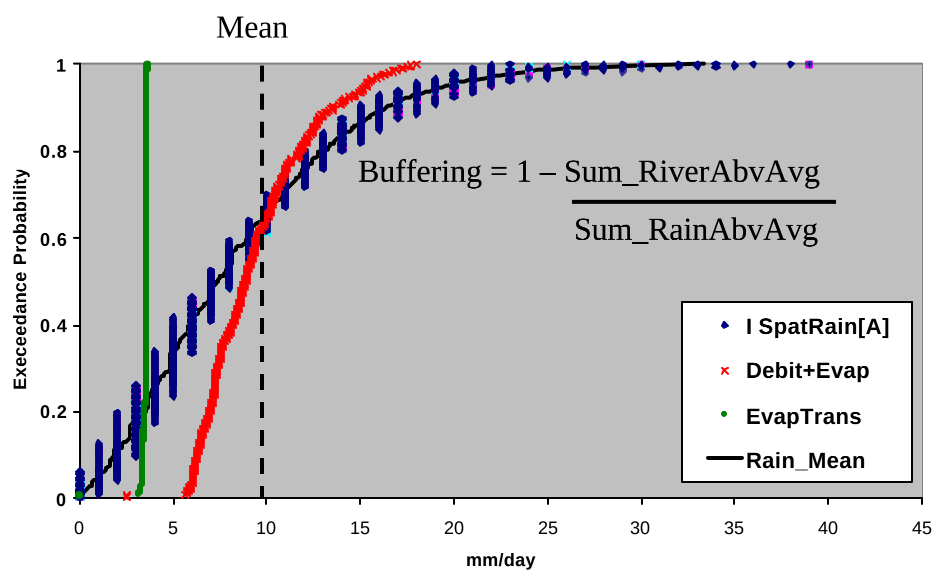

Figure App2.3. Schematic form of exceedance curves for rainfall (P), evapotranspiration (E) and river flow (Q), based on an example generated with the GenRiver model

In an 'asphalted' watershed, the riverflow curve may be expected to coincide with the rainfall curve and there is no buffering. In an ideally buffered situation the riverflow may be constant and equal to the mean at every day of the year. In between these two extremes we'll find real watersheds with a partial 'buffering'.

A quantitative indicator of 'buffering' (0,1) can be derived as

$$Buffering = 1 - \frac{\sum_{0}^{1} riverflow\_exceding\_mean}{\sum_{0}^{1} rainfall\_exceding\_mean}$$

If, hypothetically, rainfall would be constant, the watershed will not be able to express any 'buffering', and the buffering would be zero. With this definition we can explore 'buffering' as the resultant of:

Site

- local rainfall regime (and its temporal autocorrelation)
- underlying landscape and geology that determines release of groundwater

Scale

- size of the catchment (upstream of the observer/stakeholder) relative to the spatial autocorrelation of rainfall

Land use

- infiltration and supply to groundwater as potentially influenced by vegetation and land use
- the properties of the riverbed (and temporary storage) that dominate pulse transmission

Engineering

- any regulating structures or dams in the river

We can thus separate the 'buffering component' that is attributable to land use (and thus to ***human 'environmental service providers***') from those that '***come with the territory'*** but do not reflect any specific effort (and thus form no basis for ES function rewards…).

7.2.3 Water quality

Water from forests streams can be directly suitable for drinking, if one can be sure no people live upstream. Otherwise, surface water is hardly ever directly suitable for drinking – even if many people in rural areas are in fact relying on it. Water from wells that tap into subsurface flows of water or groundwater may be safe, as long as the filter effect of the soil surrounding the well is not overcharged. pathway of the water. Below the standards for safe drinking water, a range of other uses have less stringent criteria for quality:

- other domestic use
- fishponds and drinking water for domestic animals
- industrial processes
- irrigation
- cooling systems
- filling a reservoir for future use (but allowing sedimentation and other changes in water quality to occur)

Where water from watersheds with natural vegetation may meet the criteria for all, human activity in watersheds may decrease water quality before it has any substantial effect on the other watershed functions (Fig.7). Where point sources of water pollution can be many orders of magnitude above the detection capacity, it is understandable that long range effects of land use on water quantity have been recorded, at least to catchments of 10^5 km^2. Pollution of water can be a consequence of mining (especially where mercury (Hg) or cyanide (HCN) are used for gold mining in riverbeds…), use of pesticides and fertilizer (especially in the quantities often used on vegetable crops) and people living around streams and using the streams for personal hygiene. More directly linked to land use, erosion in its various forms (sheet erosion, gully erosion and collapse of river banks) can increase the 'sediment load' of rivers. Disturbance of groundwater flows by agricultural crops that use less water than the native vegetation that they replaced can bring salt into circulation, especially in drier climates with deep salt deposits.

