Alternatives to Slash-and Burn-Programme

FUNCTIONAL VALUE OF BIODIVERSITY - PHASE II
(December 2002-December 2003)

Technical Report For Activity 2:
Landscape and (Sub) Catchment Scale Modeling of Effects of Forest Conversion on Watershed Functions and Biodiversity in Southeast Asia

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Contract No. 7114805, Phase II, Modification B, signed between the World Bank and International Centre for Research in AgroForestry (ICRAF), 28 November 2002
Funded by: BNPP (Bank Netherlands Partnership Programme)

This work was supported [in part] by the Bank-Netherlands Partnership Program. The findings and interpretations are the authors' and do not necessarily reflect the views of the World Bank, its Executive Board of Directors, or the countries they represent.

This project is a component of ASB's crosscutting assessment entitled "Forest and Agroecosystem Tradeoffs in the Humid Tropics", which is a Sub-global component of the Millennium Ecosystem Assessment (MA).

Summary

Natural forests are, rightly or wrongly, the global benchmark for both 'watershed functions' and 'biodiversity conservation'. While both these functions can be affected by forest conversion and further intensification of agriculture, the trajectories of both functions are essentially different. 'Watershed functions' can be defined as the way landscapes determine quantity, timing and quality of river flow, by the way they ***1) transmit***, ***2) buffer*** and ***3) gradually release*** the rainfall that is received, 4) ***modify water quality*** and 5***) maintain the integrity of the soil capital*** in the catchment area. For these 5 '***criteria***' we developed ***quantitative indicators***, applicable in assessments at different scales. There is only a very partial direct overlap between watershed functions in this sense and the ability to conserve, provide habitat and connectivity for biological diversity in landscapes. The relationships between land use change, watershed functions and biodiversity conservation are captured in a series of 10 hypotheses and 5 major questions studied in this report. We tested the hypotheses for internal consistency through the construction and use of quantitative simulation models that can be compared with actual data sets. We concentrated on the first three criteria and indicators for this report.

Two ASB benchmark areas in Southeast Asia were the focus of this study, Mae Chaem in northern Thailand and Sumber Jaya (Way Besai) in Lampung in the southern part of Sumatra (Indonesia) have an annual rainfall of about 1.5 and 2.5 m year-1, respectively. Total water yield (after subtraction of an estimated evapotranspiration of 1.3 m year^{-1}) is about 0.2 and 1.2 m year^{-1}, or 15 and 50% of rainfall. These values may broadly represent the hydrology in subhumid and humid tropics. In Mae Chaem the difference between actual and potential evapotranspiration dominates the water balance via total water yield. In Sumber Jaya (Way Besai) changes in soil structure that partition total water yield over quick and slow flows are the main feature that needs to be better understood.

The total amount of water supplied to downstream users generally increases with forest conversion to upland agriculture, but will be reduced to levels of the original forest or below that if irrigated agriculture or reforestation with fast-growing trees become a major water user. This overall effect of land cover change can be directly predicted by summation over the plot-level water balance, as total river discharge equals rainfall minus evapotranspiration, when considered at time scales where changes in the storage terms can be ignored. As the absolute changes in water use due to land use change are approximately equal across a wide range of annual rainfall values, the relative effects are highest in the driest areas considered.

For a study area in northern Thailand and for the Mekong river system as a whole, with annual rainfall of around 1.5 m year^{-1}, land-use induced changes in total water yield can lead to a doubling of the total discharge volume (from 13 to 25% of estimated annual rainfall) and to a significant increase in flooding risk for parts of the river where technical control over river flow through reservoirs is limited. For the Mae Chaem study area river discharge was about 20% of station-level rainfall, but area-averaged rainfall may be considerably higher than the data for the rainfall station suggest. For a study area in Indonesia with annual rainfall of about 2.5 m year^{-1}, the fraction of rainfall that was measured as river discharge increased from about 40 to about 70% over the 1975 – 1998

period. The number of days the river meets the target of a hydroelectric run-off generator has probably increased.

While the various hydrological models broadly agree on the direction and size of these effects on total water yield, public policy and investment remain often based on expectations of increases in total water yield as effect of ‘reforestation’. In the absence of effects of such land cover change on rainfall, there is no known mechanism or empirical data set to support the views underlying such policies.

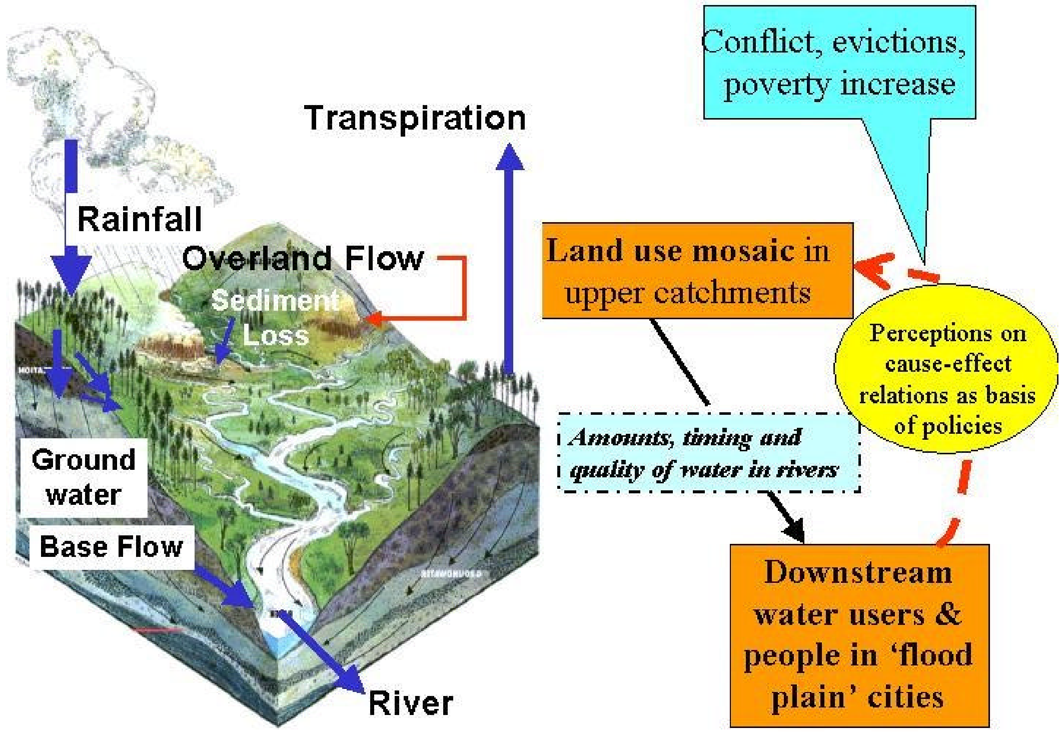
More controversial is the impact of land use change on the ‘evenness’ of river discharge or the degree to which river discharge is buffered relative to rainfall peaks. Both high peak discharge, that leads to flooding of downstream areas and is generally linked to reduced infiltration into the soil and increased channeling of drainage, and low levels of base flow that are the result of reduced infiltration into the soil and/or increased uptake of soil water by trees are generally considered to be undesirable. A newly defined ‘***buffering indicator***’ allows the empirical study of changes in buffering. For a watershed in Indonesia a change in forest cover from 60 to 10% and conversion to a coffee-dominated agroforestry landscape lead to a decrease in buffering (on a scale from 0 to 1) by 0.15, from 0.85 to 0.7. This means that twice as much water flows in the river as ‘above-average flow’. Modeling studies suggest that a conversion to open-field agriculture with ensuing degradation of soil structure could reduce the buffer indicator by a further 0.2, trebling the total amount of ‘above-average’ river flow relative to the forested condition of the watershed. Empirical and modeling studies for northern Thailand show only a small change in buffering indicator in response to the land use change in the past decades. These changes in buffering essentially depend on changes in soil structure and are expected to have thresholds markedly below the loss of biodiversity value during intensification of land use.

