# Hydrological Impacts of Forest Conversion to Agriculture and Local Perceptions in a Large River Basin in Northeast Thailand

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## 1 Introduction

Tropical forests are assumed to be important for preventing flooding, protecting dry-season water supply and maintaining rainfall patterns (Myers, 1995). Numerous studies have shown that a large reduction in forest cover increases annual streamflow and peakflow and stormflow volumes both in temperate, humid and dry tropical areas, though the extent of the increase varies (Bosch and Hewlett, 1982; Bruijnzeel, 1990). These studies have, however, mainly been based on data from plots or small catchments of a few hectare. Large river basins tend to be a mosaic of different land uses and practices, with heterogeneous geology, topography and soils. This spatial variability, in combination with spatial and temporal differences in precipitation patterns will moderate the integrated river basin hydrological response. It is therefore uncertain that conclusions drawn from small scale studies will be relevant for large catchments. Alford (1994) found no evidence that the streamflow regimes had changed significantly in mountainous watersheds in northern Thailand since the 1950s despite extensive forest loss. Adequate baseflow during the dry season is also of great concern in the tropics. After forest clearing, if infiltration capabilities can be maintained to allow the water gained by decreased transpiration to penetrate the soil and not be lost to surface runoff, an increase in baseflow will result (Bruijnzeel, 1990).

Though the forest's role in the hydrological cycle is gradually being clarified in small and larger catchments, as well as which activities and processes are most important in deciding the resultant changes in streamflow after land use changes, the views of local inhabitants towards this issue are equally valuable. Whether or not local inhabitants without scientific training are "right" or "wrong" in their perceptions of their environment, if this can be so easily determined, their perceptions shape their interactions with their local environment. Infiltration, which is now considered one of the pivotal factors in deciding the streamflow changes after forest conversion, is highly dependent on human activities such as road building, overgrazing, land management techniques, etc.

The objectives of this study were to ascertain any hydrological changes in outflow from the upper Nam Pong catchment after extensive forest removal. Secondly, this study was performed to assess if and for what reasons local inhabitants value forests and perceive both forests and their own capacity to influence the local water balance.

## 2 The upper nam pong river basin

The Nam Pong river basin lies in the northeast region of Thailand and is one of the many sub-basins of the Mekong. Its upper basin (upstream of the Ubolratana reservoir) covers an area of 12,100 $km^2$. A large part of the basin area is relatively flat with an average elevation of 300 m above sea level (m.a.s.l.) while the western edge is more rough and rises to heights of 1,300 m.a.s.l. The upper Nam Pong basin yields water for the Ubolratana reservoir that provides downstream areas with hydropower as well as irrigated water for agriculture. It has a capacity of 2,550 million $m^3$ of water storage and has an average annual inflow of 187 mm. The catchment contains a few additional smaller reservoirs including Chulaphorn lying in the western portion of the catchment with a storage capacity of 188 million $m^3$. Most underlying rocks in the basin are of sandstone or limestone. Surface soils are mainly sandy loam with sandy clay sub-soils and contain more clay in the west and more sand in the east. Streamflow declines very rapidly with the end of the rainy season, indicating poor soil moisture retention. Underlying geology in the basin consists mainly of limestone and sandstone (ibid) which are notorious for deep leakage.

## 3 Changes in the upper nam pong river basin

When the Ubolratana reservoir was completed in 1965, forest cover was estimated at 80% from areal photographs by the Government of Thailand (personal communication, S. Johnson). Estimates based on interpretations of Landsat images indicate that forest cover in the basin had declined to 44% by 1975, to 36% by 1982 (Johnson and Kolavalli, 1984), and to 27% by 1992 (Khon Kaen University, 1995). This coupled with subsequent replacement by agricultural crops, should have caused increased streamflow according to small-catchment studies. Transpiration is reduced and solar radiation increased, conditions that support this change. Interception should be reduced but only moderately. The fact that baseflow in the basin was almost non-existent both before and after heavy forest removal might indicate poor groundwater recharge but groundwater measurements indicate deep and relatively abundant reserves (Nam Pong Environmental Management Research Project, 1979b). The existence of sandy top-soils and more clay-rich sub-soils might, however, allow streamflow generation when water exists in the sandy, highly conductive top layers but on a more limited scale when water has entered the lower, clayey soil layers.

The expansion of settlements since 1965 has probably contributed to reduced infiltration on parts of the basin (especially downstream) though expansion of paddy, where water is standing in the fields for prolonged periods, should induce higher infiltration. The Nam Pong basin has few steep areas and it is here that forests have generally been retained, thus high runoff due to deforestation on steep slopes should not be a problem. Areas without vegetative cover for parts of the year will suffer greater losses to evaporation as the PET is high in this region (1700 mm). Despite this, less water should be lost than through evapotranspiration from forests. The physical conditions in the basin should have led to a relatively good retention of infiltration after forest removal. This, combined with decreased evapotranspiration, should be expected to lead to increased streamflow and increased baseflow.