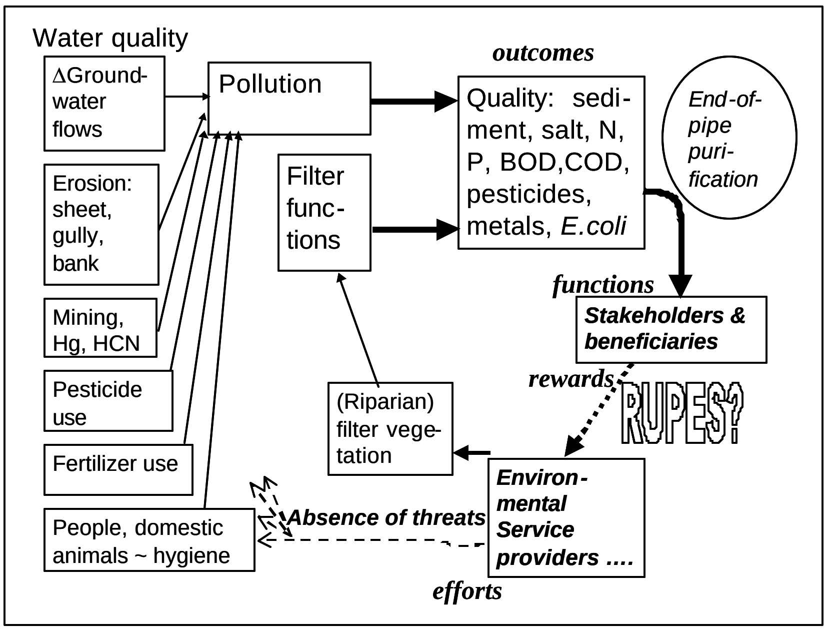

Figure App2.4. As figure App2.1, but specific to the 'water quality' function

'Absence of threats' is thus the key way to provide the 'watershed function' of delivering clean water. For some forms of pollution, especially where 'sediment loads' are due to sheet erosion, vegetation around streams and rivers, in the riparian zone, can perform a (partial) filter function and reduce the load of the river. Increasing the effectiveness of such filter vegetation can thus, under specific circumstances, be seen as 'enhancing watershed functions'.

A wide range of measurable indicators of water quality is available and mostly used for testing the safety of drinking water. River water of very low quantity can still be made suitable for consumption by technical means, relying on filtration in sandbeds, aeration and specific chemical processes. This 'end of pipe' solution can be used as a point of reference for the economic valuation of the provision of clean water (that requires less intensive or no treatment).

7.2.4 Watershed protection

The general public and policy perception of ‘watershed protection’ does not rely on the previous three outcomes, but rather specifies a desirable condition within the watershed (usually ‘forest’) – with all reductions in forest cover associated with a loss of ‘watershed functions’.

The clearest functional relation between trees (especially deep rooted ones) and the integrity of watersheds is found in the prevention of ***landslides***. Landslides can occur on any slope if the weight of a soil column after heavy rainfall is greater than the ‘sheer strength’ or the resistance to movement. Deep rooted trees can provide ‘anchoring’ of soil layers and prevent their movement. When the trees are cut (especially in a ‘clear cut’ affecting all trees on a slope) the propensity for landslide will increase – especially when after a few years, the deep roots decompose. Many landslides, however, are linked to road construction cutting into slopes and interfering with the mechanical stability. Landslides are common in natural vegetation on steep slopes (and geologically young or volcanically active mountain areas), but are usually interrupted by vegetation downhill that can act as a ‘filter’. During earthquakes or extreme rainfall for several days, such filters may loose their effectiveness. After forest clearing, landslides can more easily increase in size, and lea=d to major mudflows destroying everything in their path. Reducing human damage by landslides can be achieved first of all by not building houses in vulnerable sites. In general, avoiding clear felling of forests on slopes will reduce landslide risk. A substantial length of time of observation may be needed, however, to actually proof changes in ‘landslide risk’.

