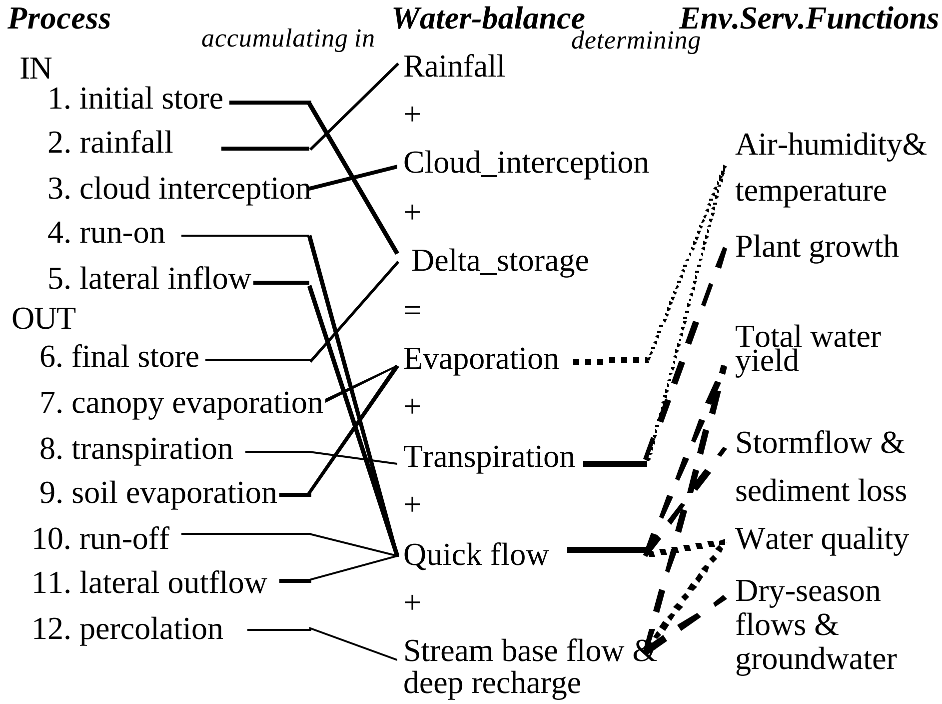
Step 2 How do the various watershed functions relate to 'land use and land cover' on the basis of the various terms of the water balance (see Phase 1 report)



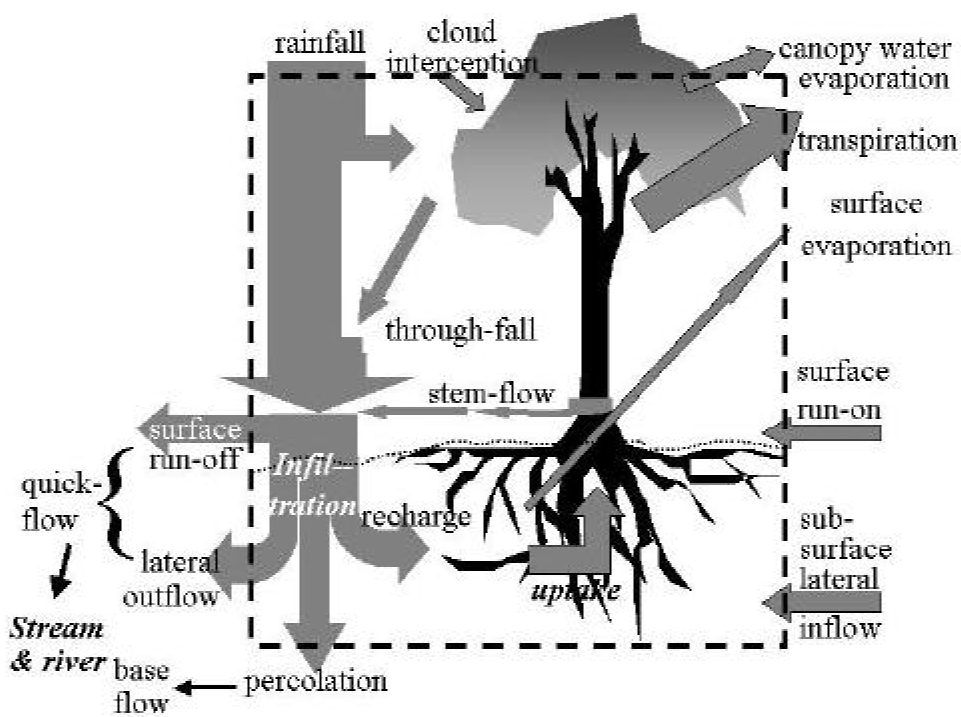


Figure 1.11. Terms of the water balance of a forest that can be modified during forest conversion and subsequent land use change; three main aspects of forests in this respect are the 'trees' that dominate aboveground interception, the 'soil' structure that regulates infiltration and the 'landscape-level drainage' that depends on presence/ absence of channels (including paths and roads), internal storage and filter zones

Step 3 How are the various terms in the water balance reflected in the analytical tools

The behaviour of rivers and the relation of such behaviour to land use and land cover can be studied using either a 'spatial pattern' approach (a common starting point in geographical studies) or a 'process' perspective (an approach commonly used in physical hydrology). When the two approaches are applied to one particular situation (e.g. the evergreen forests found at higher elevations in northern Thailand), apparently contradictory statements may arise (Table1.4).

