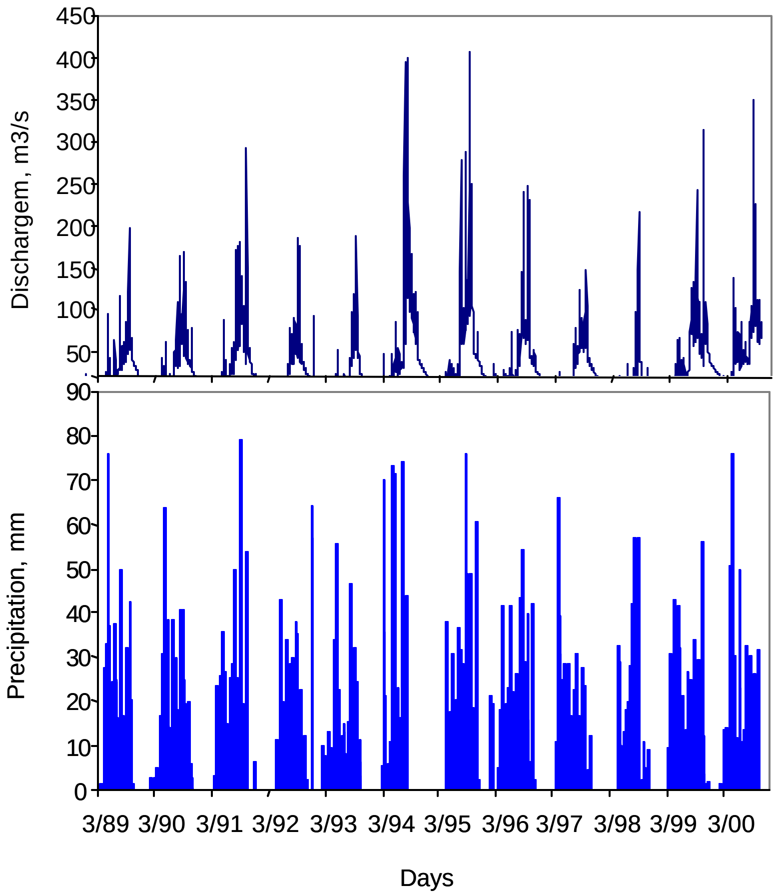

Figure 3.62. Historical records of river flow of the Mae Chaem at station P14 and precipitation at the RE station

3.9.2 Model Calibration and Testing

The spatial domain was partitioned into 150-meter grid cells, and the 3-hourly-timestep simulations were done using historical land use (1989), and climate data from June 1993 – May 1995 and June 1995-October 2000 for calibration and model testing, respectively. The simulated stream flow at the basin outlet was calibrated and tested against the daily discharge observed at RID station P.14, assuming no water diversion by irrigation or reservoirs. The climate data across the basin was computed from the 6 meteorological stations using nearest-station interpolation. The soil profile consisted of 3 root zones with the depth from top to bottom of 30 cm, 30-35 cm, and 40 cm. The lateral subsurface flow was calculated using a topography gradient. In the routing scheme, roads were not included, and the stream classification was done based on Strahler stream order and segment slope, derived from the DEM. The temperature and precipitation lapse rates were assumed constant for the whole catchment. The final calibration parameters are available in Table 3.12.

Table 3.12 Final values for DHSVM model parameters

Parameter	Values
Ground roughness, m	0.02
Reference height, m	40
Rain LAI multiplier	0.02
Temperature lapse rate, ^{o}C/m	-0.0015
Precipitation lapse rate, m/m	0.002
Overstory height, m	20-30
Understory height, m	0.2-5
Vegetation vapor pressure deficit threshold, kPa	4000
Maximum stomatal resistance for overstory, s/m	4000-5000
Minimum stomatal resistance for overstory, s/m	200-400
Maximum stomatal resistance for understory, s/m	600-3000
Minimum stomatal resistance for understory, s/m	120-175
Overstory LAI	2.3-10.8 (broadleaf) 4.8-12.5 (needleleaf)
Understory LAI	0.8-10
Overstory albedo	0.2
Understory albedo	0.2

To observe seasonal and inter-annual variability of hydrologic responses, and to study effects of land-cover change, the same set of climate data and parameters used in model testing were used to generate daily discharge, annual water yield, average flow for the wet and dry seasons (high flow and low flow), and monthly evapotranspiration for all land cover scenarios, both with and without irrigation. For the future scenario II and III, two sets of soil conditions were applied. The first condition being consistent with the soil properties of the other scenarios and the second reflecting soil compaction. In the latter case, the properties of the topsoil layer were altered. The bulk density was assumed to be 1800 kg/m^3, the typical value that interferes with root growth for crops grown in clay loam, and the soil porosity was adjusted accordingly. The soil infiltration rate and the vertical hydraulic conductivity were reduced to 10% of calibrated values.

When irrigation was considered, daily irrigation consumption was calculated and subtracted from the daily discharge computed by DHSVM to account for the water diversion to agricultural areas. The crops were divided into 3 categories based on their water demands; wet season rice, dry season rice, and cash crops, such as soybean, tomato, corn, cabbage and other vegetables (Table 3.13). The irrigated areas were approximated from the number of pixels of each crop type in the original 1989 and 2000 land cover classification schemes (Figure 2.61). The following assumptions were made. First, only 1/8 of the area designated as swidden cultivation was used for cropping and was irrigated. Second, for the general field-crop classes, half of the area was wet-season rice and the other half was cash crop. Third, 40% of incremental croplands in each scenario were irrigated, and they were equally divided for cash crops and wet-season rice. Finally, the actual water diverted from the stream was equal to the crop water needs.

Table 3.13. Monthly irrigation water demand (in mm) of northern agricultural crops. (Schreider et al., 2002)

Crops\Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Wet season rice	0	0	0	0	250	300	350	150	50	50	0	0
Dry season rice	250	200	200	0	0	0	0	0	0	0	300	500
Cash crops	150	150	100	0	0	0	0	0	0	0	300	100

3.9.3. Hydrograph Analyses (Based on Simulation Runs)

a) Evapotranspiration. Annually, the simulated evapotranspiration made up 70% of the total basin-wide rainfall, and the overland and sub-surface runoff was 30% of the rainfall. The estimated evapotranspiration was lower than the pan evaporation, but both values were in the same order of magnitude and were comparable to the values found by Tangtham in 1998 and to Hirota's work in 2001.

The modeled result had the same seasonal pattern as the pan evaporation, but the latter reaches the maximum value 2 months earlier (Figure 3.63). Hirota estimated evaporation by the Force-Restore Method (FRM) and by a heat balance model, and his seasonal evaporation also shows a one-month lag from the pan evaporation.

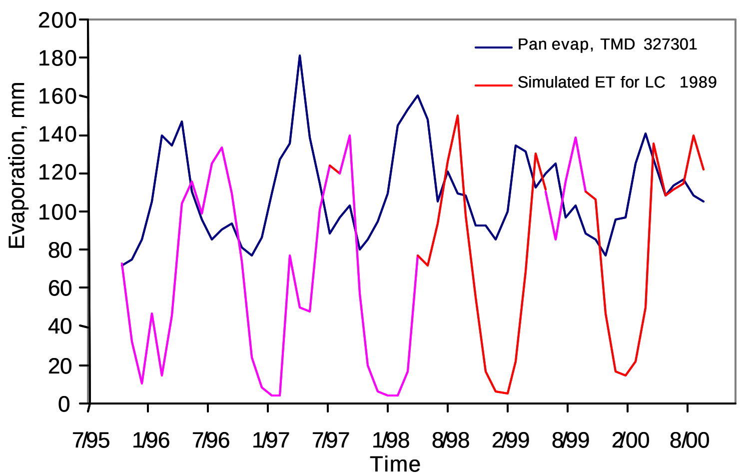

Figure 3.63. Seasonal pattern of evaporation loss : pan vs modeled

The evaporation loss from DHSVM was much lower than the pan evaporation from December to February. This does not necessarily mean that they are underestimated. The pan evaporation was done using an agrometeorological station where field crops are the major vegetation, and it is at low elevation, so the values are more sensitive to temperature. On the other hand, the actual evapotranspiration depends on the air temperature, humidity, and the type of vegetation. Therefore, we would expect to see more seasonal variation because of the evergreen and deciduous trees, as shown by lower evapotranspiration during the period with no deciduous leaves. Tangtham's work illustrates the effect of vegetation. He found that the annual evapotranspiration is about 1230 mm/yr for mountainous watershed (excluding cloud forests) and 750 mm/yr for watershed covered by hill-evergreen forest in Chiang Mai. This is because the cloud forest is very moist (low vapor pressure deficit) and receives low radiation inputs.

