Forests and Water in Northern Thailand

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INTRODUCTION

***Everyone knows that forest is the source of water for all people who live on Thai soil. We do not have any other source of water in Thailand ... [the forest] provides for underground water storage, making the ground moist as a benefit for all people... The result of cutting forest is the destruction of the water source of the Thai people.* (Royal Forest Department/Suan Pa Sirikit, 1998, my translation)**

***The community knows that these areas of forest apart from naturally storing water also protect springs by preventing them from drying out, somewhat similar to the way skin protects capillaries in the body. As such, many communities maintain the forests in areas where there are springs—referring to these community forests as* nam sap *or* pa nam jam *or* pa nam phud*—by way of various regulations under the control of people within the communities themselves.* (Royal Forest Department, 1998, my translation)**

***Thung Kao Hang is a village...in the upper part of the Li watershed, an important source of water for the fertile rice growing areas downstream. ...Efforts to exert more control over local resources began only after the richly forested areas around the village had been mostly destroyed by logging and shifting cultivators and the villagers began to experience severe water shortages.* (Wittayapak and Dearden, 1999)**

***Villagers manage each type of forest differently. For example, they don"t farm in the* Ker Ner Meu *forest. As this type of forest is a water source surrounded by large trees that are characteristically cool and dense, if rice was planted here it would produce little; alternatively if the forest was cleared the streams and creeks would dry up or be reduced in size and number. Thus, the villagers look after these kinds of forests as water sources within a community preserve. ... It is forbidden to cut down any trees in the protected community forest. This is to protect it as a water source for production and for use and consumption by the community.* (Northern Development Foundation, 1999, my translation)**

***A simple lifestyle, using minimal resources, having just enough to eat and being at one with nature, leaves the forest, soil and water, surrounding the village, abundant and fertile. Vast humid forests bring rain. Some of the water from the rain washes fertilizer from decomposed leaves down into the fields, paddies and orchards. The rest is absorbed by the forest and slowly released for the community to use all year, forming streams and creeks that flow unhindered into rivers.* (Northern Development Foundation, 1996, my translation)**

The catchment is under high forest cover and the soil is covered by grass, bark and litter... This watershed functions like a sponge, absorbing water during the rainy season and with a long period of seepage into stream during the rest of the dry season. **(International Board for Soil Research and Management, 1997)**

In northern Thailand there is considerable disagreement about the best strategies for the management of upland forests, but there appears to be broad agreement on the importance of forests in maintaining the hydrological health of local and national river systems. Official and alternative accounts—often replete with images of mountain streams tumbling down verdant hillsides—commonly state that watershed forests are the key to securing downstream water supplies. At the same time, water shortages experienced by upland and lowland irrigators are regularly attributed to forest loss in upstream catchment areas—as the forest "sponge" is destroyed the ability of catchments to store and steadily release water is compromised. As the above quotations indicate, this particular relationship between forests and water supply has become an accepted part of the knowledge and aesthetic of northern Thai landscapes.

However, despite the importance of these issues for resource management and agricultural development, relatively few attempts have been made to critically examine the hydrological perspectives that lie behind such claims. There are some notable exceptions (McKinnon, 1989; Alford, 1992; Thangtham, 1994; Enters, 1995; Vincent et al., 1995; Forsyth, 1996) but these appear to have had relatively little impact on public debate, perhaps too readily dismissed as inappropriately "Western" or "technical" perspectives on the Thai environment. Recently, conferences and seminars in Thailand[1] have focussed some attention on international research on the hydrological properties of forest but, once again, the challenges posed by this research are not readily taken up in policy forums or in analyses of social and environmental processes in the forested uplands.

It is primarily because popular views about the relationship between forest and water are so influential in public discourse and policy formulation that I believe further attempts to open up some debate are called for. In this paper my primary aim is to present an accessible, but scientifically informed, account of forests, deforestation and water supply in northern Thailand that challenges the conventional wisdom contained in the passages quoted above. Ongoing discussion of these issues—outside hydrological circles–is crucially important because the *biophysical* claims about forest and water have important *political* implications in that they motivate a divergent range of regulatory practices that seek to define appropriate livelihoods for farmers in upland areas. I discuss the politics of upland livelihoods in more detail elsewhere (Walker 2001; Walker forthcoming) and in this paper my aim is to scrutinise and challenge the shared *hydrological* assumptions which contribute to official *and* alternative visions of upland futures. My emphasis on "standard" hydrological science should not

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[1] For example, Environmental Services and Land Use Change: Bridging the Gap Between Policy and Research in Southeast Asia, International Centre for Research in Agroforestry, Chiang Mai, 31 May-2 June 1999 and International Symposium on Watershed Management. Highland and Lowland in the Protected Area Regime: Towards New Principles and Practices, Chiang Mai University, 23-26 March 2001. See Forsyth (1999 and 2001).

be read as a dismissal of alternative forms of "indigenous" knowledge about catchment processes. Rather it is an *initial* attempt to open up the debate and create room for alternative forms of hydrological knowledge that may not be consistent with prevailing views about the "necessity and wisdom of trees" (Li, 2002).

My discussion draws extensively, but not exclusively, on data from the Mae Chaem catchment in the west of Chiang Mai province.[2] My work in Mae Chaem dates from my involvement in the Integrated Water Resources Assessment and Management (IWRAM) Project, a research initiative that explored the interaction between socio-economic and biophysical processes in upland areas of northern Thailand (Scoccimarro et al., 1999). While every area is, in many respects, specific, I believe that the comparative data and secondary accounts that I discuss demonstrate the wider applicability of the issues raised.