The contradiction apparent between the two statements given in Table 1.4 can be resolved by realizing that, as in Thailand, evergreen forest tends to occur in locations where rainfall is highest. The real question, then, is whether this higher level of rainfall is the *cause* or the *effect* of the presence of evergreen forest. If either model is used to predict the impacts of land-use change on watershed functions, uncertainty with regard to the causes and effects of rainfall plays a key role.

Remnants of the 'spatial pattern' approach still exist in public perceptions; however, the theory of river discharge that dominates current scientific thinking is based on our understanding of 'hydrological processes'. The validity of many of the hydrological-process models appears to be constrained, however, by incomplete data on rainfall, due to spatially inadequate sampling schemes resulting from, for example, too few rainfall gauges and a bias towards easily accessible locations.

Table 1.4. Some characteristics of two 'modelling approaches' applied to the relationships between land cover and watershed functions (Joshi et al., 2004)

Starting point	<u>Spatial patterns</u>	<u>Hydrologic (water balance, processes)</u>
General characteristics	• Approach starts with existing land cover and river discharge properties, as they vary across space • Correlations are analysed and used for extrapolation • Models can be based on data obtained at different scales, and can apply to various map resolutions	• Approach starts with rainfall and traces water, through various pathways, to evapotranspiration or delivery to oceans • Land-use change is taken into account, as it can affect interception, infiltration and evapotranspiration (seasonality) • Models can be strongly spatially disaggregated, 'lumped' or 'parsimonious'
Typical statement	'Evergreen forest is associated with highest water yields….'	'Evergreen forest uses more water and allows less rainfall to reach associated streams than other land-use types....'

All models considered here follow a basic 'water balance' logic:

Rainfall => Interception evaporation + (Infiltration + Runoff)

Infiltration => Vegetation water use + Baseflow

Runoff + Baseflow are routed through a stream network

Effects of land used change ('deforestation') on increase in total water yield are, relatively speaking, the highest in climate zone with the lowest annual rainfall. For annual rainfall amounts of over 2500 mm year^{-1} the relative change in total water yield is likely to be less than 25% and thus within the likely inter-annual variability making it difficult to observe unless long time-series are available.

Table 1.5. Order of magnitude estimate of the effect of land use change on total water yield

Annual rainfall, mm year^{-1}	Typical water use of natural vegetation, mm year^{-1}	Total water yield, mm year^{-1}	Range of differences in vegetation water use, mm year^{-1}	Relative impact of land use change on total water yield, %
500	400	100	-200 – 0	0 – 200
1000	800	200	-300 – 0	0 – 150
1500	1100	400	-300 – 0	0 – 75
2000	1150	850	-300 – 0	0 - 35
2500	1200	1300	-300 – 0	0 - 23
3000	1250	1750	-300 – 0	0 - 17
3500	1200[1]	2300	-300 – 0	0 - 13

1. A reduction in evapotranspiration is expected at high rainfall due to increased cloud cover and thus reduced energy supply

While an increase in annual water yield can be positive from a downstream water use perspective, especially if the flow can be temporarily stored in reservoirs in the river, the general fear is that this increased discharge will largely be in the form of 'peak flow', directly after heavy rainstorms, while the 'base flow' that is, per m^3 of river discharge, of much higher potential value downstream may be reduced. To get this effect of land use change correctly predicted, we have to focus on the way '***infiltration process***' is described in the various models available.

The models directly accessible to project partners (which will be described in more detail in chapter 2) differ in the time steps: yearly for Fallow, monthly (with daily approximation) for WBM, daily for VIC, WaNuLCAS and GenRiver, 4-hourly for DHSVM (further descriptions of these models and the underlying assumptions are provided in chapter 2).

The models directly accessible to project partners also differ in the spatial resolution, but appear to handle ‘interception’ and ‘evapotranspiration’ issues in a similar way, driven by the energy balance (potential evapotranspiration).

The ‘infiltration versus runoff’ partitioning is handled with different degrees of sophistication. All models keep track of current soil water content and the soil recharge capacity that is stimulated by antecedent water use. Some of the models also include options for surface infiltration as a rate-limiting process (but to do so they need rainfall intensity at less-than-daily time scale) and the potential for subsurface of vertical outflow during the rainfall event. Some of the models distinguish ‘soil quick flow’ (water that can infiltrate to soil saturation but not stored at field capacity) as intermediate term between direct runoff and the recharge of the pool that feeds base flow.

In predicting the quantities and timing of river flow, models

1. will normally include rainfall, energy balance (potential evapotranspiration), soil storage capacity and landscape (routing times in the stream network) properties,
2. they normally also include properties of the land cover (derived from remote sensing or otherwise) with respect to rainfall interception and actual evapotranspiration as a function of soil water storage, and thus respond to changes in area fractions of different land cover types,
3. some may include influences of land cover on the infiltration capacity, and require data on rainfall intensity to predict surface runoff on sloping lands, and thus include effects of land use change on the peakflow/ baseflow ratio,
4. some may explicitly include overland flows, the entrainment of soil particles into this flow, and the sedimentation of soil particles in ‘filter’ zones, thus becoming sensitive to the spatial organization of the landscape,
5. a few will actually treat the change in soil properties affecting infiltration as a dynamic process (rather than instantaneous change), and thus become sensitive to the time course of land use change, rather than just the final outcome in terms of area fractions of different land cover types.