A set of four scenarios for ‘plausible’ land use change was developed for the Upper Ping River Basin driven by forces in society scenarios that emphasize food production or environmental conservation. The four scenarios, “Fields and Fallow”, “Food Bowl”, “Parks and Cities” and “Agro-forests”, in turn, can be thought of as being nested in larger scale scenarios about national and regional global development. These larger scale scenarios are being developed by the Global Scenarios working group of the Millennium Ecosystem Assessment. In this study the four scenarios for the Ping Basin were applied to the Mae Chaem sub-basin. This was done in three steps. First, historical analysis of land-use change over the past 10 and 20 years were made using multiple regression techniques. Second, ‘soft’ models were constructed to make explicit some of the main assumptions underlying each of the scenarios and how they could be articulated in a quantitative landscape evolution model. Third, a platform for modelling and visualization landscape evolution was built in Visual C++. This allowed us to both include systems of differential equations based on regressions of land-use change on a set of categorically transformed predictor variables and rule-based processes. The first version of the model with which the set of simulated landscapes presented here is based largely on modifying small subsets of the underlying regression coefficients guided by the soft models. Land-covers modelled were: orchard, paddy, field crop, hi-value intensified crop, fallow/secondary shrub, human settlements. Other land-uses such as water bodies were assumed to stay constant. Predictor variables were similar to those shown in the soft model diagrams, including, for example, elevation, past land use, estimates of travel times and distance to water. The scenarios differ in the degree of forest cover they predict for Mae Chaem in 50 years time, ranging from 25% for the 'Food bowl' to 50% for the 'Parks' scenario. Hydrological evaluation of these plausible future landscape configuration lead to relatively small changes in predicted total water yield or buffering.

As previous studies indicated a lack of empirical evidence for effects of land use change on river flow (except for water quality linked to point-pollution), we explored the hypothesis that spatial variability of rainfall enhances the 'buffering' of river flow and reduces the potential impact of land cover change on the time pattern of river flow. An internally consistent model representation can indeed 'explain' a reduced sensitivity of the buffering indicator to land use change with increasing spatial scale. This effect may help in defining the decreasing degree to which downstream land users are real 'stakeholders' in upland land use, as they live at increasing distance.

Water quality, as third category of watershed functions, can be strongly affected by land use change if organic pollution linked to human settlement and agro-chemicals directly reach the streams. Sediment loads of rivers, linked to enhanced erosion, depend strongly on the spatial organization of a landscape, rather than on average degree of forest cover. Model calculations suggest that riparian forests may be more effective per unit of forest cover in reducing net sediment loads of rivers than forests in other landscape positions. Integrity of riparian buffer zones can play an important role in biodiversity conservation and thus there is at least some parallelism between land use patterns that favour watershed functions and biodiversity conservation. But our overall conclusion is that the two function groups have essentially different thresholds and dependencies on specific land use decisions, making them separate domains for policy attention.

The main policy problem on 'watershed functions' may be in the perceptions that exist in lowland and urban communities about the role of forests in providing such 'functions', without specifications of how other land use would actually affect them. A coherent analysis of the local ecological, public/policy and ecological/ hydrological science perspectives on watershed functions, informed by actual observables in case study areas may be needed to move the policy agenda forward and effectively communicate results (that may be contrary to 'intuition', current and past support for 'reforestation' efforts) to the audiences that negotiate decisions.



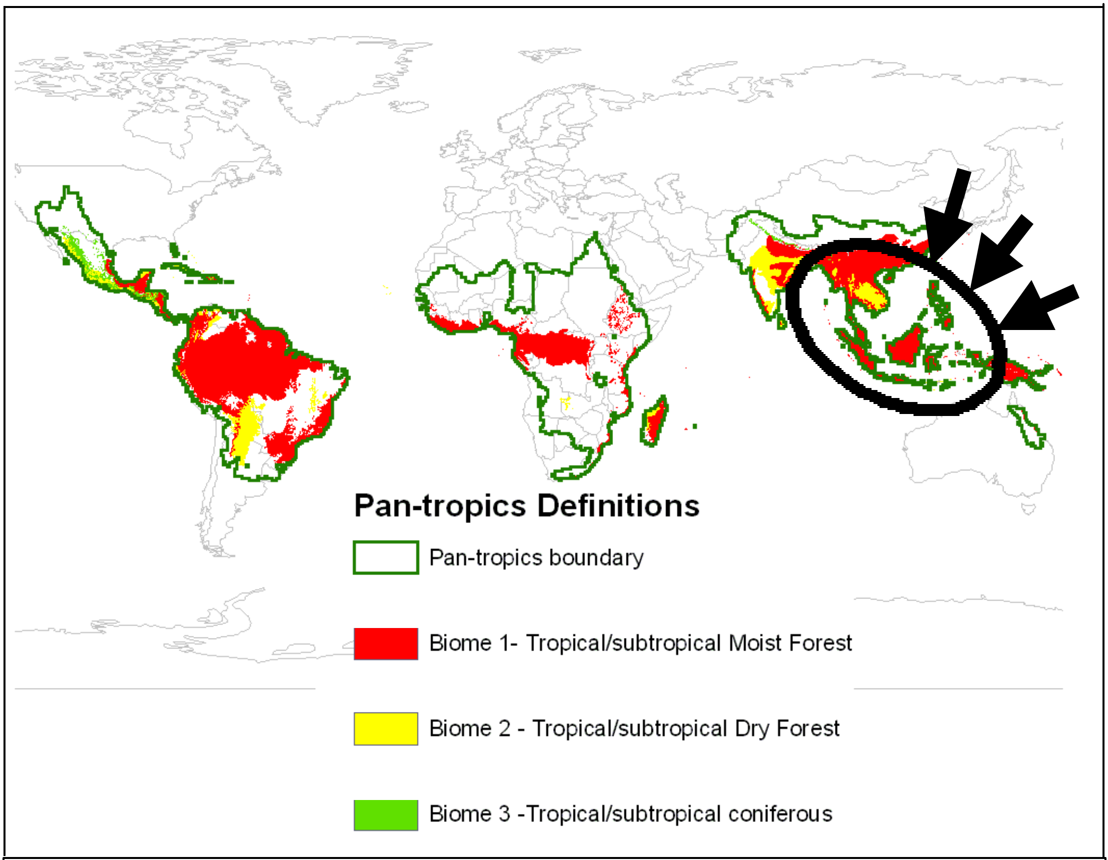
What is the problem? Actual changes in river flow or perceptions that ground policies and development intervention s that enhance conflict, evictions and poverty?