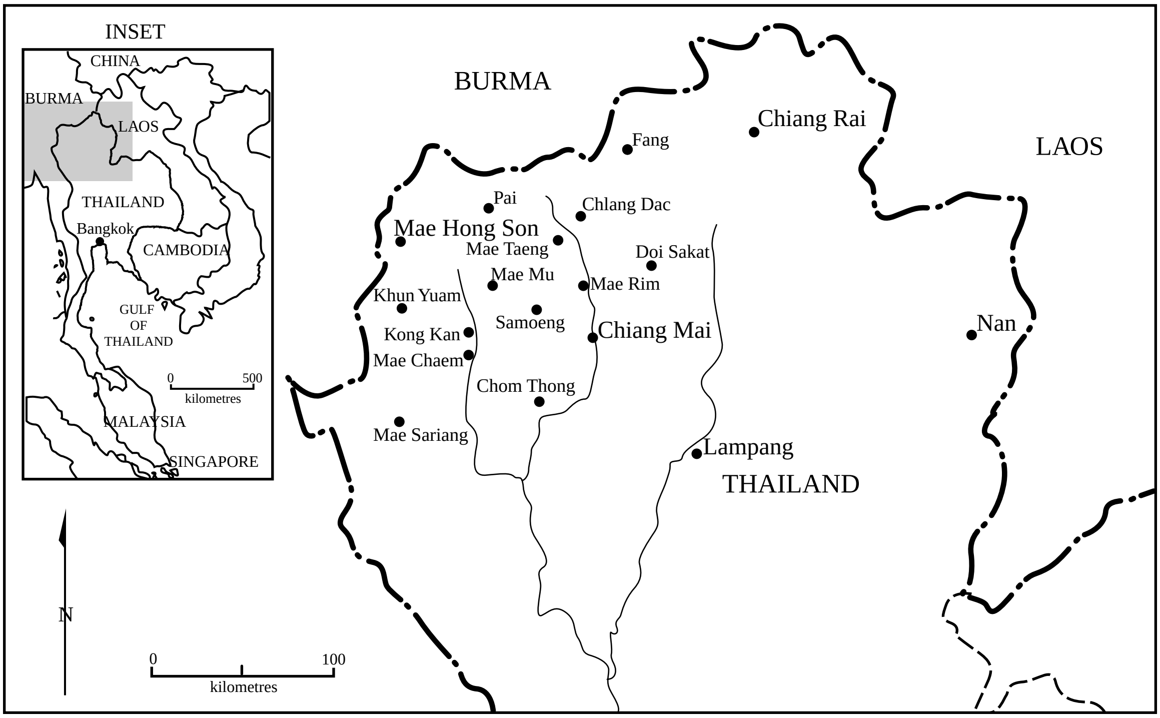

Figure 1. Northern Thailand with locations referred to in this paper

STREAM FLOW AND RAINFALL

Before moving to a discussion about the role of forest—and forest clearing—in catchment hydrology, I would like to make some general observations about stream flow in northern Thai catchments and the relationship between stream flow and rainfall. While some of these relationships may seem self-evident, a general discussion is needed to focus attention on some of the central issues considered in the sections that follow.

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[2] For location of all places referred to in the text see Figure 1.

The first point to be considered is the distinctive seasonal pattern of stream flow in northern Thai catchments. Data from the Mae Chaem catchment is illustrative of this widespread pattern: from a low point in April, the volume of flow climbs steadily from May to August-typically peaking in September-and declining again from October to March. This pattern is evident from data obtained at two points on the stream network, one on the main stream itself and one on a small tributary (Figure 2). These data indicate that the annual *pattern* is very similar, despite the very significant difference in the size of the catchments—2,175 square kilometres and 68 square kilometres respectively—and, accordingly, the overall volume of flow.

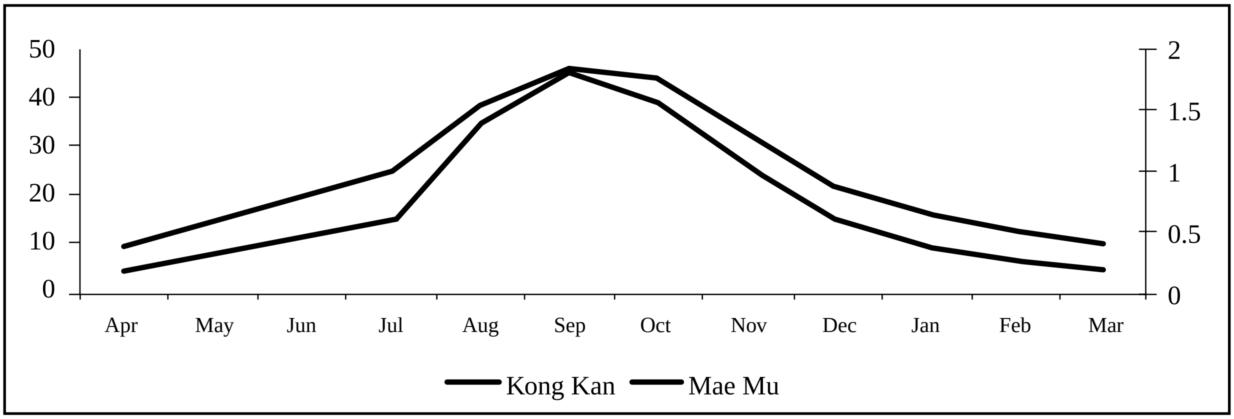

Figure 2. Average stream flow (cubic metres per second) at Kong Kan (left axis) and Mae Mu (right access). **Source:** IWRAM Project database.

The seasonal distribution of rainfall—with distinct wet and dry periods—accounts for this hydrological pattern. Rainfall data from Mae Chaem indicate that, typically, the wet season commences in April or May and lasts—though sometimes punctuated by a relatively dryer spell—until October. The dry season proper usually commences in about November and from December to March there is minimal rainfall (Figure 3). Monthly rainfall totals of zero are a common occurrence during this dry period. Donner (1978) provides a brief account of this broad rainfall pattern in northern Thailand, highlighting the strong monsoonal and maritime influence:

> [T]he Pacific-born typhoon storms blowing in the north-western direction reach the region every year in June, bringing heavy rainfall and resulting in a sharp rise of the rivers. On their way back from the north, these typhoons bring some rain again in August and the heaviest rains of the year in September before they disappear in a southern direction. This regime is superimposed on the south-west monsoon blowing from mid-May to mid-September and supplying fairly regular rainfalls every year.[3]

The most important issue that arises from these simple observations of seasonal patterns is that *dry season stream flow originates overwhelmingly from rain that has fallen in*

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[3] Of course, the local influence of these broad climatic patterns varies considerably.

the preceding wet season. While there are occasional showers during the dry season, the level of rainfall between December and March is insufficient to support the level of stream flow observed during these months. This can be illustrated by a simple comparison of rainfall and stream flow data: typically stream flow in the driest four months accounts for around 20 per cent of annual flow, whereas only three per cent of annual rainfall occurs in this period.[4] The crucial issue to understand, then, is *how the catchment "stores" and "releases" wet season rainfall to provide dry season stream flow.* Put differently, why is it that the rainfall graph declines precipitously from October to December whereas the stream flow graph has a gentler slope?[5] This crucially important issue will be the focus of discussion in later sections of this paper.