The models to be used in the BNPP project belong to different categories in terms of time course of changes in soil properties affecting infiltration. All models will be used for a comparison of ‘natural vegetation’ (baseline) versus ‘current land use pattern’, with current climate. A specific effort will be made to derive location-specific scenarios of plausible land use change, that will be evaluated for its bearing on hydrological functions. Further scenario development is described under activity c.

The ways river networks are represented (routing time, modification of pulse) vary. The essential characteristics are the delay in time of delivery of water to any point of observation and the change in shape of any ‘pulse’ that arrives in the stream.

Table 1.6. Classification of the hydrological models to be used in the BNPP project, according to 5 levels of complexity[1]

Model	WBM	VIC	DHSVM	Genriver	Fallow	WaNuLCAS
Time step	Month	Day	4 hours	Day (+ rainfall intensity)	Year	Day (+ rainfall intensity)
Scale	10-50 km	1 km	30 m	100 m (?)	100 m	1 m
Level 1	X	X	X	X	X	X
2	X	X	X	X	X	X
3			X	X	X	X
4			Under development		X	X
5					X	X
Biodiversity indicators					X	
Land productivity					X	X

1. spatially explicit rainfall, soil storage, potential evapotranspiration and routing
2. vegetation-dependent water use, with 'antecedent water use' effect on infiltration
3. land cover dependent surface infiltration capacity of the soil
4. overland flows of sediment, sensitivity to spatial organization of the landscape
5. dynamic changes in soil structure in response to land cover

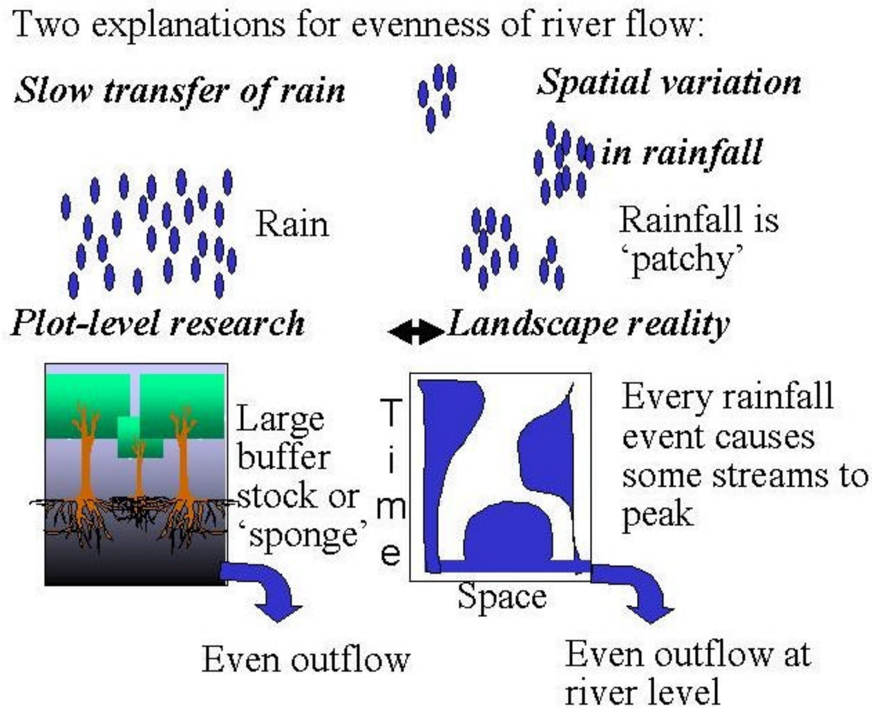


Figure 1.12. Integration of river discharge over a network of streams that show peaks in discharge in response to spatially heterogeneous ('patchy') rainfall can lead to 'buffering' of the discharge (relative to station-level rainfall records) and provides a scale-dependent equivalent to the 'sponge' effect that depends on infiltration into a large buffer stock

Explicit integration over larger areas when considering the scaling rules of river discharge may require that models carefully consider the degree of space-time correlation of rainfall (compare Fig. 1.12 and 1.13). Patchiness of rainfall may lead to a 'buffering' of river discharge when compared to station-level rainfall records.