Contents

The FVOB-BNPP project in a nutshell

Activity 1 Global assessment of the Pan-tropical domain of all watersheds that have at least a partial overlap with the Tropical/Subtropical Moist or Dry Forest Biome

Activity 2 Focus on Southeast Asia and landscape and (sub) catchment scale modeling of effects of forest conversion on watershed functions and biodiversity



Where are we in the watershed confusion matrix?

- Forests create rainfall...?
- Rainfall creates forest...?
- Planting trees reduces river flow...?
- Planting holes for trees increase infiltration...?
- To get more infiltration we depend on earthworms.... which depend on litter.... that derives from trees.... which depend on farmers expecting harvestable yield?
- Flooding damage to people is primarily caused by 'living in the wrong place', not by loss of tree cover?
- Hydro-electric schemes never have the amount of water they would like... and always have deforestation as a scapegoat?
- Vested interest in 'reforestation' will carry on, regardless of data and understanding of effects on river flow?

1. Introduction

1.1 Functional value of biodiversity – exploring links between biodiversity and watershed functions across spatial and temporal scales

Forests are a point of reference for both biodiversity conservation (B) and watershed (W) functions. As both these ‘environmental services’ are strongly affected in ‘degraded lands’, it is logical that the general public expects that ‘forest protection’ is essential to meet both the B and the W agenda. This leads to the expectation that local interests in watershed functions may be sufficient ground to achieve, or even pay for, biodiversity conservation.

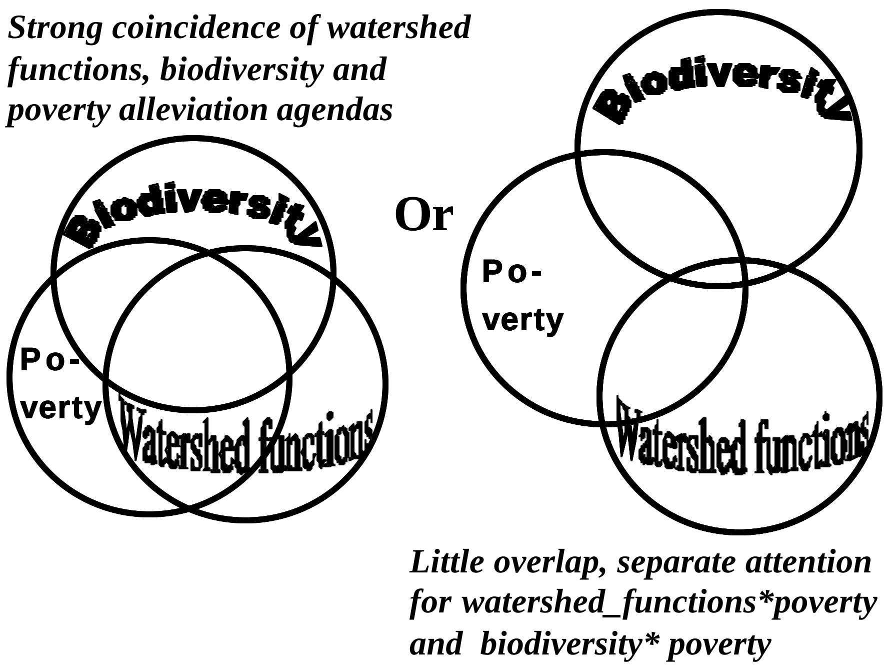


Figure 1.1. The key question of the BNPP-ASB-FVOB project relates to the degree of overlap between poverty reduction, biodiversity conservation and watershed protection agendas

The overarching question in the ‘functional value of biodiversity’ research (Fig. 1.1) is:

> are ‘biodiversity conservation’ and ‘watershed protection’ strongly connected issues that can be addressed simultaneously in a sustainable development context, or do the issues only overlap in very specific situations and at specific scales?

Two distinct aspects of this question are:

- do areas on the globe (or within the tropical domain) that are generally recognized to be of high importance for global biodiversity conservation have an ***above-average*** importance for ‘watershed functions’?
- does the pattern and type of land use change that occurs within specific areas affect the B and W aspects in similar ways?

The project tries to answers these questions in '***Activity 1***', focused on the global correlation of biodiversity hot spots and areas of above-average significance for maintenance of watershed functions, and '***Activity 2***', focused on the impacts of gradual land use change on B and W and the possible thresholds in the process of land use intensification. This report covers activity 2.

In answering questions on 'watershed functions', it may help to separate the '***outcomes***' (quantitative indicators) of dynamic landscapes from the concept of '***functions***'. Functions, like beauty, depend on the eye of the beholder. Changes in water flow regime that are desirable for some stakeholders are not desirable for others. For example people who care for the natural biota living in these river basins may take the 'natural level of variability' as their target and prefer situations where floodplains get periodically flooded, while people who built their house in a floodplain may find absence of fluctuations of river discharge desirable. Potential impacts on, and thus perceptions of value to, different stakeholders generally depend on a combination of the 'outcomes', along with their opportunities to benefit (or suffer) from being at the right place at the right time (or avoid being at the wrong place at the wrong time), and technical engineering interventions. We will restrict ourselves here to a discussion of 'outcomes' that remains in the realm of biophysical landscape models.

