Table 4.3. Summary of evidence regarding the 'scale effects' of land use change impacts on watershed functions (compare Table 1.2)

Aspect	**Intrinsic scaling relationship**	**Is the restriction of LU impacts to 100 km^2 real?**
Total water yield	Proportional to relative discharge efficiency of all land uses upstream, weighted by rainfall	1) Lack of evidence for areas > 100 km^2 is probably based on difficulties of inference for the slower process of land use change when larger areas are considered. 2) A major hypothesis that emerges is that additional water after forest conversion creates opportunities for irrigation that tend to be used on a decadal time scale, leading to neutral effects on overall flow
Peak flows	Intrinsic scaling rule for maximum daily flow rate of $area^{0.75}$; our analysis suggests that the power of the scaling rules does depend on land use	Lack of evidence of noticeable impacts on peak flows may well reflect a real 'lack of impact' rather than 'lack of evidence'; within the reduced uncertainty world of models impacts can be traced further downstream, but uncertainty about the areal extent of peak rainfall events that are the driver for peak flows limits empirical inference
Dry season flows	Where the flow pathways for slow flows are not beyond the root zone of (deep-rooted) trees, substantial effects of spatial pattern can complicate the intrinsic area-based scaling rule	Impacts in areas larger than 100 km^2 can be real, but the multitude of flow pathways when larger areas are considered makes inference more complex. In dry areas the impacts of land cover change through changes in groundwater flow and its salt load can extend to 10,000 km^2 areas or more as in the Australian case
Sediment load	Larger areas tend to include areas where sedimentation can occur, as well as involve a change from 'substrate limited' to 'energy limited' dynamics of the sediment load of streams by passage through 'sedimentation fans' or 'alluvial deposits'	The change from direct land use related drivers to conditions in the river bed as main explanation of sediment loads makes impacts of land use change less important when larger areas are considered

4.6 Reflection on the hypotheses

Hypothesis	**Evidence**	**Adequate model representation that allows testing**
0. 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 (W) will be sufficient to achieve biodiversity conservation (B)	Conversion to coffee-based agroforestry mosaic in Sumberjaya ASB benchmark is OK for W, but involves large B loss. W thresholds relate to soil (and thus to belowground biodiversity?), riparian zone filter and wetland buffer areas (a subset of B), rather than on B as a whole	Scaling relationship of biodiversity value from patch to landscape mosaic remains major challenge; biophysical side of W and its scale relationship and pattern dependency is sufficiently understood; translation to 'stakeholder value' is still a challenge
1. 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	Logging operations tend to damage W rather than B depending on log transport through streams; 'reduced impact logging' has less negative W impacts; selective NTFP extraction is a risk for B rather than W, at population densities < 5 km^{-2}; open field agriculture with fallow rotations can maintain most of B and W values till 10- 15 persons km^{-2}; forms of modified forest with 'domesticated' NTFP's can allow for 30 persons km^{-2} in high B and high W landscapes	The initial stages of land use intensification as such are poorly represented in models, as they tend to lead to gradual changes that are not easily recognizable by remote sensing. The FALLOW model is available as vehicle for translating effects on B and W known at the ***activity*** level to their consequences in a land use mosaic
2. 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	Conversion to rubber agroforestry mosaic as in Jambi ASB benchmark is OK for W and maintains B, but close to its threshold at 50 persons km^{-2}; further intensification in tree crops affects B rather than W; for 'open field agriculture' the B loss in reducing fallow periods clearly proceeds loss in W	Most existing models can translate changes in aboveground vegetation to changes in interception and seasonal patterns of evapotranspiration. Impacts on the 'slow variables' via changes in soil structure are modeled only in some of the more recent models – and need further parametrization