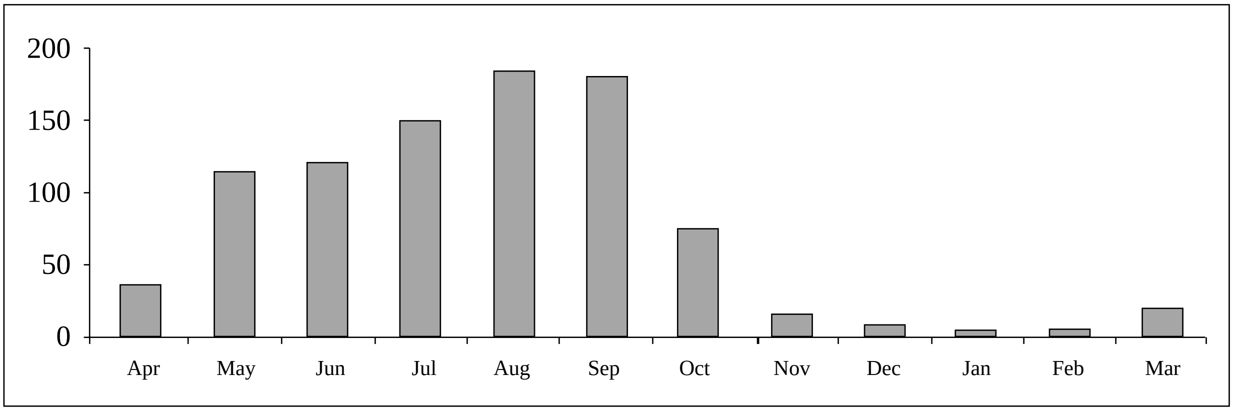

Figure 3. Average rainfall (millimetres per month) at Mae Chaem, 1931-1995. **Source:** Department of Irrigation.

Moving from seasonal variation to annual variation, it is evident that stream flow displays significant year-to-year volatility. This is an important feature that is often ignored when, for example, water shortages experienced by irrigators are attributed to *medium-term or long-term*[6] trends in climate or land cover. Figure 4 illustrates the extent of this short-term variation in relation to the main stream of the Mae Chaem (at Kong Kan). Here, the extent of short-term inter-annual variation is clearly evident, especially in relation to the peak-flows during the wet season. However, given their low absolute values, the variation in dry season flow—which can have crucial socio-economic consequences as farmers compete for irrigation water—is less evident. To highlight the extent of dry season variation, Figure 5 provides average flow for each December to April period. Other researchers analysing data from northern Thai catchments have noted similar patterns of *short-term* inter-annual variation (see, for example, Enters, 1995; Alford, 1992).

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[4] Based on the data used to compile Figure 2, Kong Kan"s percentage of flow in these months is 17 per cent while in Mae Mu it is 20 per cent. Based on the data used to compile Figure 3 an average of only 3.3 per cent of rainfall fell in Mae Chaem in these months.

[5] Though by Alford"s (1992) international standards the decline in stream flow is also relatively rapid—"an indication of the very limited storage (soil moisture and groundwater) in these mountain basins."

[6] By medium term I am referring to the past 10 to 20 years, while for longer term I am referring to the last 100 years.

The obvious cause of this variation in stream flow is variation in the annual level of rainfall. The level of rainfall variation is, once again, evident in records from Mae Chaem. Figure 6 provides short-term rainfall data for Mae Chaem (at Kong Kan), covering the period from 1988 to 1995. The average for the period is 1,003 millimetres, while the lowest record was 738 millimetres (26 per cent below average) and the maximum was 1,377 millimetres (37 per cent above average and 86 per cent above the minimum). Analysis of the monthly rainfall data for this period indicates that these annual differences are the result of variation in the onset, intensity and duration of the wet season. As would be expected, comparison of annual rainfall and stream flow data from Kong Kan suggests a strong relationship between the two ($r^2 = 0.70$) and the relationship is even stronger ($r^2 = 0.79$) if the stream flow at Kong Kan is compared with an *estimate* of rainfall from *throughout* the catchment area (Figure 7).[7] The data, then, appear to support the seemingly self-evident claim that short-term variations in the level of stream flow in northern Thai catchments are largely the result of short-term variations in the level of rainfall in the catchment area. There is, of course, nothing new in this conclusion (Vincent et al., 1995; Thangtham, 1994) but it is worth re-emphasising given a common tendency to ignore the extent of *naturally occurring* short-term variation in water supply when commentators rush to attribute water shortages to human-induced catchment degradation.

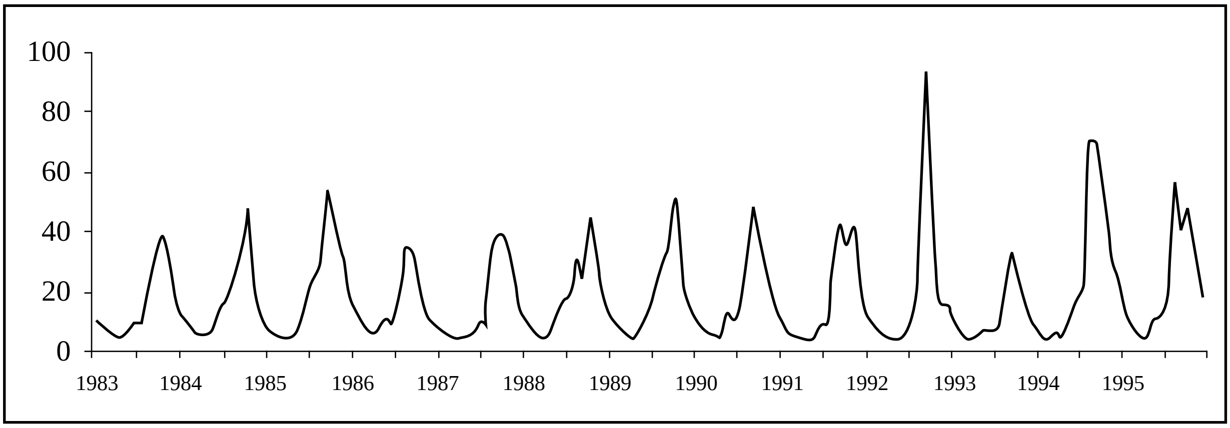

Figure 4. Stream flow at Kong Kan (cubic metres per second) from 1983 to 1995. **Source:** IWRAM Project database.