Interest of policy-makers in these issues is, however, dominated by '***damage to people and economic infrastructure***'. The types and severity of impacts on human societies of changes in watershed functions are usually due to a combination of changes in land cover ('deforestation'), engineering constructions that modify drainage channels and temporary storage structures, and the location where people choose to live (Fig. 1.2). Where damage to human lives and livelihoods are involved in droughts and floods, we can recognize three levels of causation: (i) direct (proximate), (ii) intermediate and (iii) underlying (ultimate). The underlying (***ultimate***) cause may be that insufficient precautions were made in the location and nature of human activity in the lower reaches

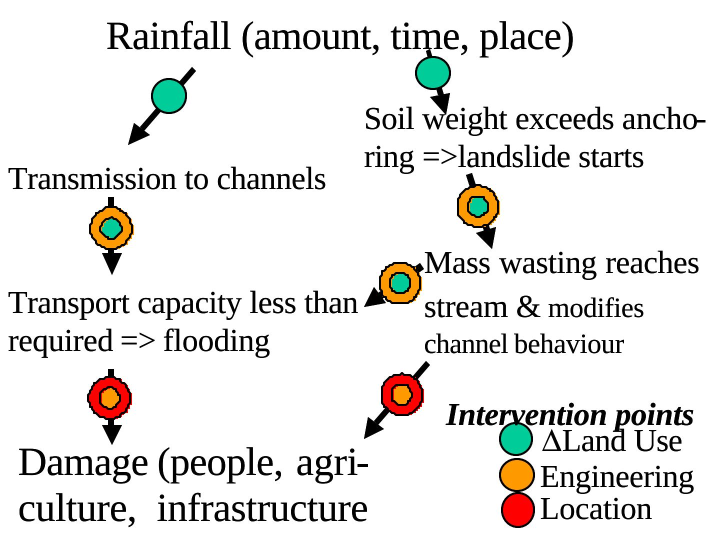


Figure 1.2. The cause-effect chains that link (negative) human impacts to (lack of) rainfall, normally involve a number of intermediate steps, that reflect (changes in) land cover and land use, engineering interventions into storage and flow of water, and the specific location of the human activity that is affected

of a river, because expectations about high and low levels of river flow do not match reality. The direct (***proximate***) cause is nearly always a period of higher-than-expected (flood) or lower-than-expected (drought) rainfall. ***Intermediate*** between these 'ultimate' and 'proximate' causes is the way watersheds process incoming precipitation to generate river flow, and the degree to which this 'watershed function' is modified by land cover and hence influenced by land use change. Single-cause attribution of impacts to any of these three categories of causes is likely to be overly simplistic.

Moreover, a simplistic '*upland*' – '*lowland*' construction of watershed management issues tends to ignore the importance of the '*transmission zone*'. Changes in the riverbed, however, can have a major impact on the actual performance of rivers, and land use change in the transmission zone can be at least as relevant as land use change in the upper catchments (Fig. 1.3).

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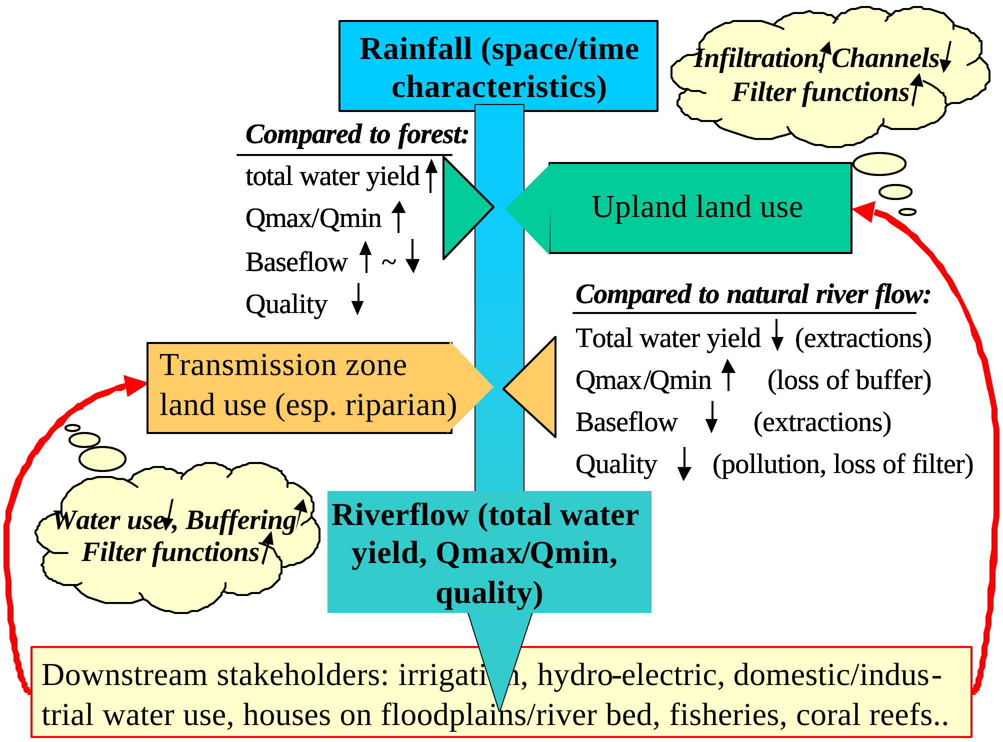

Figure 1.3. Relationships between rainfall, watershed functions in the upper catchment areas and downstream stakeholders can be strongly modified by changes in the 'transmission zone' where extractions (e.g. for irrigation) can modify the total water yield and changes in riparian vegetation can influence flow characteristics and water quality

Thus, the 'solutions' to policy problems revolving around watershed functions will generally need to involve a combination of three components:

- Reducing the types and timing of human presence and economic activities in sensitive locations
- Engineering interventions that modify water transport and storage capacity
- Maintaining or restoring 'watershed functions' in the main source areas of rivers

In this study we focus on the third component (changes in watershed functions linked to change in land cover and land use), and are thus limited in our ability to more fully assess impacts on people and economic infrastructure (which depend on components 1 and 2 as well).

A closer look at the way the B and W functions -- along with terrestrial C storage (C) -- change during a gradual process of land use intensification, as studied by the Alternatives to Slash and Burn project, reveals that the negative trend in both functions may in fact break apart on closer inspection (Fig. 1.4). In ASB benchmark sites in Indonesia, Thailand, the Philippines, Cameroon, Brasil and Peru (Van Noordwijk et al., 2001; Palm et al., 2004), we found land use practices such as 'rubber agroforest' that maintain substantial levels of biodiversity as well as providing most of the 'watershed functions', but we also found practices such as forms of coffee agroforestry that maintain watershed functions without high levels of biodiversity.

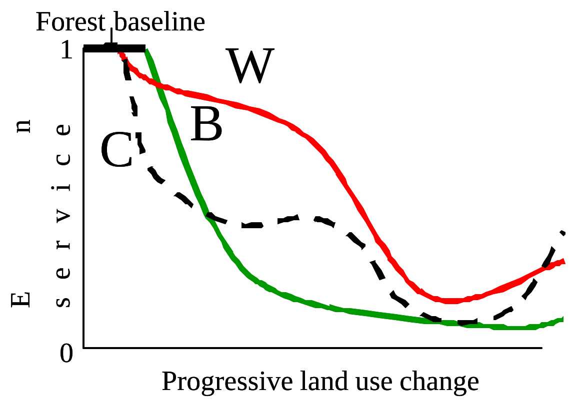

Figure 1.4. A semi-informed perception of the general trends in the three classes of environmental service functions B(iodiversity), C(arbon) and W(atershed functions) during progressive land use change, taken relative to a forest baseline

Initial evidence of the consequences of spatial organization in the landscape (Van Noordwijk et al., 1998; Ranieri et al., 2003) suggest that for some functions (e.g. low net sediment losses) the location of protective elements in the landscape is crucially important, while others (e.g. habitat for species that are not compatible with human presence) depend primarily on large areas of undisturbed forest (Fig. 1.5).