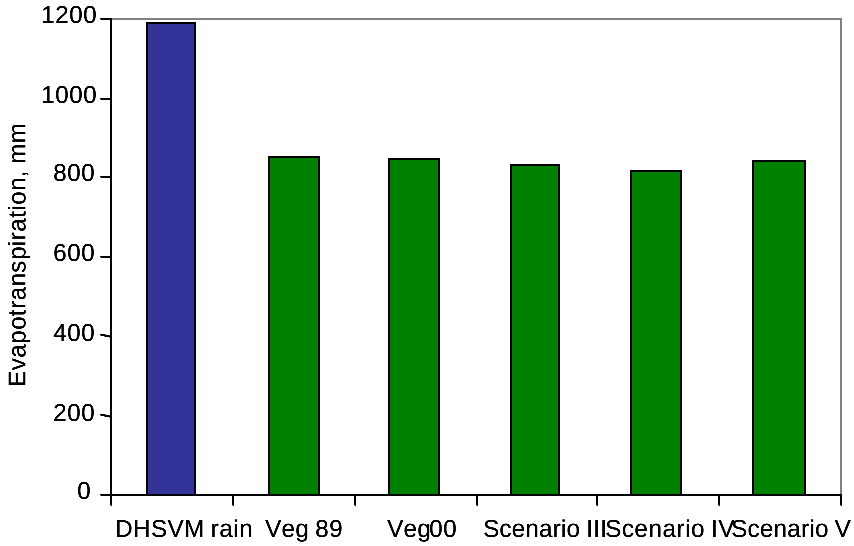

Figure 3.64. Comparison of evapotranspiration for each land-cover data

The evapotranspiration was about the same for each land-cover scenario (Figure 3.65. However, changing the spatial pattern of croplands made a difference in the evaporation loss, and consequently, on the stream water supply.

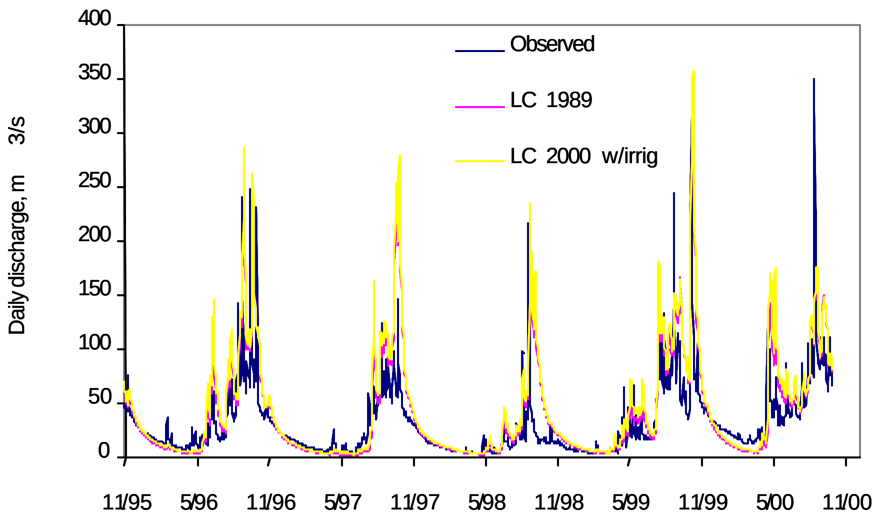

Figure3.65. Observed vs predicted hydrographs for 1989 and 2000 landcovers

b) Simulation: Observed vs Predicted Hydrographs. The simulated hydrographs on both the 1989 and 2000 land-cover data sets were very comparable to observation (Figure 3.65); both have the Pearson correlation coefficients of 0.745. The model predicted the right timing of the storm onset and the dry-season trend. The model had a higher estimation of the annual water yield and the average low flows (Figure 3.66). Overall, the stream had more water in both seasons in 2000, but this data has a substantial increase in fallow land, as well as a change in location of croplands and shrub. The increase in fallow land should contribute to higher stream flows because of less evapotranspiration loss.

The model was sensitive to soil depth, lateral hydraulic conductivities, and the precipitation lapse rate. This is due to the steep topography and the altitudinal dependence of precipitation and vegetation. Therefore, the accuracy of model results depends on the accuracy of rainfall measurement, the availability of soil data, and the seasonal values for vegetation parameters. More weather stations should be included for better climate data interpolation across the basin.

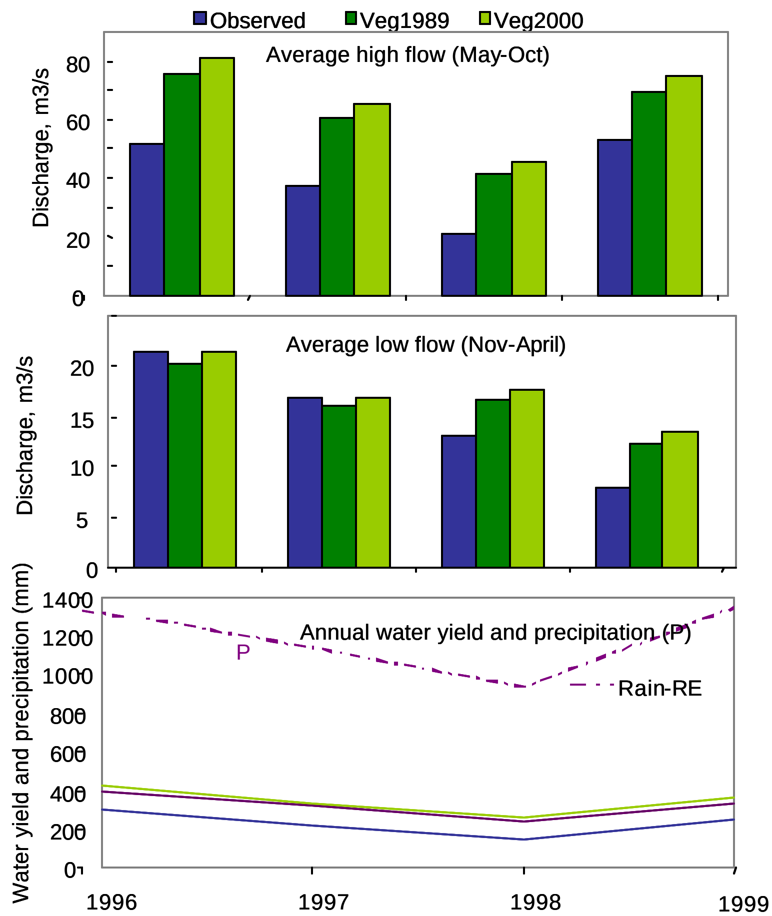

Figure 3.66. Annual and seasonal water yields from the Mae Chaem basin

c) Comparison of scenarios:

Conversion between crops and forests. Using the results from the 2000 land cover as a reference, the conversion of forest to crops in scenario I resulted in higher stream flows in both the wet and dry seasons, and the reverse was true when croplands were changed to forests, as in scenario II (Figure 3.67). This was contrary to the finding that the removal of trees causes a decrease in base flow due to the loss of sponge effect. This issue will be discussed again as related to the effect of soil compaction.