3. Further (attempts at) land use intensification will negatively affect most watershed functions, leading to land covers that represent low values for both functions	Intensification in tree crops such as coffee to 'sun coffee' can affect W in Sumbarjaya ASB benchmark. Intensification in open-field agriculture has a challenge in maintaining soil structure and thus W; Mae Chaem benchmark data on soil bulk density support this conclusion	Where soil compaction leads to measurable changes in bulk density, relative to its texture-based reference value, translation to infiltration in process-based models is feasible. Adequate process description for surface runoff exists, but the entrainment of soil particles into this flow and the way this depends on surface soil structure is still largely empirical
4. 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	The time frame required for rehabilitation of biodiversity depends on the type of habitat and the effective removal of the land-use related threats to biodiversity. Rehabilitation of watershed functions is likely to be more compatible with intensive land use. Restoration of filter and buffer functions and properties at the soil surface can be rapid, but the time frame for effective restoration of soil structure for deeper infiltration is uncertain (and may be similar to that required for aspects of biodiversity	Biodiversity restoration and its dependence on biological reservoirs in the broader landscape is not adequately represented in current models. The process-level description of regeneration of soil structure in WaNuLCAS remains to be tested with field data
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	For sufficiently longtime periods this may be a 'truism', but inter-annual variability in rainfall (incl. El Nino years) and inter-seasonal transfers via changes in the soil and river storage terms can be substantial. Model tests for larger areas generally have the 'excuse' of uncertainty in the actual rainfall amounts, as the density of rainfall stations is insufficient for direct extrapolation to the catchment areas as a whole	Models can deal with this issue with different degrees of temporal and spatial resolution, but the underlying processes are well represented

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	The Way Besai (Sumber Jaya) data summarized in Fig. 4.3 indicate independence of peak flows as well as low flows where total water yield increased after forest conversion; this data may be the first of its kind in the way of data analysis, but the underlying process is probably not unique for the location…	Controls on soil structure and infiltration operate at a different time scale form the controls on aboveground water use; some of the recent models include dynamic changes in soil properties and can thus explore the time-lags involved
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 flow strongly decreases with distance along the stream	For the Way Besai series we found that models with spatially heterogeneous rainfall can give a more satisfactory account of the frequency distribution of flow regimes than any method that assumes station-level rainfall to apply across the catchment. Impacts of river beds on stream flow are likely to be noticeable only in large areas	Engineering models of river flow can include impacts of the river bed on flow conditions, but tend to exclude effects of land use on process of water delivery to the streams. Models that started from the analysis of land cover change tend to be lacking in detail on the conditions of the river bed.
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	Data on erosion and net sediment loss after slash-and-burn land clearing in Jambi (Roodenburg et al., 2003) show the importance of land form. The FALLOW model application to Sumber Jaya makes plausible that there are impacts of location of tree cover	Models need to explicitly account for 'lateral flows' to allow exploration of locational effects. Ranieri et al., 2004 give examples.

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 flow after peak rainfall events, b) low dry season flows, c) landslides and d) changes in water quality (sediment load, pollutants, nutrients)	Where drinking water and water for other domestic use is directly derived from the landscape, local concerns over water quality may dominate over concerns over water quantity. Protection the flow lines that generate groundwater streams, through protection of forests on fill tops and upper slopes may derive from such 'quality' concerns	The location in the landscape where slow flows appear (in springs or otherwise) can only predicted from a detailed geomorphological study; changes in the amount of water that enters such pathways can be simulated by most of current water balance models. Landslide risk models tend to focus on 'permanent' features such as slope, soil type and climate, rather than on properties that can change through land use, such as root strength (but see Sidle and Dhakal, 2003)
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.	The management rules of reservoirs and dams tend to dominate flooding risk in rivers that are heavily regulated; the public perception tends to overrate the importance of forests in upper catchments for such circumstances	Extractions from the river for irrigation can, especially in dry areas, be a significant factor that tends to be underrated

4.7 Priority issues for follow up research

This study has brought to light a number of weakness in existing models and the underlying process knowledge, and opportunities to make significant progress. Important challenges are:

- Better quantification of water use by different forest types, especially for subhumid zone as in Mae Chaem
- Better representation of long term changes in soil physical properties and opportunities for rehabilitation under local farm management (dynamics of soil properties in models such as GenRiver)
- Representation of filter effects on overland flows into models based on generation and infiltration of overland flow, entrainment of soil particles in overland flows and conditions that allow sedimentation
- Dynamic representation of landslide risks linked to dynamics (growth and decay) of deep root system for different forest types and trees in sparse vegetation
- Role of bank erosion and changes in storage capacity of the river bed in net sediment flows
- Conditions under which flooding risk will increase more than proportionally to the average buffering indicator
- Role of bank overflow and temporary water storage in wetlands on flooding risks downstream (‘landscape level buffering’)
- Rainfall patterns with complex orographic effects such as in Mae Chaem and their impact on error margins in models based on input-output comparisons