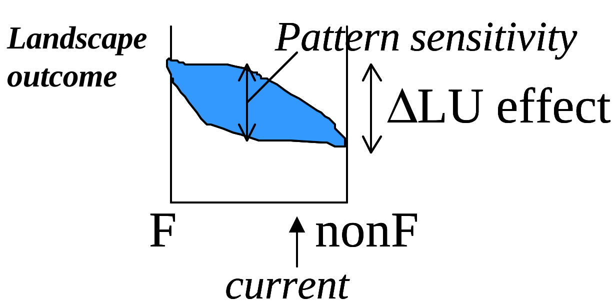

Figure 1.5. Sensitivity to 'land use change', as represented in the difference in outcome between completely 'natural forest' (F) and completely 'non-forest' (nonF) condition of a landscape, and sensitivity to spatial organization of the landscape as reflected in the maximum width of the envelope surrounding outcomes for all possible landscape configurations

A substantial de-coupling of the biodiversity conservation and watershed functions at the scale of plot-level and/or landscape-level land use has important consequences where external stakeholders want to influence land use decisions, via a form of 'reward mechanism' for actual environmental services (Fig. 1.6).

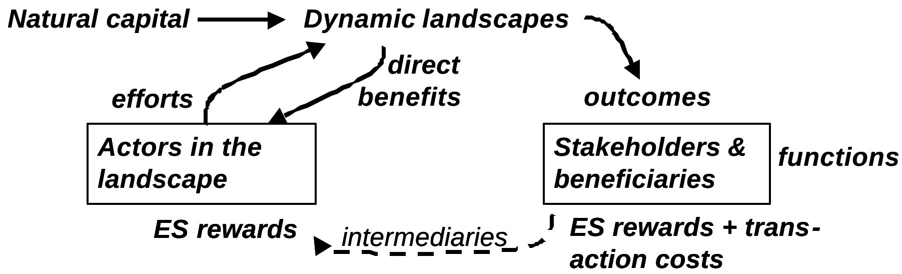

Figure 1.6. Outcomes of dynamic landscapes that can represent 'environmental service functions' (ES) in the perception of external stakeholders depend on natural capital + human actors

Both B and W vary dramatically across the globe (compare Activity 1 report) – but most of this variation represents 'inherent properties' (such as rainfall and biogeographic domain) that cannot be directly influenced (at least not at local scale). Since the focus of this project is primarily on 'sensitivity to land use change', we need to tease the 'outcome' apart into a component that reflects the ***background,*** due to factors such as climate, geology and landform, from the parts that have probably ***changed*** (usually in a negative direction) from historical natural vegetation (often a form of forest) to the current type of land cover (often a mosaic of different land use types), and are likely to undergo further change in the future as land use patterns and practices continue to change.

1.2 Defining watershed functions and choosing indicators: 'watershed functions' as co-determinants with rainfall of qualitative and quantitative aspects of river flow

While common definitions of 'watershed functions' embed rainfall, we prefer an articulation that defines watershed functions given the rainfall that occurs at the spatial and temporal scale of interest.

Thus, we separate watershed functions into the 'permanent' features of the landscape, W_p, and those that are (potentially) under human influence (W_h). The upland – lowland land users debate should focus on W_h, but is often obscured by unrecognised features of rainfall and W_p (Table 1.1). Scaling aspects of river discharge involve understanding the scale relations of rainfall, the scaling of watershed functions and the interactions between the two.

Using this approach, we will focus on four watershed functions that relate to the quantity, timing and quality of river flows:

- W1: Water transmission (total water yield per unit rainfall)
- W2: Buffering (above average river discharge per unit above average rainfall)
- W3: Gradual release of stored water supporting dry-season flows

- W4: Maintaining water quality (relative to that of rainfall)

  and a further function that relates to integrity of the watershed area as such
- W5: Stability of slopes and absence of landslides

The simple description of elements of W_p and W_h that contribute to various functions suggests that these 5 functions do not necessarily change in parallel in response to land use and land cover change. They may also vary substantially between landscapes and climatic conditions.

Table 1.1. Defining watershed functions separate from rainfall and jointly determining the features of river discharge = rainfall * (W_p + W_h**)**

Aspect of river flow	Rainfall aspect	W		
		Watershed function	W_p, permanent determinants in landscape	W_h, features under direct human influence
Total water yield	Mean rainfall	Water transmission (total water yield per unit rainfall)	Solar radiation, advective flows of dry or wet air, geological substrate and aquifers	Fraction of evergreen and deciduous vegetation, fraction of bare soil, water extractions
Peak flow (flooding risk)	Space-time patterns of rainfall	Buffering (above average river flow per unit above average rainfall)	Landform, slope, soil depth,	Changes in surface soil properties modifying infiltration; Changes in 'channeling' and rapid drainage
Dry-season flow	Seasonality of rainfall	Gradual release of stored water	Landform, geological substrate	Infiltration and (lack of) vegetation access to stored water
Water quality (incl. sediment load, suitability as drinking water)	Space-time patterns of rainfall	Maintaining water quality (relative to that of rainfall)	Riverbed, alluvial deposits, soil stabilization by natural vegetation, presence of nutrients and pollutants in the soil profile	Changes in soil cover modifying erosion and filter functions; Point sources of metal, organic pollutants, pesticides, nutrients; Changes in riparian buffer vegetation; Changes in nutrient balance; Changes in water balance modifying salt groundwater movement
Changes in the riverbed	Peak rainfall events	Stability of slopes and absence of landslides	Slope, mechanical properties of soil profile	Infiltration Anchoring of topsoil to subsoil through live or still-intact tree roots Road incisions to slopes

In the remaining text we will (try to) refrain from a discussion of generic 'watershed functions' by being specific about which function is involved. A specific issue for each of these 'functions' is how it is affected by both temporal and spatial scales. Effects of local land use change on the temporal dynamics of river discharge may 'dissipate' with increasing distance. The ability of an observer to actually notice impacts of land use change on river discharge may strongly depend on distance and scale.