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[7] Stream flow at Kong Kan is, of course, a function of the rainfall throughout the upstream areas of the catchment, not just at the location of the stream gauge itself. Ideally, stream flow would be compared with appropriately weighted rainfall records from throughout the catchment area. Unfortunately, in the case of Mae Chaem such data are simply not available. As a crude approximation of this process I have taken an average of rainfall data from two sites: Kong Kan itself and Mae Mu (the latter at a significantly higher elevation and broadly representative of much of the upper catchment area for Kong Kan).

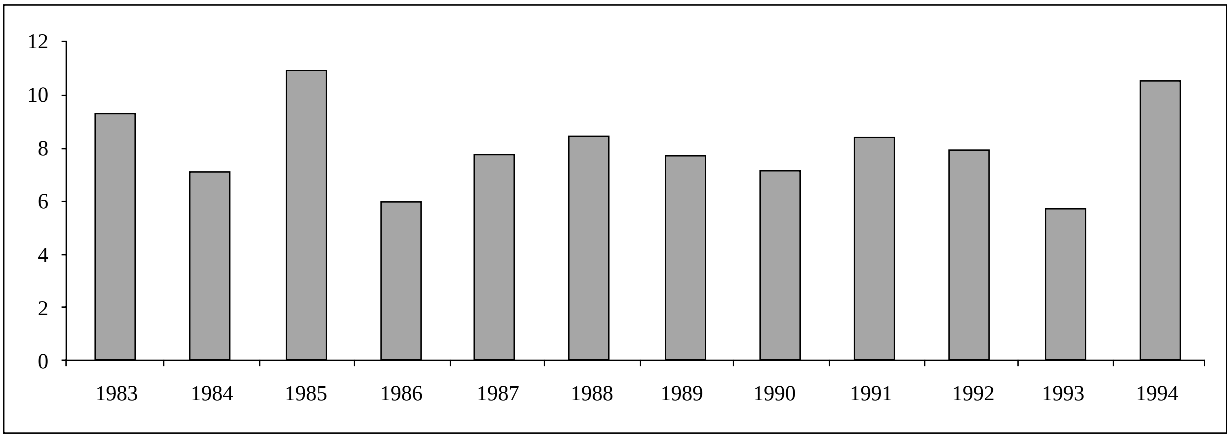

Figure 5. Average dry season stream flow (cubic metres per second) at Kong Kan. Source: IWRAM Project database.

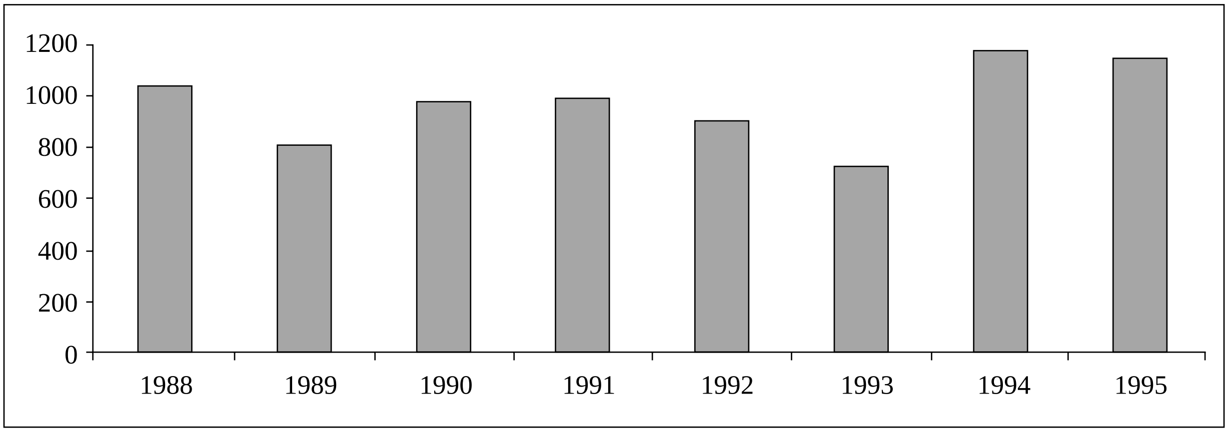

Figure 6. Annual rainfall at Kong Kan 1988-1995. **Source:** IWRAM Project database.

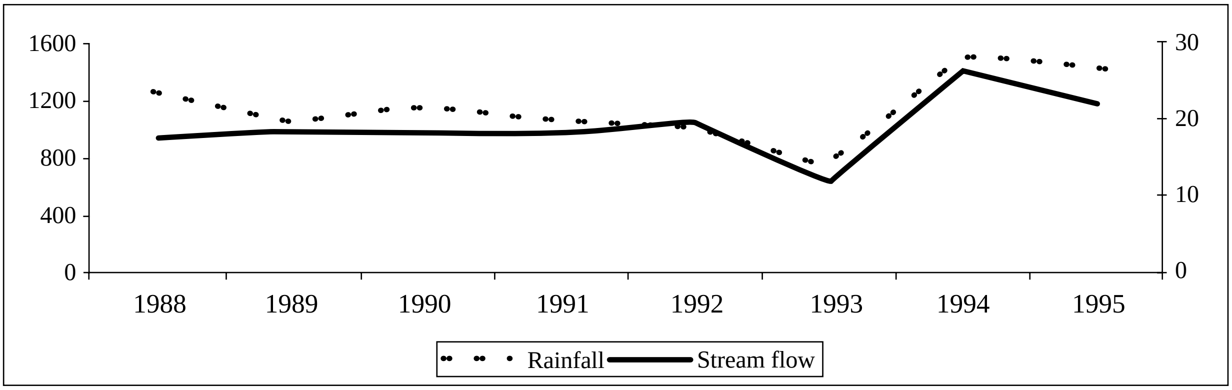

Figure 7. Comparison of stream flow at Kong Kan (cubic metres per second, right axis) and estimate of rainfall in the catchment area (millimetres per year, left access). **Source:** IWRAM Project database.

FOREST COVER AND STREAM FLOW

The suggestion that there is a strong relationship between variation in rainfall and variation in stream flow is not to deny, of course, the role of land cover in hydrological patterns. In examining the influence of land cover on stream flow in northern Thai catchments, three separate issues need to be addressed: (1) the effect of land cover change on the level of rainfall; (2) the effect of land cover change on the total level of stream flow (that is, on the percentage of rainfall that ends up in the stream); and (3) the effect of land cover change on the distribution of stream flow between the wet and dry seasons. Failing to separate out these three processes has lead to considerable confusion in discussions of northern Thai hydrological processes.