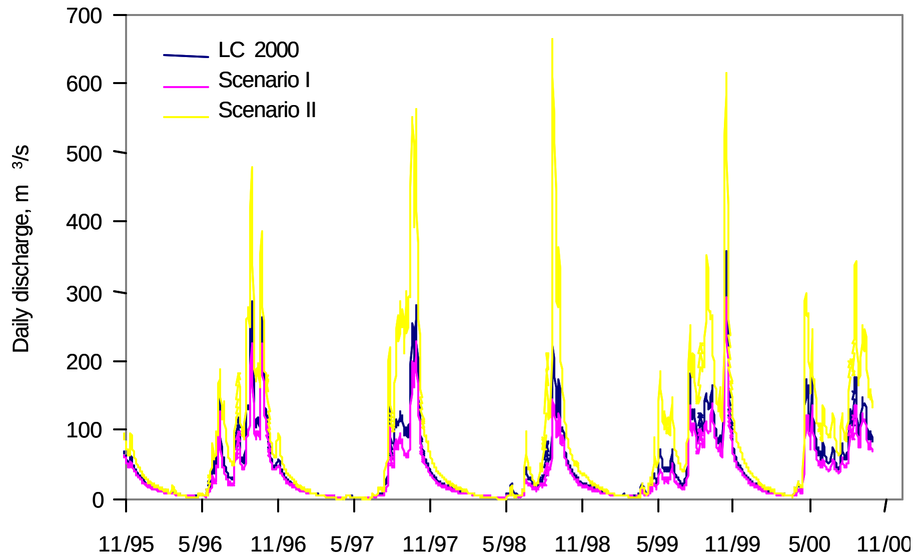

Figure 3.67. Comparison of stream flows with irrigation diversion, from different land-cover scaenarios

Effects of irrigation. Because the water demand is greatest during the dry-season, the irrigation diversion resulted in lower base flow, but did not affect stream flows (Figure 3.68)

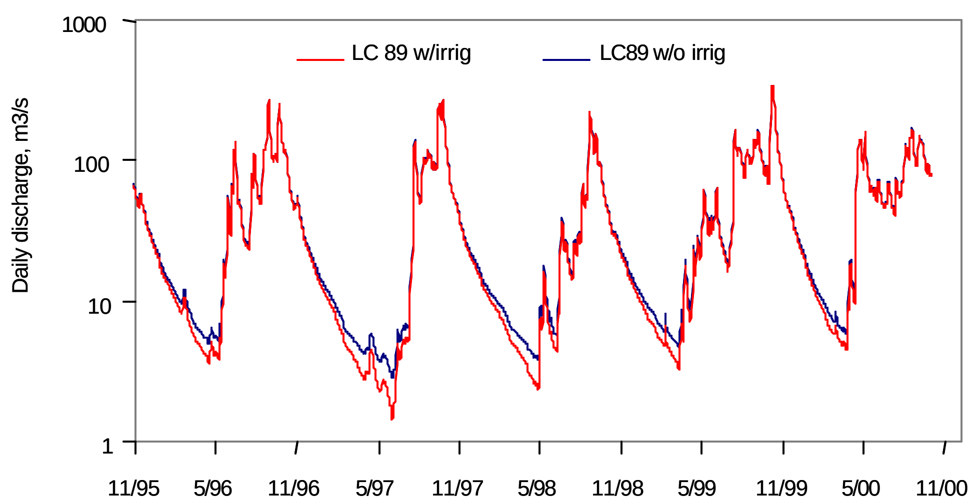

Figure 3.68. Stream duscharge at the four point on 1989 land-cover, with and without irrigation (same experiment with 2000 produces a very similar result)

Effects of soil compaction. Soil compaction is known to increase overland flow and, therefore, wet season stream flow due to reduced infiltration rate. Because the soil profile becomes dryer, the base flow is also expected to be lower. The model predicted that the annual water yield and wet-season stream flows were higher for both scenarios II and III, when the soil was compacted. However, the results were not consistent for the dry season (Figures 3.61 and 3.62). Thus, there may be other factors affecting the base flow.

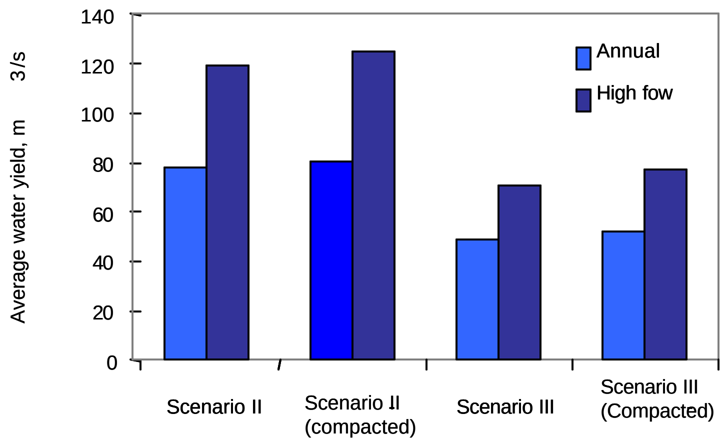

Figure 3.69. Effect of soil compaction on annual and high-season flows, with irrigation, diversion, at the basin pour point

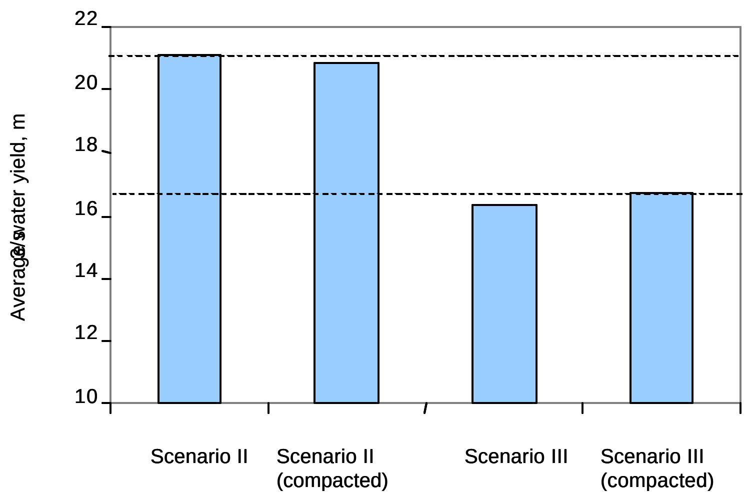

Figure 3.70. Effect of soil compaction on dry-seasons flows at the basin pour point.

Effect of spatial variation- The spatial distribution of croplands does affect annual water yield. For example, when an increase in cultivation is limited to upland areas (Scenario IV), we see a higher annual water yield due to an increase in wet-season flows (Figure 3.71). This is compared to the annual flow when cultivation increased in just the lowlands (Scenario V).

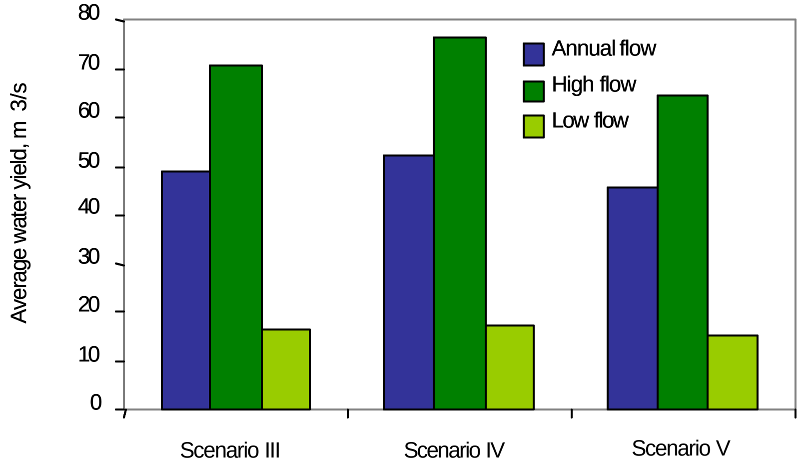

Figure 3.71. Forecasted stream flows without irrigation at the basin pour point for future scenario increasing cropland to 20% of total basin area

Far-field Effects. We selected 3 strategic locations (Figure 3.72) to observe stream discharge and to compare the relative difference among the simulated flows in 1989 and two future scenarios (II and III). The first location is Point A, situated on the main stem right below the area where the largest portion of land conversion from forest to crops occurred from 1989 to 2000. Therefore, we expect the stream discharge here to be the most sensitive to land cover change. The second location, Point B, is further down the main stem and includes an additional sub-basin. The last spot is at the basin pour point, adjacent to the main urban area. The stream distance from point A to point B and from point B to the pour point is 21.3 km and 75.8 km, respectively. The hypothesis is that as we move farther downstream, the signal from the land cover change will be less visible. What we want to know is to what extent the urban area (pour point) will be affected by the change in the sub-basin above point A. In addition, we will observe how sensitive the stream flow is to basin size.