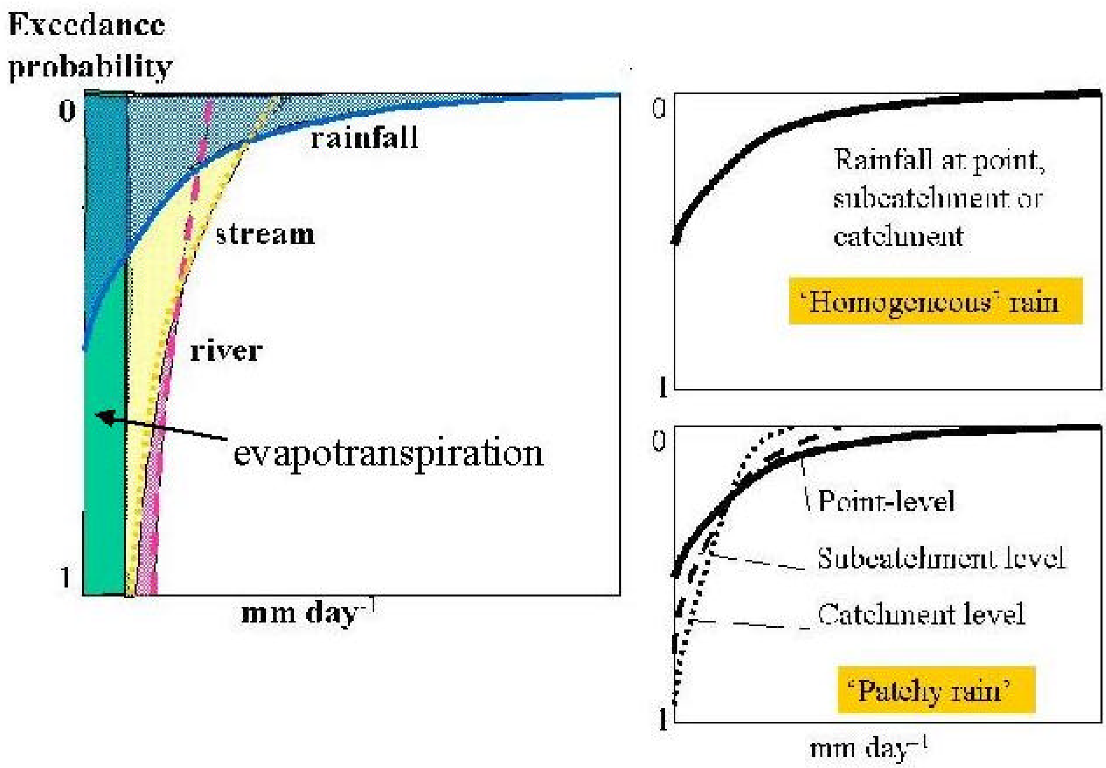


Figure 1.13. Comparison of the exceedance probability of rainfall, evapotranspiration, stream and river discharge (the area to the left of both of the latter equals the area to the left of rainfall minus the area to the left of the evapotranspiration curve when changes in storage are negligible); the shapes of the curves for (point-level) rainfall, stream flow and river flow indicate an increase in 'buffering'; the right panels indicate that depending on the degree of 'patchiness' of rainfall, the amount of incoming water per day can change from a single observation point top a sub-catchment and catchment in a way that resembles the 'buffering' shown in the left panel

Table 1.7. Policy-relevant aspects of land use change on watershed functions

	Site-specific properties	Land use change effects on change in W-function	Models
Annual water yield	***	***	All
Dry season river flow	*(*)	**	All
Flooding risk	** (transport capacity in river network <> discharge)	* (engineering interventions not fully represented)	VIC, DHSVM (WBM at monthly scale)
Landslide risk & flashfloods	** (slope, rainfall)	(*) – time since forest conversion	DHSVM

Step 4. How do the models separate 'inherent properties of sites', 'effects of land cover' and 'impacts of land use change'?

The final decision on which model applications to develop was based on a ranking of the relative uncertainty in the major contributing factors for site-specific watershed functions under the influence of land use change.

Table 1.8. Assessment by project staff of the reliability (the more **'s the better) of location-specific simulation of the various terms of the water balance and the relevance of land use change, spatial pattern of land use practices in the landscape and the time course of land use change (via the recent history) for correct predictions, as well as the options for intervening (and/or correcting) at 'engineering' level

	Reliability of location-specific simulation	Relevance of land use change	Relevance of land use spatial pattern	Relevance of recent land use history	Engineering options
Rainfall	*(*)[1]	-	-	-	(*)
Vegetation water use	***	**	(*)		-
Total water yield	**	**	-	-	-
Surface run-off/quickflow	*	*	*	*	-
Infiltration/ baseflow	*	*	*	*	-
Stream network	****	-	-	-	**

1. Rainfall appears to be adequately known for 'coarse' models, but the total input to catchments tends to be underrepresented by non-representative rainfall station locations and high spatial variability of rain; high-resolution models are restricted by ability to generate/obtain spatially explicit rainfall data

1.7 Criteria and quantitative indicators of watershed (hydrological) functions

Based on the preceding analysis, we developed a set of 5 criteria for 'watershed functions', and a set of quantitative criteria for the first three of these. The criteria focus on 'watershed functions' as modifiable by land cover and land use, given the site characteristics and rainfall pattern that is not likely to respond.

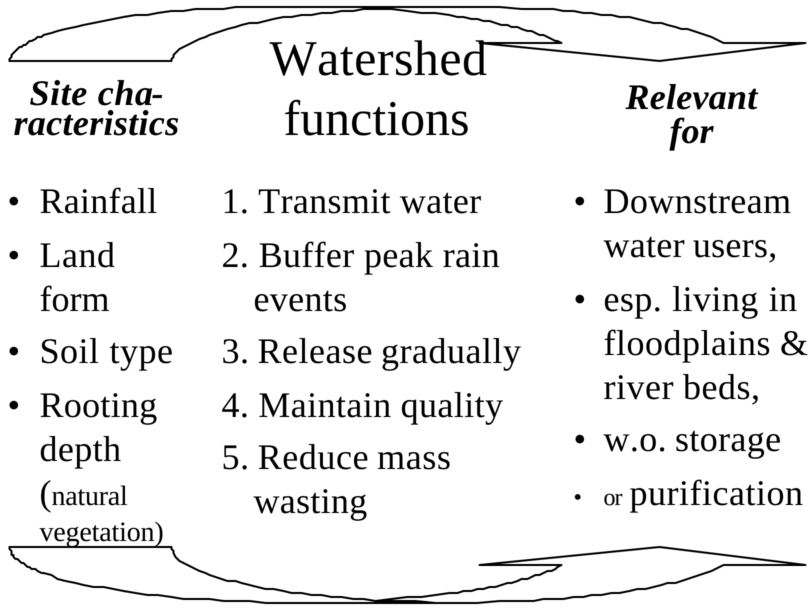


Figure 1.14. Five criteria for watershed functions that relate site characteristics to aspects of river discharge that are relevant to specific groups of downstream stakeholders