Forests and rainfall

In northern Thailand there is a popular environmental slogan—*“mi pa, mi fon”* (literally, “have forest, have rain”). The argument that lies behind this slogan is that forests create a climatological moist zone in which rainfall is relatively abundant. In more technical terms this can be expressed as the claim that relatively high rates of evapo-transpiration (ET) from forested areas enhance local precipitation. The implication is that reduction in forest cover will lead to reduction in levels of precipitation. This is a widely held position in Thailand, subscribed to by state officials and a broad coalition of NGOs and activist academics. *Is there any evidence to support the claim?*

To begin with, there is no doubt that the past 100 years have witnessed a significant decline in forest cover in northern Thailand. While there is room for debate about the extent of deforestation in particular localities it seems clear that the region has experienced a loss of forest cover of the order of 50 per cent since 1900. Official figures cited by Hirsch (1993) indicate that northern region forest cover has declined from 69 per cent in 1961 to 50 per cent in 1985 and Kaosa-ard (2000: Table 1) cites a further decline to 44 per cent in 1995. There is considerable debate, of course, about the causes of deforestation, but its extent seems uncontroversial.

What have the trends been in relation to rainfall during this period of progressive deforestation? Recently, I analysed long-term rainfall data for numerous sites in Chiang Mai and Mae Hong Son province compiled by the Royal Irrigation Department.[8] The data have to be treated with some caution given a significant degree of incomplete record keeping and, in many cases, rather short-term data series.[9] Nevertheless, there are a number of locations where relatively complete data series dating from the 1920s are available and Figures 8a to 8j set out annual precipitation figures for 10 of these locations.[10] These data underline the substantial short-term variation noted above but what do they say about longer-term trends? Consistent with popular claims about deforestation, the data from some locations do suggest a long-term decline in rainfall. This is most marked in Mae Rim but there are also minor

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[8] Rainfall data were obtained from the website of the Royal Irrigation Department at www.rid.go.th.

[9] See also the comments by Alford (1992).

[10] In compiling these graphs I have deleted years for which the data is incomplete or clearly erroneous.

downward trends in the data from Doi Saket, Chiang Mai and Samoeng. However, the data from other locations such as Chom Thong, Fang, Khun Yuam and Mae Hong Son suggest a long-term increase. Taken as a whole the data suggest long-term stability in levels of precipitation, despite very substantial reductions in forest cover. Only a very selective reading of the data could support the claim that deforestation has lead to reductions in levels of rainfall. Once again, there is nothing new or original in this conclusion. Enters (1995), for example, suggests that there were "no statistically significant changes [in precipitation] between 1927 and 1989." Similarly, Thangtham (1994) cites a study conducted in northeast Thailand to the effect that "yearly statistical analyses showed an insignificant relationship between monthly, seasonal and annual rainfall patterns and the remaining forest areas. In other words there was no correlation between the rainfall parameter and the percentage of remaining forest area."

Given the contribution forest makes to atmospheric moisture (due to high rates of ET, as discussed below), why is it that considerable forest clearing does not appear to have produced a significant reduction in rainfall? The answer to this important question lies in the passage cited from Donner above (page 4): the rain that falls in northern Thailand is predominantly monsoonal and derives not from ET in northern Thailand itself but marine sources to the west. Climatological research suggests that the strong maritime influence in southeast Asia generates a significant degree of climatic stability which greatly moderates the impact of reduced evaporation caused by forest clearing (Tinker, et al., 1996; Henderson-Sellers, 1993; Polcher and Laval, 1993; Calder, 1998; Chomitz and Kumari, 1998). Even studies of the vast Amazon basin, where maritime influences are less marked, suggest that modelled reductions in rainfall "apply only to extreme conditions of complete replacement of forest by grassland over very large areas" (Tinker et al., 1996).[11]

There are, however, two factors that may account for the widely held view in Thailand that deforestation has caused a reduction in rainfall. One factor is temporal while the other is spatial. In temporal terms there does appear to be some evidence that a relatively drier period has occurred during the 1980s and early 1990s and that this followed a relatively wetter period during the 1970s.[12] Shorter-term analyses of rainfall patterns are likely to show up this declining trend.[13] Importantly, the dryer period during the 1980s and 1990s has coincided with a dramatic increase in interest about forest policy in Thailand and it is not surprising that these two key environmental issues—water supply and forest loss—have become linked in public debate and policy discourse. But it must be emphasised that the recent dryer period is by no means unprecedented, with the longer-term data showing a

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[11] The one case where local forest clearing may have an effect on local rainfall is in the case of "cloud forests" that actually harvest moisture from the surrounding clouds. However these have very limited distribution in northern Thailand, occurring only at very high altitudes (over 2000 metres) and, according to Thangtham (1994) perhaps contribute only an additional "50 mm per year of additional annual rainfall in forested areas over and above cleared areas of the same altitude."

[12] Alford (1992) also refers to this relatively wetter period: "An important feature of this time-series is the peaks that characterized the decade of the 1970s. There is evidence that much of Asia was experiencing increased precipitation and stream flow during this decade."

[13] Giambelluca and Ziegler (1996) refer to an unpublished and undated study that reports a 15 per cent decline in northern Thai rainfall between the 1950s and the 1990s.

long-standing oscillation between relatively wetter and relatively dryer periods, seemingly independent of the progressive decline in forest cover. The ten-year moving average data in Figures 8a to 8j illustrate this pattern.

Spatial factors are also likely to be important in accounting for the strong cultural association between forests and rainfall. Forested areas in northern Thailand tend to be located at higher altitudes and these are also the areas that receive the highest rainfall. Why do these areas receive higher rainfall? This is primarily because rainfall occurs as warm moist air masses rise to higher and cooler, altitudes. How dramatic the influence of altitude on rainfall can be is demonstrated by a simple comparison of the rainfall records of Mae Chaem town and Doi Inthanon which is located only eleven kilometres to the east but more than two thousand metres higher. In Mae Chaem, rainfall averages around 920 millimetres per year while at the peak of Inthanon the average annual rainfall is over 2,200 millimetres![14] Clearly then, the belief that "where there is forest there is rain" has a strong basis in common-sense experience and observation but the higher levels of rainfall in highland areas are a function of altitude rather than forest cover.