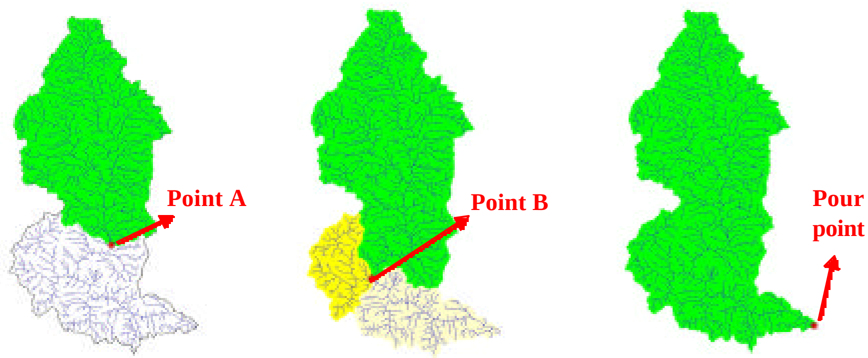

Figure 3.72. Selected locations on the main stream of Mae Chaem to observe far-field effects

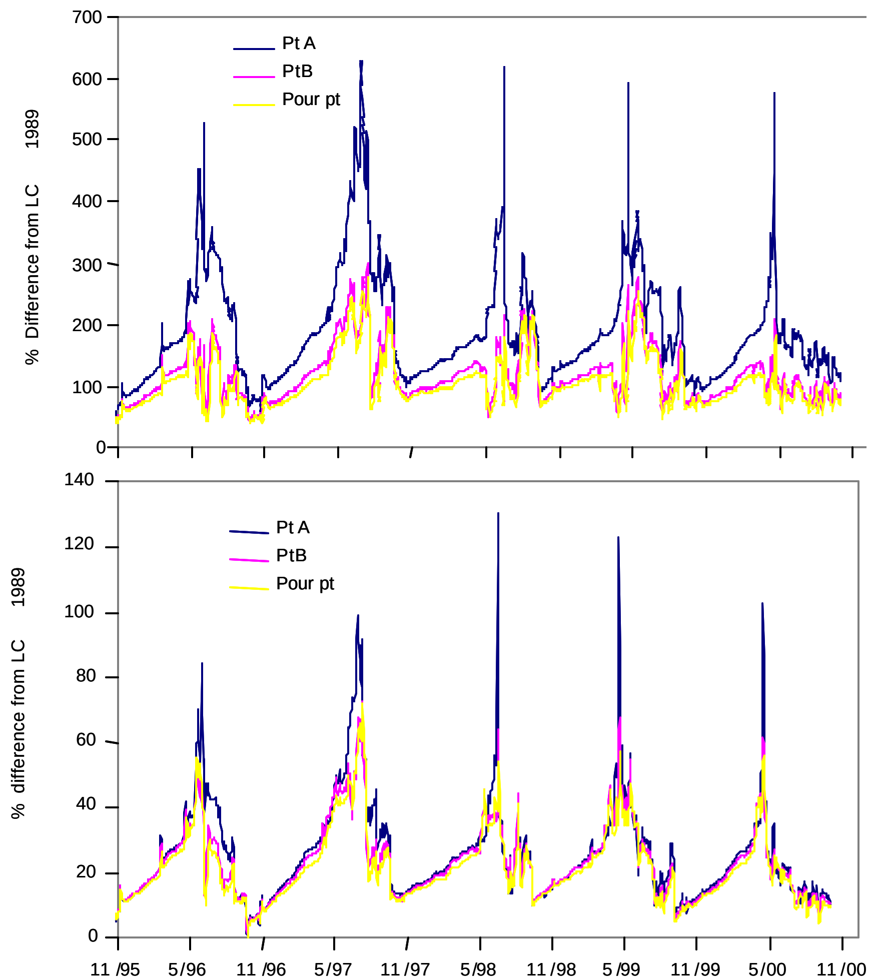

Figure 3.73. Deviation of daily stream flows without irrigation of Scenario II from LC 1989 (top panel). Deviation of daily stream flows without irrigation of Scenario III from LC 1989

As expected, the discharge at Point A in scenario II varies the most from the base case in 1989, and the deviation decreases as we moved away from the source (Figure 3.73). At all locations, the forecasted stream flow differed significantly in the wet season. When the land-cover change occurred throughout the basin, as in scenario III, the discharge from smaller sub-basins showed a more dramatic impact than did the discharge from bigger sub-basins (Figure 3.74).

Based on these results, the implications of land cover change on flood forecasting are predictable. For example, if we know certain locations in the basin are prone to flooding and we know the magnitude of the typical flood, we could use the model to simulate how much water would arrive at downstream watersheds.

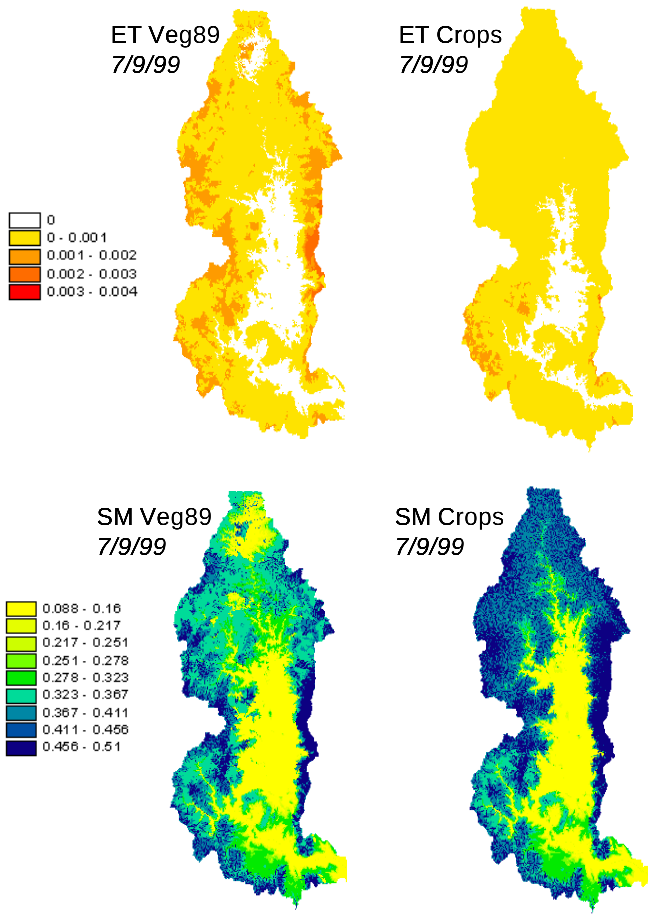

Figure 3.74. Illustration of the underlying dynamics producing changes in the hydrographs, with the explicit representation of ET and soil moisture changes (here for 1989 vegetation, with increased crops)

3.9.4. Preliminary Conclusions

While considerable work remains in interpreting these results, there are several important "take home" messages:

The utility of a spatially explicit, process-based analytical modeling environment is demonstrated by its ability to reproduce hydrographs across a range of conditions, in a basin where data are relatively sparse. At a minimum, the efficacy of the models as an intelligent data-interpolation engine is clear. That the model does as well as it does implies that the constituent dynamics are relatively well understood (e.g., Figure 3.74), and some confidence can be placed in the quantitative implications of scenarios.

The hydrology of the basin is quite sensitive to changes in land cover attributes, with a general pattern of increasing runoff with migration from trees to crops. This is due to decreased evapotranspiration and soil compaction. Irrigation would have a counter effect, withdrawing water.

4. Discussion

4.1 Effects on Biodiversity and Watershed functions of historical land use change

Question 1 was phrased as: "What impact on the range of 'watershed function' and 'biodiversity conservation' indicators can we attribute to historical land use change between 'natural vegetation' and 'current land use at plot, landscape, subcatchment and catchment scale?"

We will review the evidence at plot and catchment level.