Table 1.2. Measurability of land use impacts by basin size (Kiersch and Tognetti, 2002) x = Measurable impact; - = No measurable impact

Impact type	Basin size (km^2)						
	0.1	1	10	10^2	10^3	10^4	10^5
Thermal regime	x	x	-	-	-	-	-
Pathogens	x	x	x	-	-	-	-
Average discharge	x	x	x	x	-	-	-
Peak discharge	x	x	x	x	-	-	-
Base discharge	x	x	x	x	-	-	-
Groundwater recharge	x	x	x	x	-	-	-
Organic matter	x	x	x	x	-	-	-
Sediment load	x	x	x	x	-	-	-
Nutrients	x	x	x	x	x	-	-
Salinity	x	x	x	x	x	x	x
Pesticides	x	x	x	x	x	x	x
Heavy metal	x	x	x	x	x	x	x

The general expectation that impacts of land use change on 'watershed functions' can be extrapolated from small-scale studies to large-scale reality has not been borne out in summaries of empirical evidence (Table 1.2). Lack of 'hard' data for most watershed functions beyond 10 km^2 may be largely due to inadequacies in study design, but may also reflect the importance of other 'drivers'. One prime candidate for such 'other driver' status is spatial variability in rainfall. We will explore this explanation in detail.

1.3 Defining biodiversity conservation functions and choosing indicators for 'inherent richness' and 'impacts of land use change'

Similar to the manner in which we separated 'watershed functions' from rainfall, we can try to separate inherent richness from 'biodiversity conservation functions' that landscapes under the influence of people and changing land use exert on the survival and possible recovery of biological diversity.

The main positive impact people can have is to cause a reduction (or absence) of 'threat factors', whereas there appears to be relatively small roles for 'mitigation' effects such as restoration of landscape-level connectivity and 'ex situ' conservation. The main threats to biodiversity are loss of habitat, negative effects at population level (disturbance of reproductive cycles, over hunting, over harvesting, pesticide use and pollution) and the introduction of invasive species that can replace local species or eliminate them as a predator or in a disease role.

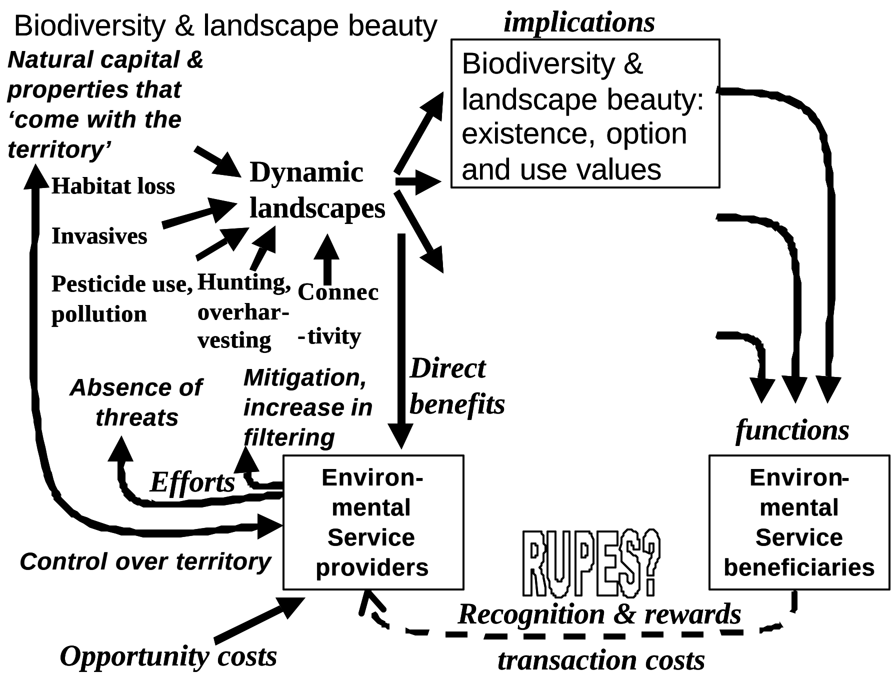

Figure 1.7. as figure 1.6 but specific to the 'biodiversity and landscape beauty' functions

Thus, the main options for providing 'environmental service functions' in the biodiversity domain are:

- B1. Protecting the integrity of conservation areas by preventing loss of habitat and threats at population level in the areas directly around core protection areas,
- B2. Providing habitat for a sub-set of the original fauna and flora inside agriculturally used landscapes (this increases in relevance with the increasing loss of more natural habitat; it will only allow the conservation of part of the original species pool – with losers among the organisms that few people want to have in their backyard (tigers, elephants) or as direct neighbours (e.g., pests), and those that can not tolerate people as neighbours from their side),
- B3. Maintaining connectivity between protected areas via corridors,
- B4. Creating opportunities for local-level 'restoration', in landscapes where connectivity is still maintained.
- B5. Various forms of ex *situ* conservation.

Table 1.3. Tentative ranking of the degree of overlap between the 5 aspects of watershed functions (W1….W5) and the 5 aspects of biodiversity conservation (B1…B5), ranging from weakly negative (-/0), via neutral (0), to weakly positive (+/0) and positive (+)

	Protect	Habitat	Corridors	Restore	Ex Situ
	B1	**B2**	**B3**	**B4**	**B5**
W1 - transmit	-/0	0	0	-/0	0
W2 - buffer	+/0	+/0	+/0	0	0
W3 - release	0	0	0	0	0
W4 - quality	+	0	+/0	0	0
W5 - landslides	+/0	0	+/0	+/0	0

Direct links between the 5 B and 5 W functions are likely to be weak (Table 1.3). Some interventions in a landscape, such as connectivity of vegetation along riparian corridors may favour both biodiversity conservation and watershed functions in a landscape. Other interventions may favour or harm one of the functions more strongly than the other.

The scale relationships of biodiversity and watershed functions differ essentially; global biodiversity conservation starts with what is globally unique and proceeds to identify 'hot spots' where local conservation will be of high global significance. Watershed functions are very clear at the local scale where people depend directly on surface and groundwater for drinking water and domestic use, as well as to provide water to their crops. Technically, watershed functions can best be understood by aggregation of the impacts of rainfall on the water-balance.

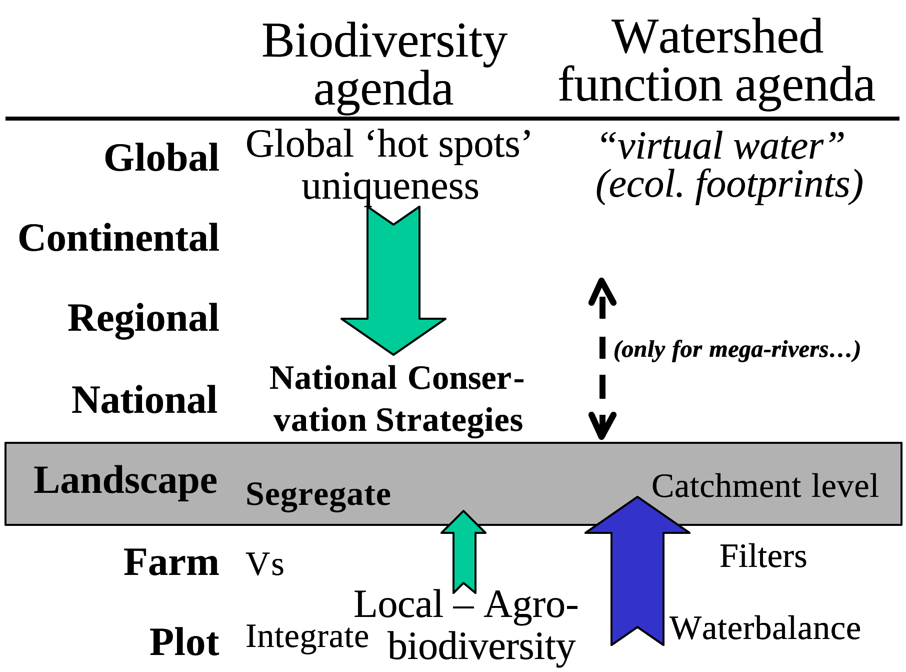

Figure 1.8. Scale relations of the 'biodiversity' and 'watershed function' agenda's and their meeting point at the landscape scale