Forest cover and total stream flow

In the path-breaking and influential edited collection *Farmers in the Forest,* Thiem (1978) reports on an experiment undertaken in Huay Kok Ma, a small forested watershed in Chiang Mai province. He notes that this small 65-hectare watershed, with a rainfall of 1,938 millimetres was able to deliver 481,825 cubic metres of water to the Mae Ping River network. "This suggests," he writes "the importance of preserving permanently all the forests in the land category as watershed protection in the source areas of essential water supplies" (Thiem, 1978). At first glance, the numbers look impressive and his conclusion is typical of the widespread claim that forests help to secure downstream water supplies. However some simple mathematics raises intriguing questions. Assuming that precipitation is uniform over the watershed area (a reasonable assumption given the small size of the catchment) the total amount of rain falling on the watershed amounted to 1,269,390 cubic metres (650,000 square metres of catchment multiplied by 1.938 metres of rainfall). With a discharge of only 481,825 cubic metres (only 38 per cent of the total rainfall) it seems that Huay Kok Ma has almost 800,000 cubic metres worth of explaining to do.

Where did all the water in Huay Kok Ma go? The usual culprits—forest clearing upland cultivators—have the perfect alibi: this was a *fully forested* catchment "covered with dense vegetation of the Hill Evergreen (Lower Montane) type" (Thiem, 1978). It is possible that some rainfall may have been lost as a result of catchment "leakage", a condition which "holds especially for small headwater catchments, where streams are often not incised through the entire weathering mantle" (Bruijnzeel, 1989); *however an examination of the hydrological record of the forest itself suggests that it certainly warrants suspicion as the main water consuming culprit.*

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[14] Rainfall data were obtained from the website of the Royal Irrigation Department at www.rid.go.th.

A solution to the “mystery” of Huay Kok Ma can be found by examining the route from rainfall to stream flow. As rain falls in a forested catchment such as Huay Kok Ma, a significant percentage is “intercepted by the forest canopy ... [and] evaporated back into the atmosphere during and immediately after the storm” (Bruijnzeel, 1997). Clearly the amount intercepted varies according to the type of forest and the timing and intensity of rainfall events, however average levels of leaf interception typically range from 10 per cent to 30 per cent (Bruijnzeel, 1997; Witthawatchutikul and Suksawang, 2000; Klinge, et al., 2001). According to Bruijnzeel (1997), teak trees, for example, have an interception rate of about 20 per cent “over a range of climatic conditions” though studies undertaken by the Thai Royal Forest Department found average interception rates in Nan province of 36 per cent (Charoensuk et al., 2000) and, for a mixed deciduous forest with teak, 39 per cent in Chiang Mai province (Chanpaga and Watchirajutipong, 2000). In some cases very high rates of interception (around 70 per cent) have been recorded, for example in relation to dense bamboo forests (Saengkoovong et al., 2000).

Once the rain reaches the ground (as direct through-fall, leaf drip and stem flow) it can either soak into the soil or run across the soil surface. It is widely believed that rates of infiltration in forests are very high (sometimes as much as 100 per cent of the rainfall that has escaped leaf interception). This is a crucially important issue in relation to the timing of stream flow and will be discussed further below, but for now we will accept that very high rates of infiltration are achieved. Once rainwater has soaked into the soil it then has to contend with the extensive root systems of forest trees. Compared with other forms of land cover, forests have deep root systems and high rates of root production, especially in the drier montane forests of northern Thailand (Holbrook et al., 1995: 245). Though precise measurements are lacking it is clear that a large percentage of the rainwater that enters the soil is captured by the forest root systems and returned to the atmosphere in the form of transpiration. The combined effect of canopy interception-evaporation and transpiration is substantial. Analysis undertaken by Giambelluca and Ziegler (1996: Figure 3) provides a figure of 850 millimeters per year out of an annual rainfall of 1,170 millimeters. This is consistent with model estimates derived from the work of Perez et al. (2002) in which the level of forest ET ranges from 720 millimeters (out of 900 millimeters of rainfall) to 1,160 millimeters (out of 2,000 millimeters of rainfall). Significantly higher rates of ET—about 1,500 millimetres or 90 per cent of total rainfall—were reported for a study area of forest, cassava field and fruit trees in Rayong province, with forest having higher rates of ET than the other land covers (Witthawatchutikul and Jirasuktaveekul, 2000).

So, on the basis of research on the hydrological properties of forest cover, it should come as no surprise that of the roughly 2,000 millimetres of rainfall in Huay Kok Ma only 38 per cent ends up as stream flow. Canopy interception-evaporation and transpiration can easily account for the balance. The crucial point is that *natural hydrological processes in forested catchments account for very significant losses of moisture from the catchments* without any human intervention at all. Alford, working with catchments on a much larger scale than Huay Kok Ma, suggests that the mountain catchments of northern Thailand have an “*extremely low* ‘runoff efficiency’” averaging, from his data, approximately 20 per cent (that is, only 20 per cent of the water that enters the catchment as rainfall leaves the catchment as stream flow). My analysis of rainfall and stream flow data for the predominantly forested Mae Chaem catchment (at Kong Kan) suggests that annual stream flow averages about 24 per cent of total rainfall.[15] Alford"s (1992) conclusion that "the mountain catchments of northern Thailand are among the most 'arid' on earth, when considered solely from the standpoint of specific runoff" may seem somewhat extreme but it is a sobering reminder of the relatively high water consumption of natural forest cover. Forests may be effective "sponges" but they are also very effective catchment "pumps" (Hamilton 1987).

The implication of this simple case study is that there is considerable hydrological potential to increase *annual* stream flow by lowering the level of interception and transpiration in upland catchments. The most common way in which the ET profile of a catchment is lowered is by clearing forest and replacing it with grasslands or crops. Let me put this quite explicitly: forest clearing—and replacement with land covers that have lower rates of ET—*increases the annual stream flow of catchments* and, in terms of total annual rainfall, the percentage increase can be very significant (Bruijnzeel 1997). As Vincent et al., (1995) have reported "trends of increasing annual stream flow have been found in many tributaries after deforestation occurs." This is a widely drawn—but much ignored—conclusion supported by a considerable body of empirical and theoretical research in both Thailand and internationally.[16] It is a conclusion that warrants much more attention in future discussions of water resource management and land use regulation in northern Thailand.