4.1.1 Plot and landscape scale

Table 4.1 Summary of evidence at plot level for the ASB Benchmark areas in Thailand (Mae Chaem) and Indonesia (Sumber Jaya) of impacts on watershed functions and biodiversity

	Mae Chaem		***Sumber Jaya (Way Besai)***	
	Natural Forest	***Current LU***	***Natural Forest***	***Current LU***
Soil bulk density	Considerable variation between forest types and elevation zones; high bulk density in dry deciduous Dipterocarp forest (Fig. 2.17)	Increase with reduction of fallow period and switch to permanent cropping (Fig. 2.17)	Few data on variation	Compaction mainly linked to foot paths and motorbike tracks
Signs of surface erosion	After the typical dry season burns of the litter layers the first rains lead to soil movement in the dry deciduous forest	In open field crops	Landslides on the steeper slopes	The open phases of young coffee plantations and in heavily weeded 'sun coffee'
Sediment filter effects	Abundant litter layer leads to virtually sediment-free overland flow in most forest types	Paddy rice fields in the mosaic probably play this role	Abundant litter layer leads to virtually sediment-free overland flow	Banana and grass strips, paddy rice fields play this role
Water quality	Streams leaving forest appear to be clean	Current monitoring program by villagers; growing concern about health impacts of pesticides	Streams leaving forest appear to be clean	Main issue may be the pesticide levels derived from horticultural crops
Biodiversity	High elevation has several endemics as 'last outcrop of the Himalayas'	Long fallows still allow for forest flora and fauna to survive	Part of the 'Sunda lands' hot spot; both mountain and low elevation forest threatened	Shade coffee has fair bird but low plant diversity

The simple indicators of Table 4.1 suggest that in Mae Chaem the land use change from fallow-crop rotations to permanent open field crops is the main threat to sediment transfers to rivers, while the loss of biodiversity probably occurs in the transition from long to shorter fallow periods, and through human activities in the high elevation forest. In Sumber Jaya, the conversion to a coffee-dominated landscape has created some challenges to watershed functions (as well as opportunities to maintain these in the context of 'shade coffee' systems with intact litter layer), but has lost most of the biodiversity value of the original forest. Forest birds are still able to use the shade coffee habitat, however. Apparently the thresholds in the land use change process that affect watershed functions and biodiversity differ.

Further evidence was obtained for the ASB Benchmark areas in Jambi and Sumber Jaya (Indonesia):

- In the first year after slash-and-burn land clearing in rotational rubber agroforests in Jambi there is substantial surface movement of soil ('erosion'), but the transfer to streams and rivers may be small due to land form (convex slopes with high erosion followed by a concave filter zone before reaching the river) (Rodenburg et al. 2003). Riparian vegetation has a better chance of surviving the burn because it does not dry out so easily in the dry season), and in the absence of specific effort in clearing this zone may retain its filter function relatively easily.
- Logging tracks and roads in areas that were commercially logged in Jambi some 15 – 20 year ago remain compacted and clearly visible as a thick layer of ferns on top of the soil (without noticeable soil penetration) prevents establishment of woody plants (Hairiah and Van Noordwijk, 2000)
- Loss of species richness in termites during conversion of forests to agroforestry and crop-based landscapes in Jambi does precede the critical loss of function in maintaining soil structure (Gillison et al., 2003)
- A detailed assessment of the impacts of soil compaction in coffee gardens and on foot paths and motor bike trails in the coffee zone in Sumber Jaya (Fig. 4.1), suggests that surface runoff is a direct consequence of compaction, but that soil movement (erosion) is highest for intermediate degrees of compaction, as the 'entrainment factor' that determines the likelihood that soil particles can be picked up into the overland flow is highest in loose soil.

An attempt to synthesize the available information on various land use systems (Fig. 4.2):

- the gap-succession cycle in natural forests will tend to increase watershed functions (increasing total water yield per unit rainfall without reductions in soil structure and allocation towards quick flows), with negative effects (initially) on plot level species richness; during the recovery the biodiversity value may recover slower than the watershed function indicators return to the original state, as water use in young secondary vegetation is high while species richness tends to increase with successional age
- for shifting cultivation and long fallow rotational systems we can expect a pattern similar to that for the gap succession cycle in natural forest; with increasing land use intensity and shorter fallows, however, the system is likely to settle on a cycle in the lower part of the graph with reduced biodiversity, but with watershed functions that can be maintained as long as soil degradation and a switch to overland flow is avoided

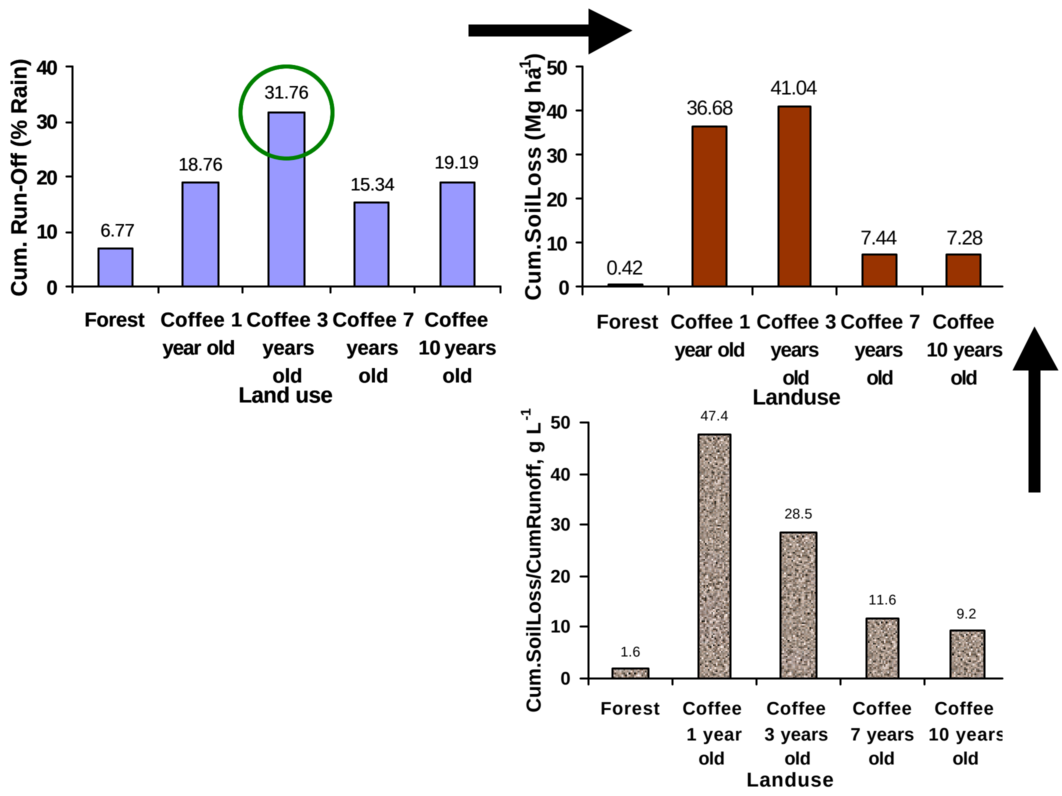

Figure 4.1. Overland flow, soil loss per unit overland flow and the resulting net erosion from small ($20\ m^2$) plots in forest and coffee gardens of different age in Sumber Jaya

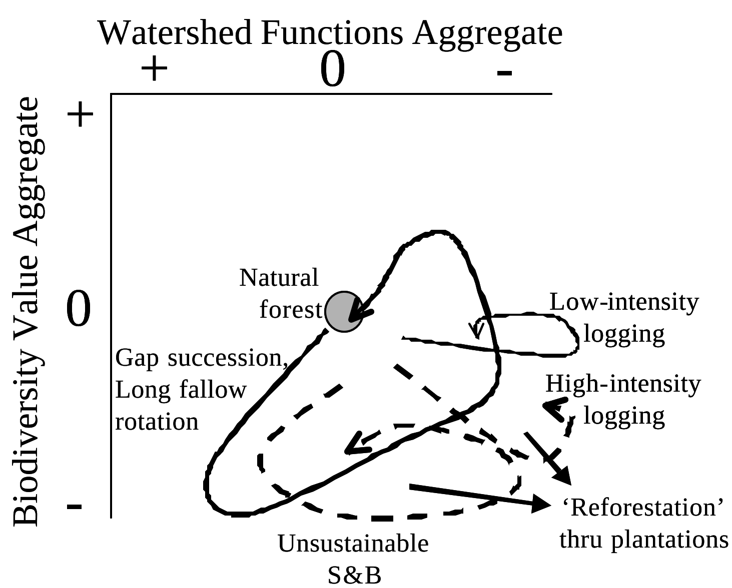

Figure 4.2. Tentative trajectories of plot-level performance on watershed function and biodiversity indicators of different land use systems, suggesting considerable variation around the diagonal that represents proportional impacts on B and W, taking a natural forest as point of reference; the trajectories are 'guesstimates' not based on solid empirical evidence