An important difference between biodiversity and watershed functions is thus (Fig. 1.8) that for biodiversity functions a ‘top down’ approach that starts at global diversity is appropriate, while for watershed functions a ‘bottom up’ that starts with a single drop of rainfall and its subsequent fate in moving through a catchment and river area is appropriate. An intermediate scale of landscape organization may in fact be the main scale where the B and W issues overlap Initial analysis suggests that biodiversity may be best served by a spatial ‘segregation’, while watershed functions may be better served under an ‘integrate’ scenario. There is, however, considerable scope for avoiding a negative trade-off between the two functions, if specific attention is given to riparian zone vegetation that is relevant for both the B and W perspective.

In terms of the degree of overlap of ‘biodiversity’ and ‘watershed function’ issues, we may tentatively conclude that there is only a very partial overlap. Therefore, a deeper exploration is warranted into the relationship between land use intensification and W functions, thus complementing earlier analyses by the ASB project of the relationship between land use intensification and B functions. We focus this analysis on benchmark areas of the ASB project in Sumatra and N Thailand, and base it on a set of generic hypotheses and research questions.

1.4 Hypotheses

Two complementary sets of hypotheses about processes occurring during intensification of land use address relationships between biodiversity and watershed functions generally, as well as properties that determine watershed functions of landscapes undergoing transition.

1.4.1 Hypotheses regarding biodiversity and watershed functions during intensification of land use

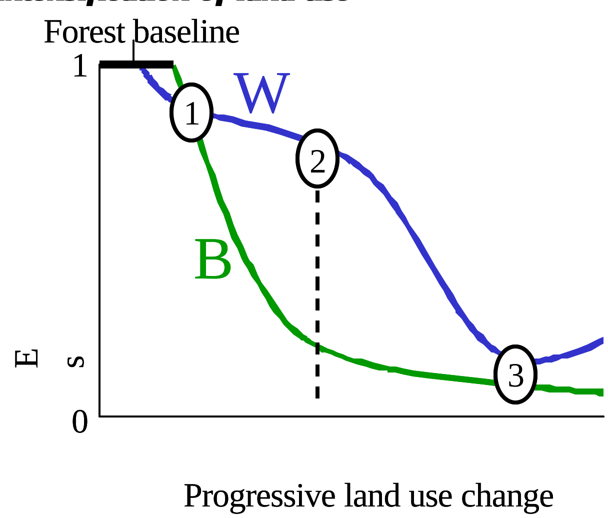

Figure 1.9. Four hypotheses regarding land use change and coincidence of watershed and biodiversity functions

0. (biodiversity conservation and watershed protection issues only coincide when viewed from a substantial distance)…. **Differences in the thresholds involved in the relations between land use intensity, biodiversity conservation and the various watershed functions make it unlikely that**

local interests in watershed functions will be sufficient to achieve biodiversity conservation

1. (some human use of forest lands can be OK for both functions) … **Initial stages of land use intensification allow both watershed protection and biodiversity conservation functions to be maintained at levels close to that of natural forest**

2. (beyond the biodiversity threshold)… **Substantial further intensification is feasible without major negative impacts on any of the watershed protection functions through forms of agroforestry, but with major losses to biodiversity value**

3. (beyond the watershed function threshold)… **Further (attempts at) land use intensification will negatively affect most watershed functions, leading to land covers that represent low values for both functions**

4. (recovery of watershed functions but less so for biodiversity values)… **Starting from landscapes in which both watershed functions and biodiversity values are highly degraded, opportunities for rehabilitation of most watershed functions exceed those for recovery of biodiversity values**

1.4.2 Hypotheses regarding determinants of watershed functions during intensification of land use

5. **Total water yield from catchments primarily depends on a) rainfall, b) the fraction of rainfall used in evaporation of canopy-intercepted water, c) the amounts transpired by 'evergreen' and 'deciduous' natural or managed vegetation and d) the extractions for water use elsewhere**

6. **The ratio of peak and base flows primarily depend on a) properties of terrain and soil profile and b) land-use related changes in plot-level soil (surface) structure and c) landscape-level drainage structure, and can thus operate independent of changes in total water yield**

7. **Temporal dynamics of high and low flows of rivers are influenced by spatial scale through a) the space-time characteristics of rainfall, b) the land-use related speed of delivery to streams and c) the (riparian-zone related) transport properties of the river system; the direct influence of land use change on stream discharge strongly decreases with distance along the stream**

8. **Spatial organization of a landscape, at given fractions of land cover types, has a strong influence on net sediment loads of streams and rivers but less so on total water yield or peak flows**

9. ***Local hazard to people living in a (sub)catchment* due to changes in watershed functions in response to land use changes are primarily linked to a) peak discharge after peak rainfall events, b) low dry season flows, c) landslides and d) changes in water quality (sediment load, pollutants, nutrients)**

10. ***Far field effects on people living downstream* are primarily linked to changes in a) total and seasonal water yield in relation to the transport capacity of the river network and the probability of bank overflow at critical locations, and b) the storage capacity (in lakes, reservoirs, floodplains) of the river network.**

1.5 Specific questions for BNPP-ASB-FVOB Activity 2

Tests of these two sets of hypotheses will enable us to address five major questions that are key to achieving the goals set for Activity 2 of the BNPP-ASB-FVB project.

1) What is the quantitative impact on the range of 'watershed function' and 'biodiversity conservation' indicators at plot, landscape, subcatchment and catchment scale of the historical land use change between 'natural vegetation' and 'current land use pattern'? (***Testing hypotheses 1-3***)
2) How do the impacts of land use change on watershed functions and biodiversity vary with spatial scale (***Testing hypotheses 5,6 and 7***)
3) What degradation/recovery of watershed functions and biodiversity can be expected for a number of 'plausible' land use change scenario's? (***Testing hypotheses 4***)
4) Does landscape pattern (given land use cover data) matter for the functions generated (i.e. is 'spatial planning' a relevant part of the answer)? (***Testing hypotheses 8***)
5) Which interventions are likely to reduce 'local hazard' (***Testing hypotheses 9, 6, 7 and 8***) and 'far field effects' (***Testing hypotheses 10 and 5***) on watershed functions? Are these interventions relevant for biodiversity conservation?