Forest cover and dry season flow

I must emphasise that the discussion in the previous section refers to total *annual* stream flow and not to stream flow in particular months or seasons. These are two quite separate issues and I will open this section with an extreme, but illustrative, example that demonstrates the difference between them. *What would happen if a forested catchment was cleared and completely lined with smooth concrete?* Leaf interception-evaporation and transpiration would, of course, be zero. There may be some evaporation losses from the concrete itself but, especially if the catchment was relatively steep, the bulk of the rainfall would run off quickly into the stream network. The run-off efficiency would probably be well over 90 per cent—annual stream flow would increase dramatically. But—and this is a crucially important "but"—*the pattern of flow would be very different.* The fact that the rainfall ran off quickly into the stream network would mean that once the rain stopped (or very soon after) there would be no water left to make its way slowly into the stream network. *Dry season flow would be close to zero.*

This extreme example is illustrative of what some suggest is the fate of forested catchments when they are cleared for agriculture. The argument is this: as agricultural activity proceeds, the absorptive "sponge-like" properties of the humus-rich forest floor is lost; exposed and treated soils become compressed, rates of soil infiltration decline and rates of surface runoff increase, often causing flooding in the wet season and leaving less soil

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[15] Calculations based on the stream flow and rainfall figures referred to in Figure 7.

[16] See, for example, Bosch and Hewlett (1982); Bruijnzeel (1989); Hamilton (1987); Durbidge and Henderson-Sellers (1993); Enters (1995); Sahin and Hall (1996); Tinker et al., (1996); Chomitz and Kumari (1998); Douglas (1999); Hobart et al., (2001); and Vetchaporn (2000).

moisture available to contribute to dry season flow. Some may acknowledge that the level of annual flow has increased but, in the absence of the storage facilities provided by the forest "sponge," the additional water is wasted in the form of wet season flooding and little is left for the crucially important lean season from December to April.

In this section, I seek to assess this widely held view of catchment processes in northern Thailand. The fundamental question to be addressed—*in relation to dry season flow*—is whether the "benefit" of reduced rates of ET is outweighed by the "cost" of reduced levels of infiltration. In my hypothetical concrete catchment, the "cost" clearly outweighs the "benefit" and the result is a dry season flow that is virtually zero. However catchments in northern Thailand—even intensively cultivated catchments—are a very long way from this extreme. What, then, is the trade-off between ET and infiltration in these catchments? In order to approach an answer to this complex question it is necessary to assess the magnitude of both ET and infiltration changes as forested catchments are converted to agriculture.

ET: forest versus crops

It has already been noted that forest has significantly higher rates of ET that most other land covers. How much higher? Table 1 sets out an estimate of the percentage of total rainfall that is lost in the form of ET under forest and two major upland crops given different levels of annual rainfall. Results are derived from a "soil moisture balance" model developed by Perez et al., (2002). In the case of forest, the model assumes year-round forest cover. For the crops the model assumes a single rain-fed crop grown in the wet season on upland fields; however the ET figures include the growing period of the crop *plus* bare soil evaporation before planting and after cultivation *and* ET from a simulated fallow cover (grass or weeds) during the dry season. From these results it is evident that forest has a rate of annual ET that is typically about 20 per cent higher than that of upland crops widely grown in northern Thailand. The biggest difference, of course, emerges during the dry season. With deep rooting systems, forests continue to extract water from the catchment during these minimal rainfall months whereas the level of dry season ET from unirrigated agricultural areas is minimal. Giambelluca and Ziegler (1996) suggest that "dry season evaporation on non-irrigated agricultural land was estimated to be as low as 16% of the undisturbed forest rate."

Table 1. Annual ET as a percentage of annual rainfall. Source: model results from simulations undertaken using CatchCrop (Perez et al., 2002).

	Annual Rainfall		
	2000 mm	**1500 mm**	**900 mm**
Forest	58	74	80
Upland Rice	37	48	60
Soybeans	40	44	61

There are two caveats that must be placed on these single crop/single plot results. First, the conclusion that clearing of forest areas for cropping will lower the ET profile of the catchment must be tempered somewhat by the finding that forest fragmentation can increase

ET within the forest itself, as a result of what is called the “edge effect” (Giambelluca and Ziegler, 1996). Forest fragmentation increases the amount of forest “edge” that is exposed to higher levels of air movement and sunlight, both of which may increase the level of ET. However, the edge effect only “*partly* reverses the reduction in regional evaporation due to deforestation.” (Ziegler et al., unpublished mss: 19; Laurance, 2000).

Second, the figures in Table 1 would be quite different if a second, irrigated, crop was grown during the dry season. Irrigation can increase the level of annual ET from crops to a level much closer to—or even in some cases more than—natural forest. However, in this paper I do not consider the effects of irrigation for two reasons. First, the incidence of irrigation on cleared forest land is relatively low, with most irrigation taking place in lowland zones of longstanding agricultural activity. Second, and most importantly, even where there is irrigation on cleared upland areas, it must be remembered that irrigation is *a catchment-wide water demand issue* with both upland and lowland farmers contributing to the extraction of water from the catchment system. In this paper I am focusing specifically on the *water supply* implications of forest clearing rather than on the *water demand* issues that emerge when irrigation systems (or industries, resorts or residential estates) are developed. The crucially important issue of water demand is dealt with in a separate paper (Walker, forthcoming).

Infiltration: forest versus crops

The crucially important issue of infiltration is considerably more contentious and it is much harder to draw clear conclusions, *but it cannot be assumed that forest necessarily has higher infiltration rates than replacement land covers.* A brief review of a number of studies provides an indication of how difficult it is to draw clear conclusions about this issue and highlights the need for ongoing research.

In a study undertaken in northern Thailand, Ziegler et al., (2001) found that actively cultivated fields have high rates of infiltration and accordingly, very low run-off values (less than or equal to four per cent), equivalent to the low run-off values of *advanced* fallow fields with dense vegetation cover. Interestingly, the study found that hoed fields have infiltration rates *approximately five times higher than forest,* a finding consistent with that of a similar study undertaken in northern Vietnam (Ziegler et al., unpublished paper). There was, however, some evidence that infiltration rates on upland fields may decline during the cultivation period and, in particular, they found that *rates of infiltration on recently abandoned fields were relatively low,* with run-off up to 40 per cent during storm events (Ziegler et al., 2001; unpublished paper; see also Sarmiento, 2000). Their studies also acknowledge that they may have underestimated infiltration rates in forest given that their sampling took place in flat, relatively accessible and probably somewhat trampled areas of forest. A key finding of their research is that paths play a key role in generating overland flow during storms. The study found that these paths have very low rates of infiltration and that rates of storm run-off can be very high indeed Given the close association between paths and cultivated fields at a landscape level, the very low rates of infiltration on paths may significantly compromise the relatively high rates achieved on cultivated surfaces.[17]

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[17] However, even taking into consideration the effect of paths, the study concludes that cultivated areas contribute a similar magnitude of storm flow to the stream network as do unpaved roads, despite the fact that roads occupy 95 per cent less catchment area (Ziegler et al., 2001; see also Douglas, 1999).