## 4 Assessment of changes in streamflow

Streamflow measurements were available for eight years (1957—1964) before the reservoir construction and then from 1969—1995. During this period, a trend could not be detected in annual recorded streamflow (Qrec) at the Ubolratana damsite. Neither could a trend be detected for the actual evapotranspiration (Ea) for annual values nor values divided into wet and dry seasons. There was no difference between Ea during the first eight years under heavy forest cover and the last eight years when forest cover was less, when applying the nonparametric Mann-Whitney test. A linear regression equation for the expected Qrec/P ratio was estimated, including modelled soil moisture (SM) and annual areal precipitation ($R^2$=0.54). From Figure 1, it can be seen that one year in the period before the deforestation (1963) had a significantly lower Qrec/P ratio (and consequently less generation of river flow) than expected. Four years after the initiation of the forest removal, however, had a higher Qrec/P ratio than expected (1976, 1988, 1990 and 1991). However, no general pattern can be discerned and no significant trend was found for the difference between annual Qrec/P and the Q/P calculated from the regression analysis. No significant difference was found between the two groups of years, neither concerning Qrec/P ratios nor concerning the deviation from expected and observed Qrec/P ratio.

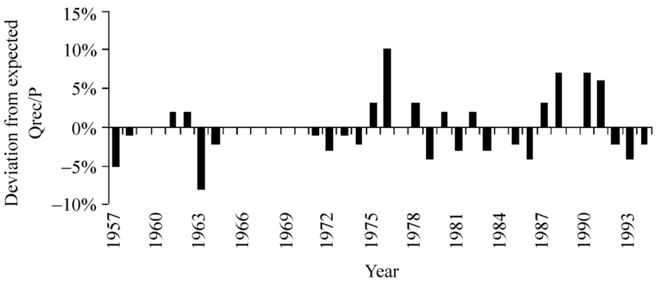


**Fig.1** Deviation (in %) between annual recorded Qrec/P and annual Qrec/P as estimated from linear regression against annual P and modelled annual average soil moisture storage (SM). A positive deviation means that Q-generation is larger than expected from the prevailing precipitation and soil moisture conditions, whereas a negative deviation means lower Q-generation than expected.

To detect if there were changes in the recession in streamflow at the end of the wet season, years with an undisturbed recession were identified. Two years before deforestation (1959, 1960) were compared with three years after deforestation (1970, 1971, and 1988). No visible pattern alterations can be noted except for the influence of the regulation of the Chulaphorn dam on daily values, which is visible in the recession of the hydrograph for 1988 (Figure 2). More detail about methods used and the results can be found in Wilk & Andersson (2001).

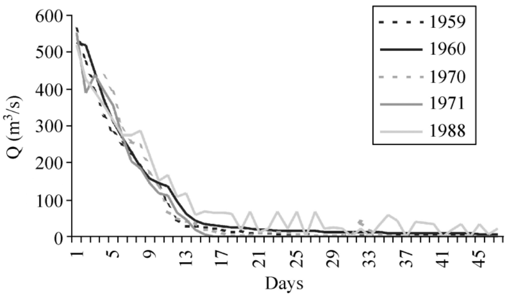


**Fig.2** Recession at the end of the wet season for two years before the deforestation (1959,1960) with about 80% forest coverage, for 1970 and 1971 with approximately 40%—50% forest cover, and for 1988, when forest cover had decreased to approximately 30% of the total area.

## 5 Hydrological model analyses

The conceptual HBV hydrological model (Bergström, 1995) was calibrated against discharge records from the period prior to the dam construction (April 1957 — March 1965), and then run for the period after the dam completion, for which inflow data were available (April 1969-March 1995). In addition, the model was calibrated against data from the last eight years, in order to assess if a different calibration improved the simulation for the period with the largest change of land use. When calibrated against discharge records from 1957—1965, a period representing 80% forest coverage, a Nash and Sutcliffe (1970) efficiency ratio ($_{NS}R^2$) of 0.72 was obtained. When the model was run with the same set of parameters for the last eight years (1987—1994), representing the lowest forest cover (approximately 30%), a $_{NS}R^2$ of 0.68 was obtained. No significant trend was found for the annual deviation between the computed streamflow (Qcom) with the “pre-deforestation” calibration (1957—1965) and the recorded streamflow (Qrec) for 1957—1995. However, a weakly significant difference ($p = 0.093$) was found with the Mann-Whitney test when comparing the annual Qcom-Qrec during the eight years before the deforestation (1957—1965) with that from the eight years with the least amount of forest cover (1987—1995).

When re-calibrated a $_{NS}R^2$ of 0.78 was obtained against discharge records from 1987—1994 and a $_{NS}R^2$ of 0.33 for the first eight years (0.68 if 1963 was excluded as it was highly underestimated). After running the model for the entire study period (1957—1995) with this calibration, representing the least forested conditions, no trend could be detected between Qrec and Qcom for the entire period. When comparing the first and last eight years of the period, there was no difference found between Qcom-Qrec which was contrary to results from the first calibration. With the first calibration (1957—1965), both periods (1957—1965 and 1987—1995) were underestimated (8 mm/year and 28 mm/year respectively). This corresponds to a decrease in runoff generation of 15% during the latter period. With the second calibration (1987—1995) both periods were overestimated, 1987—1995 by 6 mm/year and 1957—1965 by 32 mm/year corresponding to a decrease in runoff of 16% during the first period. This indicates that runoff generation had increased after the deforestation. This was, however, mainly due to the hydrological response during one single year (1963), when the Q/P ratio was very low. When excluding this year, neither of the analyses based on the hydrological model could reveal any significant change to the water balance during the study period.