➢ low intensity logging may be neutral to biodiversity (it creates gaps within a vegetation with sufficient mature patches to allow for rapid recolonization, but depending on the methods used to haul logs; it can be disproportionately damaging on sediment loads of streams, especially if logs are transported through streams and thus direct connections are made between tracks and streams; where log jams lead to build-up of barriers to water transport that can break during high rainfall events, they can contribute to downstream damage of 'mud flows'
➢ high intensity logging may combine negative impacts on biodiversity with negative impacts on biodiversity and thus return to the main diagonal
➢ reforestation is, in the short run, likely to have negative impacts on the water delivery to streams as well as low flows, as well as generally negative for local species richness; in the longer term, however, recolonization by forest species occurs, unless prevented by silvicultural 'management', and the soil conditions may improve allowing for a reduction in overland flows; these plantations can thus creep up on the main diagonal towards the natural forest point of reference

4.1.2 (Sub) Catchment scale

Quantitative indicators for the Way Besai catchment showed a significant positive trend in the total water yield per unit rainfall. The buffering indicator was negatively correlated with the total water yield, but for the other indicators the R^2 of the tradeoff relation was very low (fig. 4.3). This suggests that the potential downstream benefits of more water are not associated with negative changes in river flow during the direst moth or less buffering of peak events

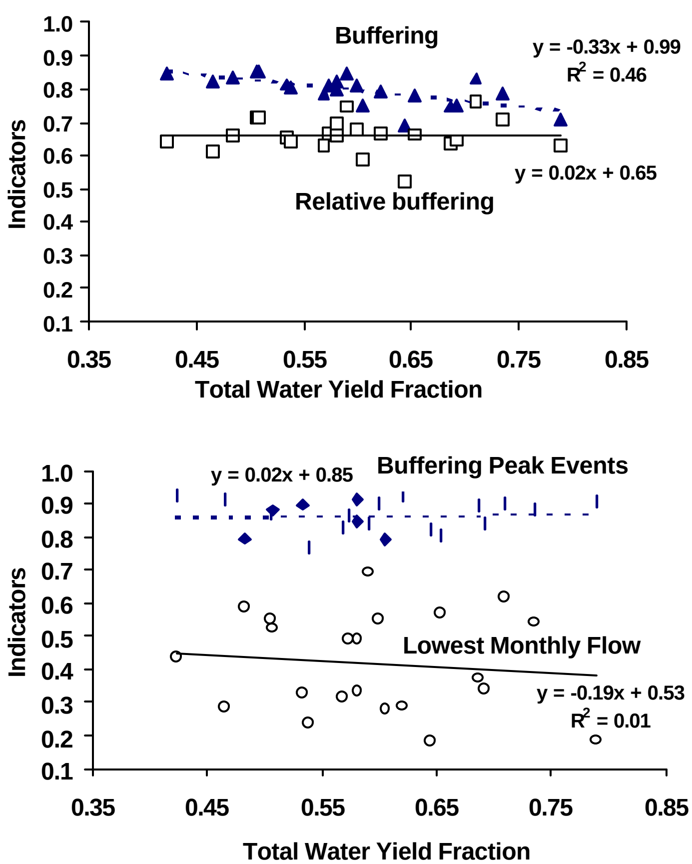

Figure 4.3. Quantitative indicators of watershed functions in Way Besai, Sumberjaya related to the total water yield indicator for 23 years of actual data

The total discharge in the month with the lowest flow, expressed as fraction of annual rainfall showed considerable inter-annual variability but did not change along with total water yield. The increase in water yield was derived in periods of higher flow rates, but the buffering indicator showed only a mild decrease and the buffering for peak events as well as the relative buffering indicator (adjusted for changes in total water yield) showed no downward trend.

For the Mae Chaem scenarios of plausible land use change a stronger indication was obtained of a trade-off between gains in water yield and reductions in buffering (Fig. 3.49). The two models that were applied to the Mae Chaem data sets were similarly successful in deriving the values of quantitative indicators of watershed functions for the current land use mix.

Work is still in progress on comparing the models on the basis of our set of indicators of watershed functions (Table 4.2).

Table 4.2 Mae Chaem watershed function indicators for two models

	DHSVM		**Actual**	**GenRiver**	
	Natural Veg	**Current LU**	**Current LU**	**Current LU**	**Natural Veg**
Total Discharge Fraction	#	#	0.21	0.19	0.13
Buffering Indicator	#	#	0.89	0.90	0.93
Relative Buffering Indicator	#	#	0.49	0.45	0.54
Buffering peak events	#	#	0.91	0.88	0.91
Highest Monthly Discharge relative to mean rainfall	#	#	3.16	3.67	3.01
Lowest Monthly Discharge relative to mean rainfall	#	#	0.20	0.22	0.27
Overland Flow Fraction	#	#	*	0.00	0.00
Soil Quick Flow Fraction	#	#	*	0.08	0.03
Slow Flow Fraction	#	#	*	0.14	0.08

Overall, the indicators of watershed functions indicate a (potential) tradeoff between positive impacts of forest conversion on total water yield (generally seen as positive as it allows for irrigation and extractions for domestic of industrial use in a water-sparse world) (compare the report for Activity 1) and negative impacts through increased likelihood of flooding and/or changes in dry season flows. Results presented here suggest that the increase in peak flows is, for the study sites, proportional to the increase in total water yield, as the relative buffering indicator does not change. In simulation studies we can reconstruct situations with a more-than-proportional increase in peak flows, in response to soil degradation – but this is not linked to forest conversion as such, but to changes in land cover/land use further down the line. It appears to be very well possible to arrest such degradation by avoiding land use dominated by open-field agriculture. One can argue that the agroforestry mosaics actually combine the best of two worlds: more water available downstream for irrigation, without more-than-proportional increase in flooding risk.

The technical report for Activity 1 suggested that the increase in total water yield to rivers is matched by the use of water for irrigation. This suggests a simple transfer of the location where actual evapotranspiration matches the potential values… forest conversion reduced evapotranspiration in the upper catchments by the same amount as irrigation agriculture increases it downstream. In terms of land-atmosphere interactions this shift may have relatively little impact, although there can be a shift in timing with more dry-season water use through irrigation that is less likely to contribute to rainfall elsewhere. In the popular dialogue on effects of deforestation and its impact on reducing rainfall via the 'small cycle', the effects of water use for irrigation appear to be ignored.

4.2 Scale effects of land use change on watershed functions and biodiversity

Question 2 was phrased as: **"How do the impacts of land use change on watershed functions and biodiversity vary with spatial scale?"**

In the introduction we raised two key explanations for the absence of evidence (Table 1.2) for impacts of land use change on watershed functions for areas larger than 100 km^2:

- absence of evidence (because major land use change in large areas tends to take more time than most empirical studies allow for; organizing 'paired catchments' for direct comparison becomes increasingly different with size of the area and number of people living in the landscape; inference from historical land use change is often confounded by variability of annual rainfall),
- declining relative importance of land use as other factors start to influence the watershed function indicators in larger areas.

We made progress on both explanations. Our data provide empirical evidence for an increase in total water yield as well as changes in buffering for Way Besai (400 km^2) for a period of drastic land cover change (60 -> 15% forest cover). For the Mae Chaem (4000 km^2) 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.

All models used here lead to an area-based scaling rule for total water yield (if the contributing areas are weighted for their rainfall) – and thus to the expectation that local impacts of land use change do contribute in a proportional manner to changes in river flow downstream. This suggests that the absence of well-documented effects is largely due to an absence of sufficiently sensitive studies that can disentangle changes in the various factors influencing river flow.