Goals phrased for Activity 2

Goal a. Use process-based hydrological models to assess the impacts of land cover changes on hydrological effects such as water flow and water quality at the micro (watershed) and meso (river basin) scale, and characterize the areas that cause and experience impacts according to population, biodiversity, and poverty (to the extent possible);

Goal b. Explore the complementarity and consistency of hydrological models with different ranges of scale and differing emphases in the representation of physical processes

Goal c. To the extent feasible, formulate guidelines or generalizations on the impact of biodiversity-relevant land use changes on hydrological processes such as sedimentation and landslides, as a function of watershed scale, land cover/land use, climate, and topography.

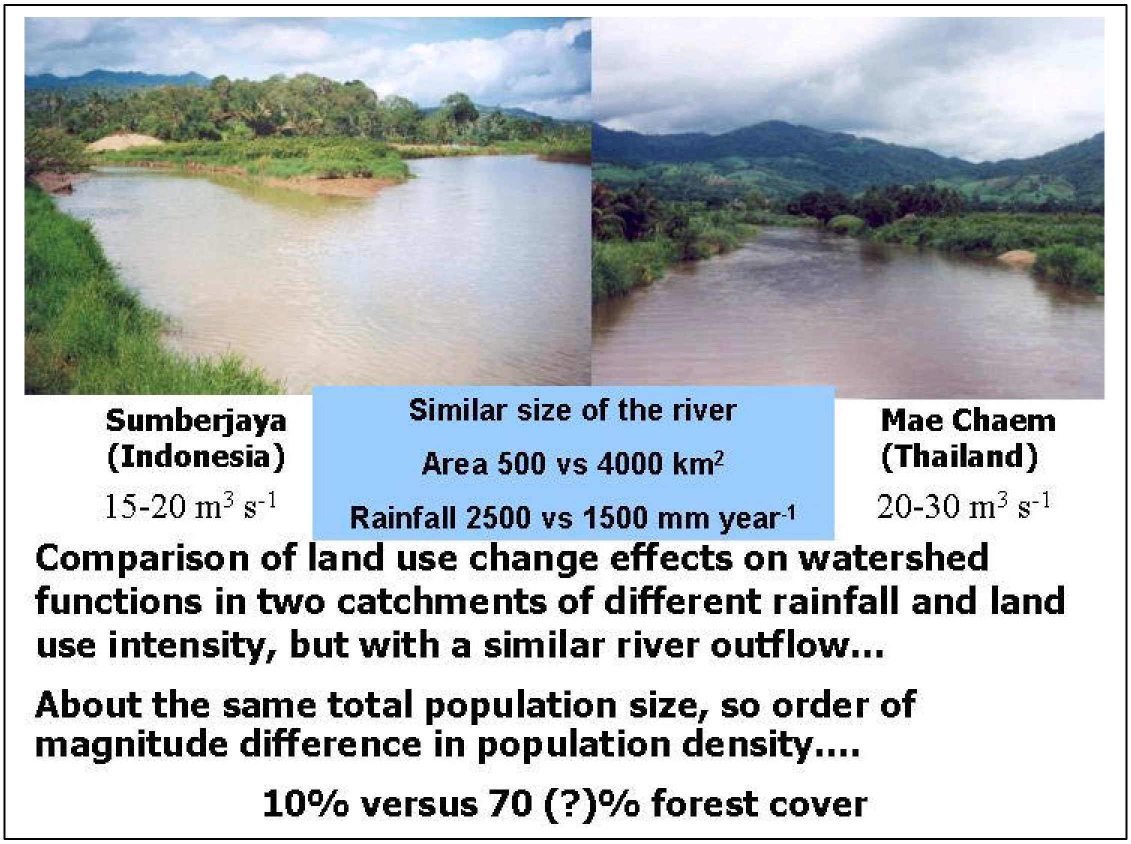

Figure 1.10. Rationale for the comparison of the Mae Chaem and Sumberjaya watersheds in Southeast Asia: both rivers have an (almost) similar discharge, but the watersheds differ markedly in population density and deforestation (land use change) history; historical rainfall and river discharge records exist for both areas, while intensive studies of historical land use change have been made in the context of the Alternatives to Slash and Burn programme in Thailand and Indonesia, respectively.

1.6 Four steps for meso (& micro) scale models to clarify land use change effects on watershed functions

Step 1. Which watershed functions are relevant for which stakeholders in what context

The first step in any site specific assessment of watershed functions is to analyze which aspects of river flow are of direct relevance to the various groups of stakeholders that currently exist or might emerge in the future.

Total water yield (the ***transmit*** function) usually has many stakeholders, especially where demand for water exceeds the supply, outside the humid tropics. The ability to use water whenever it flows during the year does generally depend on storage in natural lakes or man-made reservoirs.

The ***buffering*** function that leads to low peak flows after high rainfall events is particularly relevant for people living in flood plains (as several capital cities in SE Asia do) or river beds. Where the floodplains and wetlands along the river do, in their natural state, contribute to the buffering of river discharge for observers that live downstream, bank overflow conditions in these areas may not always be welcome by local stakeholders; their efforts to 'control flooding' may transfer the flooding risks downstream. Where peak flows are the immediate concern we thus usually deal with complex cause-effect relationships that involve various scales and actors.

Releasing water gradually is important for all people and other organisms that depend on stream flow outside of the rainy season. The specific pathways followed by water that infiltrates into the subsoil are highly dependent on geological substrate and soil forming processes. These pathways are, however, only influenced by land use after major technical interventions such as deep drainage or creations of obstructions to drainage. The amount of water feeding into the various slow flows is, however, influenced by land cover and use (Smakhtin, 2001). Lakes and man-made reservoirs in the river can partially replace this function of the upper watersheds.

Water quality has many stakeholders, using different thresholds according to their use of water as drinking water, for other domestic use, irrigation, industrial use or as habitat for fish and other aquatic organisms. Changes in water quality can be understood from point sources of pollution, changes in the overall nutrient balance and changes in the 'filter functions' that elements in the landscape such as riparian vegetation tend to perform. Residence time for pollutants in subsurface flows can be considerable and unraveling the cause-effect relationships at any site can be a considerable challenge. Water quality can be directly influenced by changes in quantities of river discharge, especially where sediment load is concerned. River bank erosion during peak flows can add substantially to the sediment load, while periods of bank over flow can lead to sedimentation. Sedimentation into lakes and man-made reservoirs as a consequence of low flow rates leads to a reduction of reservoir volume.

Integrity of soils and absence of mass wasting has stakeholders downstream (as mudflows can be particularly damaging to people living in river beds and lead to substantial sediment inputs into reservoirs and lakes), as well as affecting the productive potential of the catchment area and the stakeholders associated with that function.