5. Conclusions for natural resource management

5.1 From a natural resource management perspective 'watershed functions' and 'biodiversity conservation' are clearly separate issues, as the thresholds for change during land use intensification differ substantially; indicators at plot, landscape, subcatchment and catchment scale of the historical land use change between 'natural vegetation' and 'current land use pattern' suggest that watershed functions involved in the transfer, buffering and gradual release of water are maintained (or even improved as far as total water yield is concerned), despite considerable loss in biodiversity value. Only upon further intensification of land use with a dominance of open –field agriculture (or built-up urban areas) will these watershed functions be affected negatively. The separation of 'watershed functions' and 'biodiversity conservation' agendas at a policy level has important consequences for the overlap in stakeholders. Only in very specific circumstances can we expect local interests in maintenance of watershed functions to lead to the type of land cover that is optimal for biodiversity conservation.

5.2 The empirical scaling rule that relates maximum daily flows (and thus flooding risks) to area to the power 0.75 and mean annual flows to area as such, suggests that flooding risk is a 'local hazard' and total water yield a 'positive far field effect' of forest conversion. The scaling rule can be understood from the spatial pattern in rainfall, only in combination with a (land cover dependent) intercept in the rainfall-runoff relationship. It is thus likely that land cover change cannot only affect the maximum flows at plot level, but also the inherent scaling rule. The scaling rule for species richness (roughly proportional to area to the power 0.25) differs essentially from that for watershed functions, and we can thus expect the trade-off between biodiversity and watershed functions to differ with the area under consideration. For biodiversity values a 'segregate' scenario with areas of high biodiversity value effectively protected in a landscape otherwise optimized for productive functions may be optimal. For watershed functions a more 'integrated' land use mosaic that prevents any area from degradation beyond critical thresholds is preferable. The combination of the two functions, in terms of specific conservation areas in a 'matrix' of an agroforestry mosaic that allows for both productive and protective functions requires separate management and regulatory approach to the two types of areas and specific attention to their interface

5.3 Where earlier summaries of the impact of land use change on watershed functions had found little solid evidence for areas larger than 100 km^2, our data for Way Besai (400 km^2) and Mae Chaem (4000 km^2) provide empirical evidence for an increase in total water yield as well as changes in buffering for the former, for a period of drastic land cover change (60 -> 15% forest cover); for the Mae Chaem the historical land cover change has been less dramatic that that in Way Besai, but simulation models suggest that a significant increase in water yield between natural vegetation and the current land use mosaic has taken place; plausible scenarios of further land use change will continue on this trend towards greater water yield and less tree and forest cover.

5.4 ***The current evidence from historical change in the benchmarks and from the (validated) models suggests that increases in peak flows*** are proportional to changes in total water yield; more-than-proportional increases in peak flows only are expected for land use scenarios that lead to substantial soil degradation

5.5 ***Realistic land use change scenarios for the uplands of Asia*** have to provide livelihood and income opportunities for a rural population that is still growing. Declaring large areas as 'forest reserves' and expecting farmers to leave is not realistic. Mosaics with tree-based production systems, rather than open-field crops may provide the best way to provide income while maintaining soil conditions conducive to infiltration. The biodiversity value will depend on the opportunity to reserve (segregate) parts of the area for specific conservation purposes, in a socially integrated way. The impacts of land use patterns on biodiversity is likely to exceed the impacts on watershed functions.

5.6 ***Specific attention to riparian zone forests*** as landscape elements that can reduce sediment loads of streams as well as play a role in connectivity for plants and animals is warranted; this may be one of the main items where a watershed function and a biodiversity conservation agenda find synergy; a second shared interest is likely to be in the maintenance of wetlands along the river, that can provide a buffer function reducing the risk of flooding downstream, as well as providing important habitat for flora and fauna.

5.7 ***Ridge top forests*** can also play an important role as corridors for flora and fauna and thus for biodiversity conservation, especially where human access is primarily linked to the valleys. Ridge top forests (but not their spatial continuity) are relevant for protecting groundwater flows that are tapped for drinking water or other situations where water quality is of specific interest. The emphasis on riparian forests may thus need some nuance.