The empirical scaling rule for maximum daily flow (Q_{max} is proportional to $A^{0.75}$) suggests that spatial variation in rainfall allows the river system to dominate the buffering effect. Our explorations with the SpatRain model indicate that spatially variable rainfall in itself is not enough to explain the scaling rule, but that addition of the concept of a rainfall-runoff intercept based on infiltration can form a technically consistent explanation (Fig. 3.35). A reduction in infiltration rate would make the maximum flows closer to proportional to area, and thus increase the likelihood of an increase of maximum daily flows at ‘far field’ scale. In figure 4.4 we provide an illustration of the impact of this scaling rule

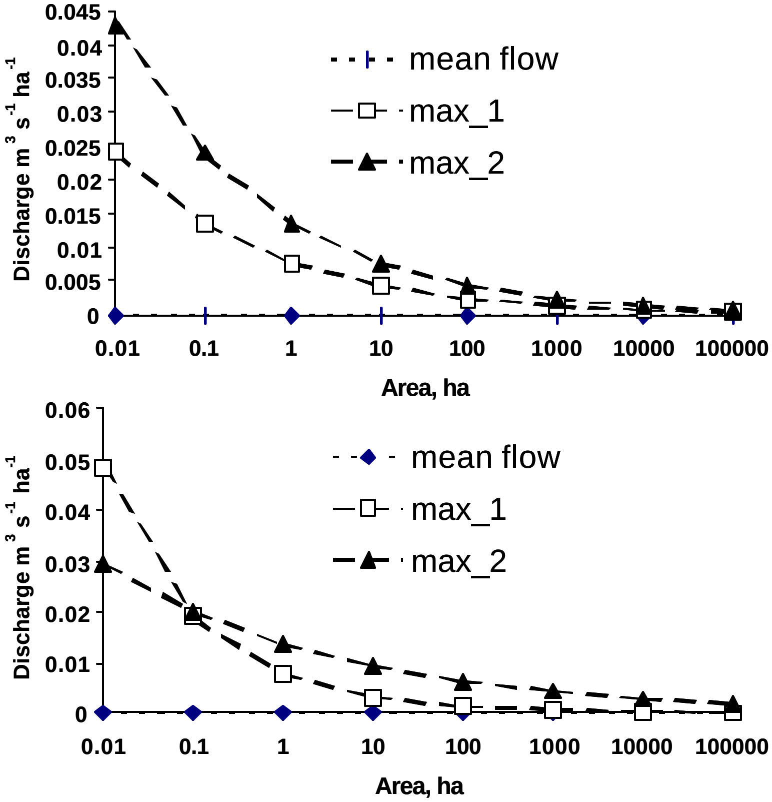

Figure 4.4 Representation of the scaling rule for maximum daily flow on the basis of a

For two land use types in the up stream area (case 1. with an infiltration offset of 30 mm day^{-1} and a transfer of rainfall to the streams of the excess 0.6 at a scale of 1 ha; case 2. with an infiltration offset of 10 mm day^{-1}, and a transfer to the streams of the excess of 0.9 at a scale of 1 ha; for both cases we assumes a maximum daily rainfall of 140 mm day^{-1}) ; in the upper panel a scaling rule of 0.75 is applied to both case 1 and 2, in the lower panel a scaling rule as derived from fig. 3.35 for the infiltration offset used: 0.6 for case 1 and 0.83 for case 2

One of the consequences of the scaling rule as such is that the maximum flow rate relative to the mean annual discharge decreases rapidly with increasing size of the area upstream. If a constant scaling rule of 0.75 applies, a change in land use upstream that increases the fraction of a peak event that is transmitted to the stream can lead to a sharp increase in maximum flow for areas less than 1 ha, but for areas of 10,000 ha (100 km^2) the absolute difference has become small. More significantly, if our theory of dependence of the scaling rule on the infiltration offset (Fig. 3.35) holds true, the lines for maximum flow can cross-over and the land use change that lead to an increase in maximum flows locally (‘local hazard’) may even decrease maximum flows when large source areas are considered. The example given here may explore the upper bound of thje likely parameter space, but it provides (probably for the first time…) a consistent account for the difference between ‘local hazard’ and ‘far field effects’.

The scaling rules for species richness are subject to continuing debate, but as a general rule we can expect total richness to increase proportional to $A^{0.25}$. The difference in scaling rules make it likely that the two issues overlap somewhere along the continuum of scales, but this will be a cross-over point at a spatial scale where biodiversity values level off and changes peak water flows are still prominent.

The results of the FALLOW model simulation confirm the potential relevance of riparian zone forest connectivity for control of sediment loads of rivers. This type of 'cross-scale' vegetation is likely to be important for connecting areas of high biodiversity value as well, suggesting that there are landscape elements with great relevance to B and W, even though the two issues do not coincide elsewhere.

4.3 Degradation/recovery of watershed functions and biodiversity?

The four scenarios for changes in the Mae Chaem catchment differ substantially from the current situation as well as from each other. However, all will likely involve a reduction in forest and tree cover and an increase in total water yield (Table 3.9).

The predicted impacts of the four scenarios on quantitative indicators of watershed functions are relatively small – smaller probably than most readers will expect. It seems likely that the impacts of the four scenario's on biodiversity value differ more than their impacts on watershed functions (although we don't as yet have the ability to quantify such effects in a similar way). A focus on 'parks' would, according to the scenario, not be able to stop the reduction in area of the evergreen forest that may have the highest value due to its scarcity, but it would maintain more of this habitat than the other scenarios (Fig. 3.45).

More severe degradation of watershed functions occurs locally in the Sumber Jaya area, where early stages of coffee on steep slopes can lead to a denuded soil. In part of the domain this may lead to degradation from which recovery is difficult, as a lack of plant growth implies a lack of litter production that could signal the way to recovery of surface structure and thus infiltration of water. In most of the coffee gardens, however, recovery does take place, along with the development of a surface litter layer. Ongoing research by the ASB Indonesia team on the conditions that lead to surface movement of litter, and thus the slow-down of recovery, suggest that large leaves move slower than small ones, and thus that pioneer-phase vegetation (with typically larger-leaved species) may have a specific role in the recovery phase.

4.4 Does landscape pattern matter?

The results of the FALLOW model simulation indicate that for processes with a strong 'lateral flow' component, such as transport of soil particles over the surface (erosion/ sedimentation) landscape pattern clearly matters, and the percentage of different land cover types is not sufficient to predict effects. Further exploration of these ideas by Ranieri et al. (2004) indicate that the width of a riparian filter zone may have to vary with the erosion risk of areas uphill from it. Models that account for lateral water flows on hill-slopes, such as the WEPP model explored by Ranieri et al. can provide more detail in these relations.

In its model structure, the DHSVM model deals with the lateral flows in a more explicit way than GenRiver or Fallow and could be a basis for evaluating the impacts of pattern.

The role of paddy rice fields in valley bottoms on net sediment transfers is subject to debate and ongoing quantitative research. The role of paddy fields as ‘filter’ appears to be limited to small valleys with a limited inflow of overland water plus sediment – otherwise farmers are likely to make ‘cut-off’ drains at the toe of the hillslope. The filter effect is partly undone during puddling and land preparation when muddy water leaves the plots. More importantly, during peak events the paddy rice fields are vulnerable to wash out and soil gradually accumulated can be lost in a single event (not easily captured in experimental data sets). Yet, for the time being we ascribe a positive filter effect to paddy rice fields, especially to those in narrow valleys (which can easily escape remote-sensing).

In our exploration of local knowledge of soil and water movement (Joshi et al., 2004) we found that concepts of overland flow and filter effects for sediment are well articulated, as are the interactions of paths and fields. Were a local process of land use planning and zoning gets a chance (as in the Mae Rak example discussed in chapter 2), interactions of this nature are well taken into account.

A comparison of the degree of public concern and land use regulation between the two main catchments in Thailand is suggestive (Fig. 4.5):

- The within-country river Chao Phraya feeds Bangkok and the main rice producing areas of Thailand, and still has substantial tree cover as well as protected areas in its upper parts,
- The Chi & Mun sub catchments of the cross-border Mekong river that flows into Cambodia and Vietnam has hardly any land with more than 20% tree cover (there is a sparse remnant of the natural vegetation in the forms of trees left on rice bunds etc.), and hardly any protected areas.

While strongest policy emphasis has been on upper watersheds of the Chao Phraya basin above important ‘rice bowl’ production areas in the central plains of Thailand, such interpretations from current land cover patterns also ignore underlying biophysical and historical factors. The “Khorat Plateau” of Northeast Thailand is primarily an area of quite gently rolling terrain, with soils that are relatively coarse-textured with poor fertility and often with strongly plinthic horizons. Thus, the natural forest in many upper areas of the “mini-watersheds” of the region is quite open and highly deciduous. The low soil fertility, poor water-holding capacity, and locally erratic rainfall patterns have meant that an average household requires relatively more land to meet their subsistence rice needs. Moreover, rapid population growth prior to the implementation of Thailand’s effective family planning programme has resulted in a population of more than 20 million people highly distributed among tens of thousands of villages; significant levels of urbanization are a historically very recent phenomenon. And, since this has been the poorest region of the country, it has been politically extremely difficult to constrain expansion of first subsistence rice-based farming, followed by the massive boom in cassava production (and more recently sugarcane) as the region’s major cash crops.