‘***Erosion control***’ is often included in lists of watershed functions, and as positive attribute of forests. In evaluating this as an ‘environmental service function’, we need to be careful. Erosion tends to reduce the future fertility of the eroding site – but this will be the immediate concern of the farmer on the site, rather than outside stakeholders. Similar to the ‘existence value’ in the biodiversity function, one can argue that knowledge of the preservation of topsoil has value to outside stakeholders. Further rationalizations of such value can be derived from the need for farmers to clear further forest lands as a consequence of loss of on-site productivity. The causal chain in these cases is rather complex. In the absence of filter vegetation surrounding the plot, or in the pathway between plot and stream, erosion can increase sediment load of the river and thus reduce water quality.

While erosion rates under most types of forests are low, there are some notable exceptions in forests that do not have an understory or permanent litter layer. Drips falling from a tree canopy after rainfall can actually have a higher splash impact on the soil and lead to greater erosion than would have occurred without (plantation) forest. A simple criterion for absence of erosion id the presence of a litter layer. This works in two ways: it is an indicator that there is little overland flow (otherwise the litter would be washed away) and it contributes to the activity of soil iota that maintain soil structure and infiltration rates for water. The watershed function ‘prevention of erosion’ may thus be better linked to the litter layer than to the presence of trees as such.

Overall, we can conclude that the holistic concept of 'watershed functions' that require 'intact forest' and 'absence of human activity' refers to only one way of maintaining measurable outcomes in the range that is acceptable to downstream stakeholders. Depending on the rainfall, landscape properties and the distance to the watershed area, quantity, evenness and quality of the water in the river can be maintained in landscapes that are used for forms of agricultural production. Key locations for maintaining forest cover are: tops of the ridges and hills if clean groundwater is important and riparian forests for filter functions and slow pulse propagation. Outside of these two 'keystone' locations, we may need enough tree cover to maintain a permanent litter layer and thus infiltration conditions, but the need for this depends on soil type (propensity to loose its structure and infiltration capacity) and rainfall distribution.

7.3 Appendix 3. Input parameters for SpatRain and GenRiver

The following parameters need to be derived from the 'virtual watersheds' that are supposed to represent the different strata in the global sampling scheme.

1. Climate

1.1 Rainfall

A number of formats are possible, as long as they allow a reconstruction of monthly exceedance curves of daily rainfall intensity:

1) 30 (or at least 20) years of daily rainfall records for a station that can represent the area (or multiple stations if these are supposed to be similar), ***or***
2) any 'rainfall simulator' equation with the appropriate parameters that can be used to generate a 30 year dataset for the site (e.g. MarkSim?)

1.2 Rainfall intensity

Data on rain duration and amount for a sampling period that is deemed representative to estimate the mean and coefficient of variation of rainfall depth per hour

1.3 Rainfall spatial correlation

An indication of the degree of spatial correlation in rainfall (correlation coefficient of daily rainfall as function of distance between stations), or of the generic nature of rainfall (frontal rains with high spatial correlation or convective storms that are 'patchy' and show low correlation)

1.4 Potential evaporation

Average values per month, derived from open pan evaporation measurements or from equation such as Penman's that is calibrated on such data

2. Landform

Coarse DEM that allows for derivation of overall difference in elevation within the subcatchment, and a delineation of subsubcatchments. If there is a generic 'language' for the shape of the subcatchments relative to the main channel, we may use this.

3. Soils

1) Mean soil depth (till major restriction for root development)
2) Average texture (or soil type in a way that allows texture to be estimated) as input to 'pedotransfer' functions to estimate soil water retention curve (saturation, field capacity, wilting point)

3) Estimated bulk density relative to the reference value for soils under agricultural use, to estimate saturated hydraulic conductivity and potential infiltration

4. Geology

We need to estimate the 'differential storage' in 'active groundwater' as well as a 'groundwater release' fraction. So far these parameters were 'tuned' to the recession phase of actual riverflow during periods without rainfall. In the absence of such data we will need to 'guesstimate'. If data on the seasonal variation in depth of groundwater table are available, we can use those.

5. Vegetation and Land cover

Fractions of total land cover that are

- deciduous (reducing LAI in dry season to near 0),
- semi deciduous (reducing LAI in dry season to less than 0.5 (??) of value in wet season),
- evergreen maintaining LAI at over 0.5 of the maximum value
- bare soil or build-up areas
- open surface water

For more detailed assessments in the Sumberjaya and Mae Chaem areas we will use the actual time course of change. On that basis we might do with an estimate whether the actual change in the 'virtual' subcatchments has been 'rapid' (like 60 - > 10% forest cover in 25 years), 'extremely rapid (faster than that), or slower (…)

6. Actual river discharge

If available, river discharge data for any period of time (expressed in $m^3 s^{-1}$ in the river or mm day^{-1} over the whole contributing catchment) will be valuable in 'constraining' the simulations. If not available, we will simply have to 'believe' the model predictions as such.