5.8 ***While the benefits of forest conversion for total water yield*** form a positive 'far field' effect, the associated higher peak levels require adjustments in the stream bed, depending on the degree to which barrages and dams regulate flows and provide temporary storage

5.9 ***Local hazards of a change in watershed functions are likely to be*** more clearly identifiable, both because of the relative size of the 'insult' is likely to be larger, and because of intrinsic scaling properties for peak flows. Local stakeholders are likely to have a clear interest in protecting the areas from where they derive their drinking water, as well as areas that stabilize slopes above villages or other vital functions; this type of land use zoning will differ from the broad land use classifications that were developed for many countries in SE Asia, with little implementation on the ground. Where derived from a local negotiation process and supported by local monitoring of water quality and other indicators of watershed functions. Local ecological knowledge is more likely to acknowledge the changes in effective infiltration than spatial extrapolation methods based on currently available soil information.

5.10 ***Protecting existing forests on slopes with soils that allow high infiltration rates*** makes sense, both for water quality and potentially for supporting dry period/season flows, especially where annual rainfall is more than say 1500 mm $year^{-1}$.

5.11 Expectations of a recovery of infiltration based on planting trees are seldom realistic (except for the direct early effect of planting holes in sealed-surface conditions), and the net effect of rapidly increasing water use and slowly recovering infiltration on dry season flows is likely to be negative for a time frame beyond 'projects' life spans.

5.12 In the interactions between stakeholders in real landscapes, the tangle of convenient myths, half-baked perceptions, sound experience and valid concerns needs to be acknowledged as such – science-based evidence (the core of this report) can only help if it can provide a common platform for discussions.

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7. Appendices

7.1 Appendix 1. Formal description and terms of reference for Activity 2

<u>Goals</u>:

a) Use process-based hydrological models to assess the impacts of land cover changes on hydrological effects such as water flow and water quality over 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);
b) Explore the complementarity and consistency of hydrological models with different ranges of scale and differing emphases in the representation of physical processes
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.

Phase II deliverables (activity I + II)

1. ***Implementation protocols*** for all sub-activities under Activities 1 and 2. These will provide detailed specification (subject to revision) of the performance of these tasks, including data sets and variables to be used as inputs, models and analytic procedures to be applied, outputs expected, geographic scale and scope of analysis, timing of activities, and assignment of responsibilities.
2. ***Technical reports*** covering all activities, detailing data sources, methods and models applied, substantive outputs, and policy or methodologically relevant conclusions.
3. ***Spatial datasets and analyses***, with appropriate metadata, in archival form (e.g. CD-ROM) available by ftp from a public website:
    a) covering the humid pantropics and impact areas, including an integrated global gridded dataset incorporating key variables from activity 1A (population, biodiversity, land use change scenarios, hydrological impact areas, hydrological hotspot areas)
    b) for MMSEA and Mae Chaem watersheds, comparable data where appropriate.
4. Two (or more) manuscripts of quality suitable for submission to internationally recognized refereed journals, possibly with World Bank staff and/or other partners as coauthors.
    a) At least one manuscript, corresponding to activity 1, should make a significant contribution to delineating, at the global scale, areas and populations that are (or are not) at potential risk from the hydrological impacts of land use change in the study focus areas; and the degree to which threat-posing land use change also impacts biodiversity. (These results also will feed into the ASB Global Synthesis Report which, in turn, will contribute to the ASB cross-cutting assessment of ‘Forest and Agroecosystems Tradeoffs in the Tropics’ that has been selected as a sub-global component of the Millennium Ecosystem Assessment.)

b) At least one manuscript, corresponding to activity 2, should represent a significant addition to the methodological and substantive understanding of the relation among land use change, biodiversity, and hydrological functions in small and medium basins. The manuscripts should also provide substantive information on hydrological risks and relevant policies in MMSEA.

5. Two (or more) ASB policybriefs derived from manuscripts described above.
    c) At least one brief on the coincidence of biodiversity-rich rainforest habitats and human populations ‘upstream’ and the exposure of human populations ‘downstream’ to degradation of watershed functions, with particular attention to flood regulation, describing implications for policies that seek to address poverty, biodiversity, and hydrological externalities through a common instrument
    d) At least one brief focusing on land management in medium and small watersheds, discussing the need for and possibilities for policies to shape land use patterns so as to improve biological, hydrological, and agricultural outcomes.

6) Two policy seminars (one in Washington, DC, at the Bank, the other in the Hague at the Netherlands Ministry of Foreign Affairs) to report results.