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:

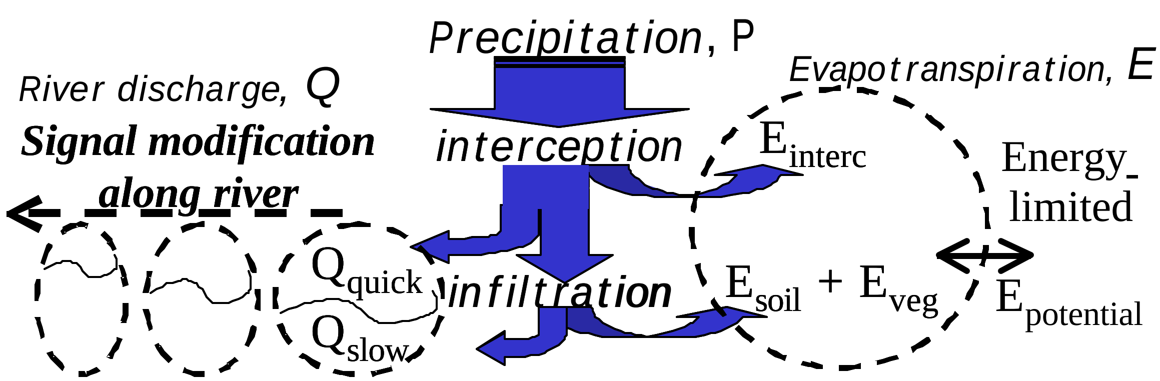


Fig. 1.15. Schematic representation of the partitioning of precipitation in its passage through the canopy, when it reaches the soil surface and after infiltration into the soil

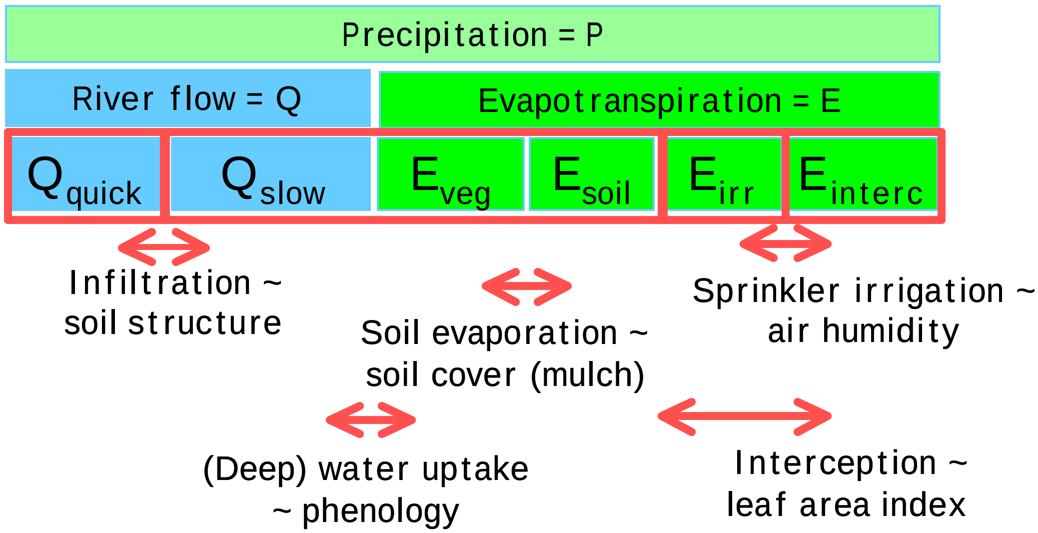


Figure 1.16. Five controls exerted by land cover and land use on the partitioning of precipitation over river discharge and evapotranspiration

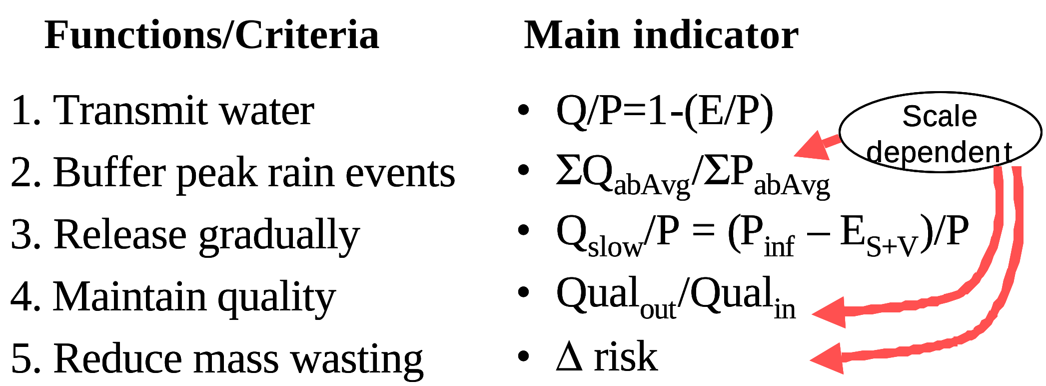


Figure 1.17. Indicators for the five criteria, acknowledging that quantitative properties of river discharge change along the river course leading to 'scale dependence' of 3 out of the 5 indicators