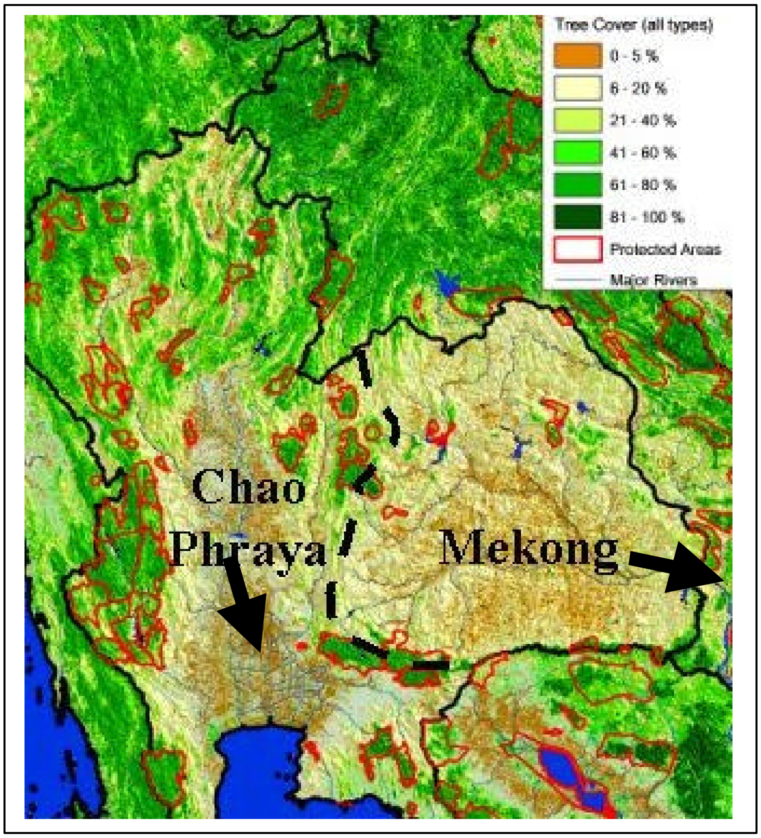

Figure 4.5 Comparison of the degree of forest cover and fraction of protected areas between the Chao Phraya basin (draining to Bangkok) and the cross-border Mekong basin

In addition, the primary targets for establishment of protected forests throughout mainland Southeast Asia has been in steeply sloping mountain areas; those are limited to the western and southern edges of the Khorat Plateau and a limited area in the northeastern corner, which is where the region's few protected areas are located. With quite high proportions of the region's population responding to labor demand associated with Thailand's industrialization and economic growth, many are now optimistic that tree cover may increase in the region, but most would likely be in the form of tree crops and community forest.

4.5 How to reduce 'local hazard' and negative 'far field effects'

From our analysis of the data and from the set of model assumptions that appears to be adequate to account for them, we can dissect the 'forest conversion' effect into a number of components that is responsible for the balance of negative and positive impacts on the various indicators of watershed functions. Conversely, this breakdown suggests the type of interventions that can reduce the negative sides of 'local hazard' while benefiting from the positive side of 'far field' effects through enhanced water supply. The key process that is under direct control of land cover is 'infiltration' – the various quantitative indicators of watershed functions follow directly from it. In a technical sense we have seen that the infiltration offset can influence the fractal dimension (scaling factor) of peak flows, and thus extend the range of 'local hazards'.

Trees are the traditional focus of 'watershed rehabilitation' projects and efforts. Yet, the direct impact of greater tree cover is likely to be negative on dry season flows (as explored in the null-model of section 3.2), while the reduction in peak flows by greater canopy interception is likely to be felt in small rather than large rain events. Tree roots can play a significant role in reducing a specific category of landslides (Sidle and Dhakal, 2003) and the highest landslide risk can be expected 3-10 years after cutting deep-rooted trees, depending on their decay rate. Deep-rooted trees are, however, in direct competition with the slow flow pathway of water to streams, as they tend to remain green for a longer period of time into the dry season. Specific locations where specific types of trees can of use include trees that are well adapted to the outer riverbed – and that help slow down flows during peak flow conditions. Farmers in the Mae Chaem area have identified some species for such a purpose (Van Noordwijk et al., 2003). In general, however, the focus on 'trees' for avoiding negative impacts on watershed functions appear to be uncritical and overrated. A good overview of the water use by trees through interception and evapotranspiration is provided in the HYLUC model of Calder (2003)

Litter layer
Resistent part: Surface cover protects from splash erosion and increases sedimentation
Decomposable part: Food for worms enhances soil structure and infiltration

An underrated part of the trees is probably their contribution to the litter layer… Litter of different chemical and physical characteristics plays complementary roles in enhancing infiltration and reducing overland flows and net sediment loss. Ongoing research in Sumber Jaya benchmark suggests that indeed mixed sources of litter in shade coffee gardens are to be preferred over monotypic litter in a coffee monoculture. Litter fall does not depend on trees as such: shrubs and perennial herbs can also provide mulch, as can the use of cover crops and retention of crop residues in agriculture that is based on 'no till' or 'minimum till' methods. Some forest types have a negligible or deficient litter layer: forests where mulch is collected for use in agriculture nearby (as tend to occur in densely populated parts of Java – see Wiersum 1984), or where the surface litter layer is burned (naturally or deliberately to enhance the production (or at least visibility…) of mushrooms, as is common in parts of montane mainland southeast Asia. High erosion rates and soil compaction in these circumstances suggest that indeed the litter layer rather than the trees is the key element of a 'forest'

Surface roughness as provided by litter layers, small depressions and a lack of rapid drainage channels is greater in natural forest than in most derived land covers, including 'reforestation'. Roughness provides some storage for water, and can increase the time-span available for infiltration on slopes. Roughness is poorly described for most land cover types, and is poorly represented in the existing models. The key issue probably is to reduce and or reverse the opportunities for rapid surface runoff. Unregulated runoff can have a strong effect on erosion, so channeling the runoff along roads and built-up areas is normal practice. It will, however, reduce infiltration in a direct way. 'Reforestation' efforts do not generally try to return to forest conditions in terms of drainage and surface roughness – they might become more effective if they would.

Wetland, bank overflow areas (spill over) and reservoirs can complement the buffer functions of the hill slopes, as is indicated in our discussion of the Way Besai data (section 3.1). Flooding upstream protects areas downstream, and reductions in flooding upstream may directly contribute to flooding risk downstream. Although the vegetation type can often be directly interpreted as indicator of flooding frequency, terrain models have to be very detailed and accurate before they can be used to predict these effects in a quantitative way. Small barrages and dams that obstruct the rapid flow of water have, in flat terrain, been shown to restore groundwater levels upstream and provide for well water in the dry season. Such interventions in the river bed are likely to have a greater payoff on watershed functions than changes in tree cover per se.

Riparian vegetation and bank stability play a key role in the sediment load of rivers, as they provide filter functions for overland flows, slow down river flow during bank overflow conditions, and control the rate of mass wasting of soil by collapse of river banks.

It may be interesting to note how a more process-based understanding of actual changes in watershed functions can inform the process of negotiations between the multiple stakeholders in an upper watershed area. In the Sumber Jaya ASB benchmark area ICRAF and partners have been supporting a process whereby farmer groups obtained a greater security of land tenure for coffee-based land use under the umbrella of 'community based forest management' (HKM in the Indonesian terminology). The starting point for this agreement from the foresters' side had a strong emphasis on the number of trees per ha (where coffee is not a tree…). The agreement is based on a broad formulation of 'maintenance of functions'. In follow up discussions the ideas of the presence of a surface litter layer as criterion is discussed, as well as village-based monitoring of water quality.

From our evidence we can revisit the observation by Kiersch and Tognetti (2002) that evidence for effects of land use change on watershed functions appears to be limited to areas of 100 km^2 or less. In our analysis (Table 4.3) the possible reasons for this 'lack of evidence' differ between the various aspects of river flow considered. For some it is a 'plausible lack of evidence or real impacts', for others a 'plausible lack of impacts'.