These results indicate that, contrary to small-scale studies, despite a large reduction in forest cover in the upper Nam Pong catchment, streamflow amounts were relatively unchanged, or the changes were smaller than errors in input data and model calculations. A partial explanation can be found in the land classification dividing forested land from non-forested. Over large stretches of land, there was no clear division between forest and non-forest, rather a gradual crossover from open areas to those with more and more trees that are finally considered forest when a certain density is reached. The manner of classification can thus mask the perceived effect that a particular land use would have on streamflow generation. Farm forest (swidden agriculture with a few shade trees remaining) for instance is classified as non-forest and has a density of 51 trees/ha while dry dipterocarp forest has 70 trees/ha (Nam Pong Environmental Management Research Project, 1979b). If one assumes that the decrease in the "forest" classes from one period to the next are due to forest conversion to farm forest, the change in tree density over the study period is 219 trees trees/ha to 104 trees trees/ha. This is smaller than the reported changes in forest cover (80% to 27%). The difference is not drastic but still indicates that the figures indicating forest area may not give a complete picture in terms of hydrological effects. Though only 27% of indigenous forest areas remain in 1992, the number of trees is much higher thus changes in evapotranspiration and infiltration may not be so extreme as the forest totals indicate. Also, abandoned areas, though classified as non-forest, presumably contain secondary growth. Rapid growth rates in humid tropical areas allow secondary vegetation to reach high transpiration rates in relatively short periods of time. In addition, large-scale simultaneous clearcutting of indigenous forest will probably and hopefully never occur. While some areas of forest are being removed, other areas are growing in thus buffering the visible effects on water yield, that forest removal causes on a smaller scale.

## 6 Local perspectives on forests and water

Local inhabitants in 104 households in three villages in the upper Nam Pong basin were interviewed to assess their perception of the forest's role in the water cycle and the value of tropical forests. In the interviewed villages, forests were highly valued by nearby residents for very concrete purposes such as firewood, food products and medicinal plants as well as more abstract benefits such as beauty. When asked if and in what way the forest is important for their household, 87% of the respondents mentioned the bringing of rainfall. Despite the overwhelming majority of interview respondents (92%) collected either fuelwood or food products (bamboo and mushrooms) in the forests which provide direct benefit, 57% mentioned rainfall first before other benefits. This is probably due to the heavy dependence of inhabitants on agriculture for their livelihoods, either directly (for landowners) or indirectly (labourers). No relationship between living standard, land ownership and education and the proportion of respondents mentioning a link between forests and rainfall amounts and patterns was apparent. More detail can be found in Wilk (2001).

Visual processes such as soil water retention were also seen as strongly associated with forests while transpiration, which is non-visible, was less readily mentioned as influencing water balance. Soil under forests is moist while bare soil exposed to the sun is dry. Air under tree canopies is moist and cool. These conditions are easily observed and forests are seen as the active partner in the hydrological cycle that regulates them. The role of humans was seen as less influential in affecting processes such as infiltration and soil water retention. Tree planting was mentioned most often as the activity that could affect local water resources, though its effect was thought to be spatially highly variable. Many believed that trees take water from the soil, (only small amounts), and then return it to the atmosphere which produces rain. One can therefore not view them as detrimental to water tables, but it is perhaps equally narrow minded to only attribute them with good in an environmental context as is often done. If rain is believed to be so highly linked with forests, as it is in the study villages, it is apparent that trees take on an extraordinary value above the tangible provisions of minor forest products, firewood and building materials that more than make up for their transpiration losses.

## 7 Summary

Significant trends in streamflow from the outlet from the Nam Pong river basin and actual evapotranspiration from the basin were not detected in spite of a reduction of areas classified as “forest” from approximately 80% to 30%. Neither was a change in recession at the end of the dry season detected. These results could partly be explained by the fact that there existed a significant number of remaining trees on agricultural land and by secondary growth invading abandoned plots. Secondly land-use change is not uniform in large river basins, neither in time or space which can explain why detectable changes of water yield or other parameters in the water balance can not be found. Due to spatial variability of rainfall, it is also probable that any possible effect of locally increased surface runoff will not be detectable in the river discharge generated from the basin.

Local inhabitants of the upper Nam Pong basin were found to perceive a strong connection between trees and increased water availability. The most important value attributed to forests by local inhabitants was its close association with rainfall. This even overshadowed the more tangible benefits of food and firewood. Tree planting was mentioned as the most important activity that affects local water resources by bringing rain and aiding groundwater storage.

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