7.4 List of files in the 'Attachment' bundle

1. Hundred Years of Debate on Forests and Water in Indonesia: Abstracts on hydrology, erosion and soil conservation from the "Bibliography of Soil Science in Indonesia 1890-1963"

2. Two chapters in the forthcoming book "Belowground Interactions in Tropical Agroecosystems", M. van Noordwijk, G. Cadisch and C.K. Ong (Eds.) CAB International, Wallingford, UK (in press)

- 2A Chapter 18: **Managing movements of water, solutes and soil: from plot to landscape scale** *by* Simone B.L. Ranieri, Richard Stirzaker, Didik Suprayogo, Edi Purwanto, Peter de Willigen and Meine van Noordwijk
- 2B Chapter 19: **Soil and water movement: combining local ecological knowledge with that of modellers when scaling up from plot to landscape level** *by* Laxman Joshi, Wim Schalenbourg, Linda Johansson, Ni'matul Khasanah, Endy Stefanus, Minh Ha Fagerström and Meine van Noordwijk

3. Excerpts from the proceedings of the 2003 MODSIM Conference, Townsville (Australia) July 2003. D. Post (Ed.)

- 3A Verbist, B.J.P., Widayati, A. van Noordwijk, M., 2003. **The link between land and water prediction of sediment point sources in a previous forested watershed in Lampung, Sumatra – Indonesia.**
- 3B Manik, T.M. and Sidle, R.C., 2003. **Rainfall spatial distribution in Sumber Jaya watershed, Lampung, Indonesia**
- 3C Van Noordwijk, M, Farida, A., Suyamto, D., Lusiana, B. and Khasanah, N., 2003. Spatial variability of rainfall governs river flow and reduces effects of land use change at landscape scale: GenRiver and SpatRain simulations.
- 3D Suprayogo, D., Widianto, Cadish, G. and van Noordwijk, M., 2003. A **Pedotransfer resource database (PTFRDB) for tropical soils : test with the water balance of WaNuLCAS.**
- 3E Sidle, R.C. and Dhakal, A.S., 2003. **Recent advances in the spatial and temporal modeling of shallow landslides**
- 3F Suyamto, D., van Noordwijk, M. and Lusiana, B., 2003. **FALLOW model: assessment tool for landscape level impact of farmer land use choice.**

4. Spatial variability of soil pH and phosphorus in relation to soil run-off following slash and-burn land clearing in Sumatra, Indonesia. By: Rodenburg J., Stein, A., Van Noordwijk, M. and Ketterings, Q.M., 2003. Soil Tillage Research 71: 1-14.

5. Agroforestry and watershed functions of tropical land use mosaics
by Meine van Noordwijk, Ai Farida and Bruno Verbist and Tom P. Tomich (Proceedings 2nd Asia Pacific Training Workshop on Ecohydrology *"Integrating Ecohydrology and Phytotechnology into Workplans of Government, Private, and Multinational companies"* Cibinong, West Java, INDONESIA. 21 - 26 July 2003)

6. **Environmental services and land use change in Southeast Asia: from recognition to regulation or reward?** Thomas P. Tomich[1], David E. Thomas[2], and Meine van Noordwijk[3]. Agriculture Ecosystems and Environment – special issue (*in press*)

7. **Bridging scales and knowledge domains of watershed functions**
by Meine van Noordwijk, Laxman Joshi, Desi Suyamto, Ai Farida and Bruno Verbist ***(Presented at CPWF Baseline Workshop Nairobi 2 – 6 November 2003)***

8. **'Montane Mainland Southeast Asia – A Brief Spatial Overview'.** By Thomas, David E. 2003. In: Xu Jianchu and Stephen Mikesell (Editors), *Landscapes of Diversity: Indigenous Knowledge, Sustainable Livelihoods and Resource Governance in Montane Mainland Southeast Asia.* Proceedings of the III Symposium on MMSEA 25–28 August 2002, Lijiang, P.R. China. Kunming: Yunnan Science and Technology Press. pp. 25–40.

9. **SpatRain: a Simulator of Space/Time Patterns in Rainfall for Predicting Scale Dependence of Variability of Rainfall-related Processes**
Draft Manuscript by Desi Ariyadhi Suyamto, Meine van Noordwijk, Betha Lusiana and Ai Farida