Table 1.9 Criteria and indicators relating to quantity and timing of river discharge

Criterion	Indicator	Dimension	Variants
1. Transmit water	**1.1 Total water yield (discharge) per unit rainfall** $TWY = \Sigma Q/(A * \Sigma P) = 1-(\Sigma E/\Sigma P)$ Q = river discharge P = rainfall A = area E = evapotranspiration	[-]	a) Accumulation over specified length of observation period b) mean of annually calculated values
2. Buffer peak rain events	**2.1 Buffering indicator for peak flows given peak rain events** $BI = (P_{abAvg} - (Q_{abAvg}/A))/P_{abAvg}$ $= 1 - Q_{abAvg}/(A\,P_{abAvg})$ *with* $P_{abAvg} = \Sigma \max(P-P_{mean},0)$ $Q_{abAvg} = \Sigma \max(Q-Q_{mean},0)$	[-]	a) Maximum during specified length of observation period b) mean of annually calculated values of maximum or mean (shift from calendar to hydrological year?)
	2.2 Relative buffering indicator, adjusted for relative water yield $RBI = 1 - (P_{mean}/Q_{mean})*(Q_{abAvg}/P_{abAvg})$	[-]	
	2.3 Buffering peak event $1-Max(daily\_Q-Q_{mean})/(A*Max(daily\_P-P_{mean}))$	[-]	
	2.4 Highest of monthly river discharge totals relative to mean monthly rainfall	[-]	
	2.5 Fraction of total river discharge derived from overland flow (same day as rain event)	[-]	
	2.6 Fraction of total river discharge derived from soil quick flow (1 day after rain event)	[-]	
3. Release gradually	**3.1 Fraction of discharge derived from slow flow (> 1 day after rain event)** $\Sigma Q_{slow}/(\Sigma Q) = (\Sigma P_{infiltr} - \Sigma E_{S+V})/\Sigma Q$ with $P_{infiltr}$ = amount of rainfall infiltrated into the soil E_{S+V} = evaporation from soil surface an d transpiration by plants	[-]	
	3.2 Lowest of monthly river discharge totals relative to mean monthly rainfall	[-]	

2. Materials and methods

2.1 Case study sites: available data sets

2.1.1 Southeast Asia

Southeast Asia and neighbouring parts of South and East Asia contain a major part of the world population, living in some of the worlds' highest population densities. Yet as a region it still contains area of closed forest, as well as many land cover types that are intermediate between closed forest and open-field agriculture or urban domains. Insular southeast Asia has probably the worlds' highest rate of land-ocean transfer of sediment per unit land area (Milliman et al. 1999). Thus the region as a whole offers many opportunities to explore the interactions between forest conversion, intensification of land use, biodiversity conservation (from local, national and/or international perspectives), and watershed functions that matter for people at a range of distances from the land units involved in the change (Fig. 2.1).

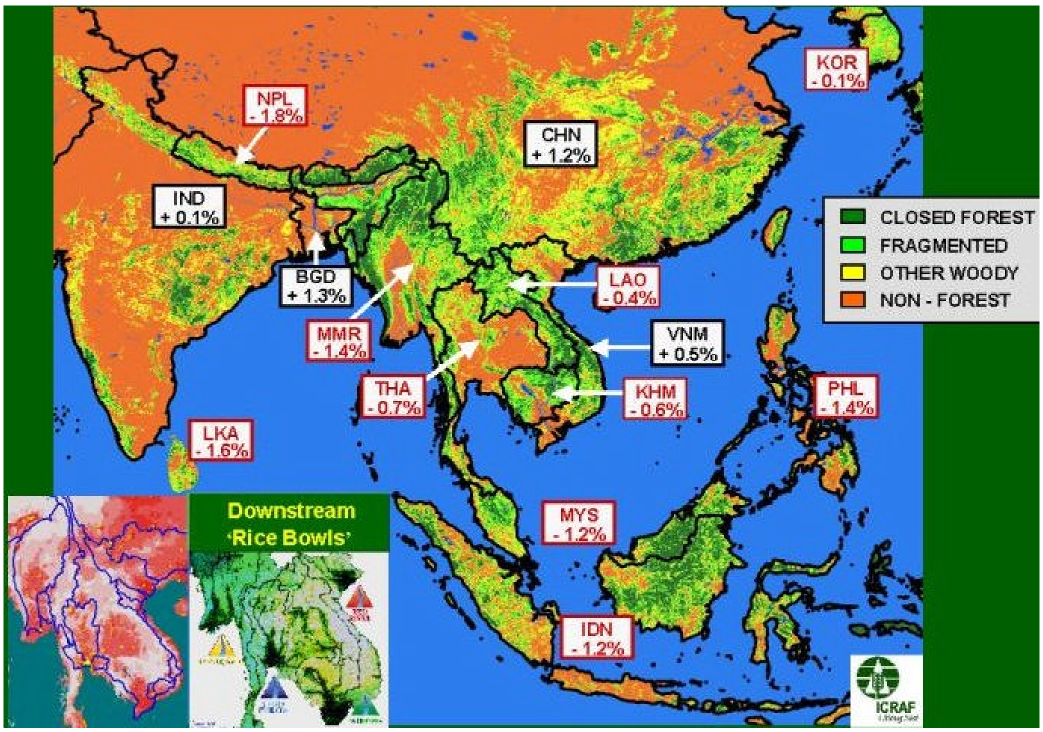


Figure 2.1. Statistics compiled by the Forest Resource Assessment (FRA) 2000 for 1990 – 2000 for countries in South, Southeast and East Asia show annual rates of change in forest cover that range from –1.8% year^{-1} for Nepal to + 1.3% for Bangladesh. Most people (inset to the left) live in the major 'rice bowls' or lowland areas, while most of the remaining forest is in the uplands. The policy discussions on 'watershed functions' focus on this dichotomy, with capital cities and political power generally in the lowlands

At the start of the new millennium, the East Asia plus Pacific region contained 1 836 M people (just over one-third of all the inhabitants of developing countries), of which 62% (1 124 M people) directly involved in agriculture; 278 M people (15% of total regional population live in extreme poverty, with daily incomes less than 1 US$ day^{-1}; a quarter of the 'extremely poor' live in China; about 240 M people (13% of total population) are under nourished; rural poverty ranges from 4.6% in China to 57.2% in Vietnam (Dixon et al., 2001).

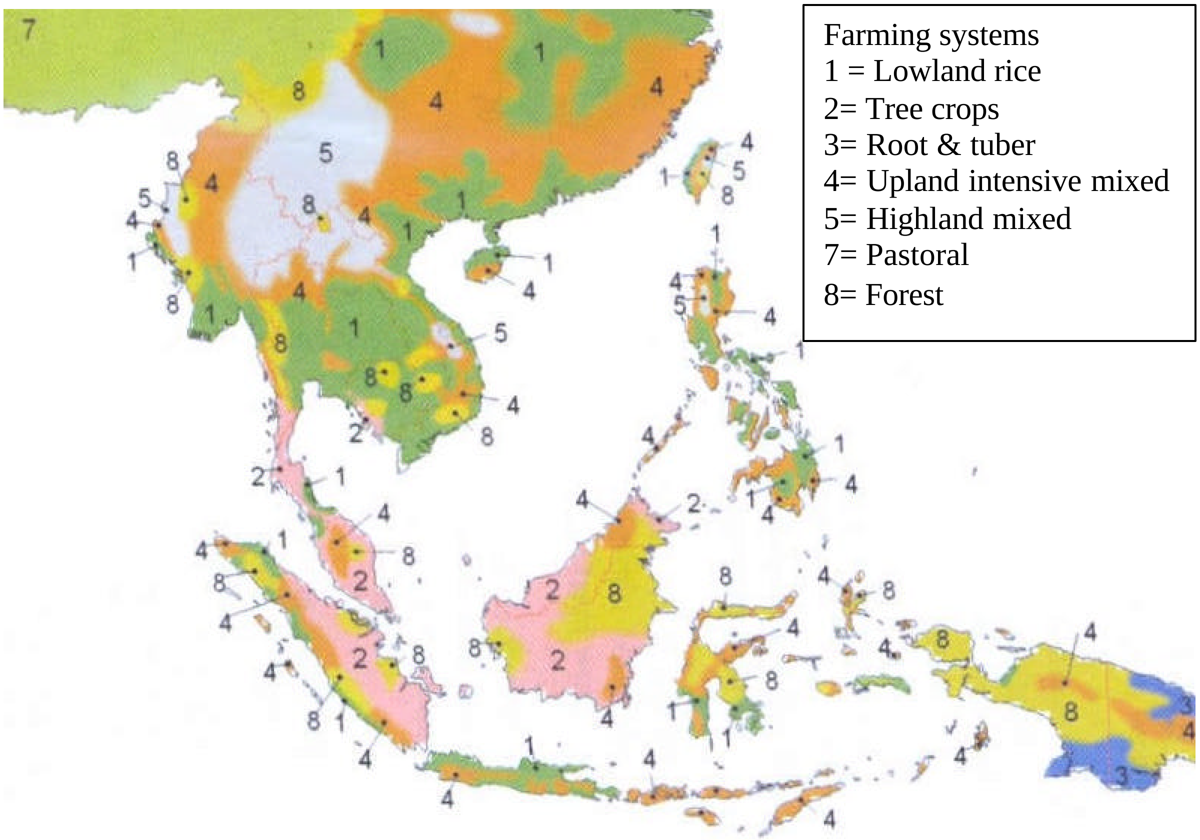


Fig. 2.2. Major farming systems in East Asia and Pacific (source: ‘Farming Systems and Poverty: improving farmers’ livelihoods in a changing world’ by John Dixon, Aidan Gulliver and David Gibbon, 2001; FAO and World Bank)

The distribution of the rural population is very uneven: the lowland rice farming system maintains on average 240 persons km^{-2}, the intensive upland mosaics 100 persons km^{-2}, the tree crop systems 35 persons km^{-2} and the sparsely populated forest systems <15 persons km^{-2}.

Table 2.1. Major farming systems in East Asia and Pacific (source: 'Farming Systems and Poverty: improving farmers' livelihoods in a changing world' by John Dixon, Aidan Gulliver and David Gibbon, 2001; FAO and World Bank); NB the data on area and population size include all of China and the Koreas

Farming system	**Areal extent (% of land area in region)**	**Rural population, population density (% of total)**	**Principal livelihoods**	**Prevalence of poverty**
1. Lowland rice	197 M ha (12 %)	474 M 241 km^{-2} (42 %)	Rice, maize, pulses, sugarcane, oil seeds, vegetables, livestock, aquaculture, off-farm work	Moderate
4. Upland intensive mixed (***incl. major areas outside of the tropics***)	314 M ha (19 %)	310 M 99 km^{-2} (27 %)	Rice, pulses, maize, sugar cane, oil seeds, fruits, vegetables, livestock, off-farm work	Extensive
5. Highland extensive mixed	89 M ha (5 %)	47 M 53 km^{-2} (4 %)	Upland rice, pulses, maize, oil seeds, fruits, forest products, livestock, off-farm work	Moderate
2. Tree crop mixed	85 M Ha (5 %)	30 M 35 km^{-2} (3 %)	Rubber, oil palm, coconuts, coffee, tea, cocoa, spices, rice, livestock, off-farm work	Moderate
8. Sparse (forest)	172 M ha (10 %)	23 M 13 km^{-2} (1 %)	Hunting, gathering, off-farm work	Moderate
3. Root – tuber (PNG)	25 M ha (2 %)	1.5 M 6 km^{-2} (< 1%)	Root crops (yam, taro, sweet potato), vegetable, fruits, livestock, off-farm work	Limited
***Others* (mostly non-tropical China)** 6. Temperate mixed 7. Pastoral 9. Sparse (dry)	 6 % 20 % 20 %	 14 4 2		 Moderate Extensive Extensive

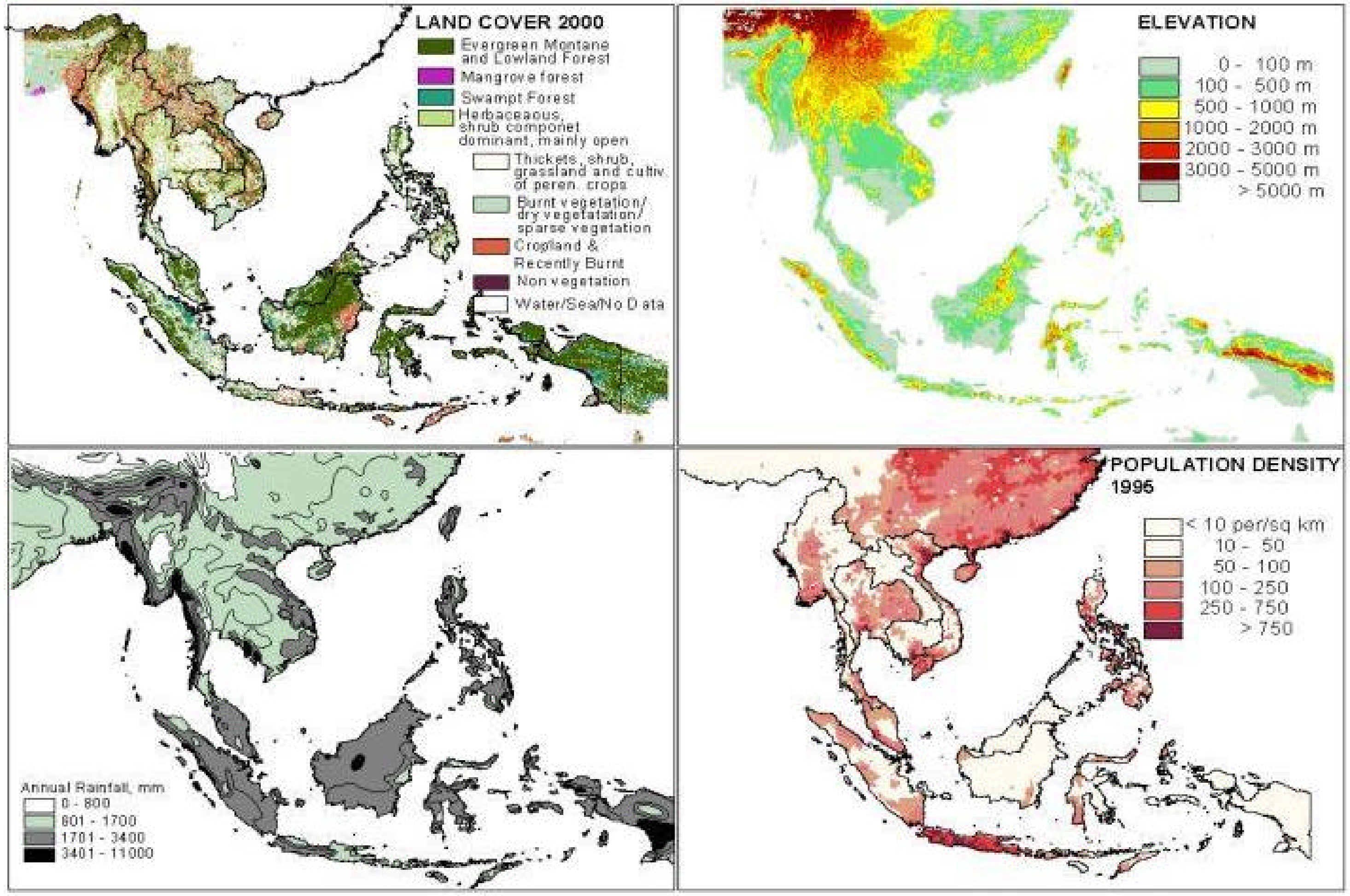


Figure 2.3. A…D Land cover[1], elevation[2], annual rainfall[3], population density[4] for southeast Asia