Research reported on by Thangtham (summarised in Enters, 2000: Table 11) lends support to the view that differences in infiltration rates between forested areas and cultivated areas may not be dramatic. In mixed deciduous forest and dry dipterocarp forest, Thangtham reports rates of run-off of 5.5 and 3.6 per cent respectively (in both cases with a slope of 15 per cent). These rates increase somewhat (10.9 per cent and 6.1 per cent) when the forest is burnt. For upland rice fields, Thangtham reports rates of run-off ranging from 2.9 per cent to 12 per cent (across a range of slopes) and for bare soil he reports rates ranging from 1.8 per cent to 12.7 per cent.[18]

Takahashi et al., (1983) provide a somewhat different perspective on infiltration and run-off in a study undertaken in northeast Thailand. They found that rates of infiltration on cultivated upland plots were *significantly lower* than they were on nearby forested land. Rates of infiltration on cultivated plots were particularly low—with runoff sometimes exceeding 60 per cent—early in the cultivation cycle, before crops and weeds provided groundcover. By contrast they found that run-off from the high infiltration forest plots rarely exceeded 10 per cent. This finding is backed by a report by Vincent et al., (1995) which, based on a review of relevant research, argues that infiltration rates are higher in natural forest areas due to the "thick layer of natural debris" which protects the soil and slows runoff. The report cites a study that found forest soil is capable of absorbing as much as 280 millimetres per hour. It acknowledges that forest clearing and cultivation may increase infiltration but argues that this is a temporary phenomenon that ceases once the soil becomes compacted (Vincent et al., 1995; see also Thangtham, 1994).

ET and infiltration: assessing the impact on dry season flow

There is no easy way to assess the combined impact on dry season flow of changes to both ET and infiltration when forest is cleared for agricultural activities. After reviewing a range of international catchment studies Bruijnzeel"s (1989) conclusion is that if a *reasonable amount of care* is taken to maintain the infiltration capacities of cleared land, the positive effect of reduced ET will be greater than the negative effect of reduced infiltration, *resulting in an increase in dry season base flow.* Obviously, how much care is required will vary considerably depending on local conditions but as a starting point it seems reasonable to suggest that *if the reduction in infiltration is less than the reduction in ET* then the impact on dry season stream flow will be very limited. Consider the following situation:

- Annual rainfall is 1,500 millimetres; and
- Forest clearing and replacement with crops reduces ET by 380 millimetres (25 per cent of annual rainfall); and
- Reduced infiltration causes an increase in runoff of 150 millimetres (10 per cent of annual rainfall);

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[18] The web site of the Royal Forest Department also provides brief details of a number of studies that warrant comment. Studies reported on by Thitirojanawat (2000a; 2000b) suggest that the water-holding capacity and porosity of soil under shifting cultivation was only slightly lower than that found in soil under forest cover. Another study reported on by the Royal Forest Department (Paramee, 2000) found that rates of runoff in "natural dry dipterocarp forest which has been affected by annual forest fire" were four to seven times *higher* than agro-forestry areas planted with jack fruit, cashew nut or mango.

Under these circumstances it seems highly unlikely that there will be negative impacts on dry season flow—and there may even be an increase—given that less than half of the ET "benefit" to the dry season has been "lost" in the form of wet season run-off. The work of Takahashi et al., (1983) provides an illustration of this sort of trade-off. As noted above they found that infiltration on cultivated upland fields was significantly lower than infiltration in forest. However, when they examined the soil itself they found that the cultivated areas had higher levels of soil moisture, which is the basis of dry season flow. In the forested area "the soil was drier in deeper horizons and always in the condition of low soil moisture, compared to the other plots" (Takahashi et al., 1983). The lower soil moisture under forest is, of course, a product of the higher levels of transpiration.

However, there may also be situations where considerably higher rates of wet season runoff can occur following forest clearing, especially when the impact of roads and pathways is taken into account. Giambelluca and Ziegler (1996), for example, assume 25 per cent overland runoff for cultivated areas (in comparison to zero for forest) and at this level the likelihood of a negative impact on dry season flow (even given a substantial "benefit" in terms of reduced ET) is much greater. Their model simulations of a hypothetical catchment suggest that 50 per cent conversion of forest to agriculture may reduce dry season flow by as much as 30 per cent (Giambelluca and Ziegler 1996: Figure 5). However, three further aspects of their research are worth noting. First, their simulations also find that a 100 per cent conversion of forest to agriculture leads to a much smaller impact on dry season flow (about 15 per cent), given that at this level of conversion the impact in terms of reduced ET is relatively more important. Second, their simulations show that the impact on dry season flow is much less when forest is converted to a mix of agriculture and secondary vegetation (probably a more realistic scenario), with a 50 per cent conversion reducing dry season flow by about 15 per cent and a 100 conversion to mixed land cover *increasing* dry season flow by about 12 per cent. Finally, when their modelling approach is applied to an existing catchment where forest cover has declined from 76 per cent in 1955 to 56 per cent in 1983 their simulations suggest that wet season flow increased substantially *"while dry season flow was not significantly altered"* (Giambelluca and Ziegler, 1996, my emphasis). This modelled finding for a small catchment is consistent with the review of actual data on the seasonal distribution of water flow for the Ping River itself undertaken by Enters (1995) which concluded that "no statistically significant changes between 1927 and 1989 could be identified."

To sum up, while there certainly do appear to be situations where forest clearing can have a negative impact on dry season flow, largely as a result of increased wet season run-off on relatively denuded and compacted land, there does not appear to be a basis for the view that reductions in forest cover necessarily lead to dry season desiccation. The popular view that forest is a "sponge" that holds water and releases it slowly during the dry season has some basis on fact—rates of infiltration in forest do appear to be relatively high (though other types of land use can also produce high infiltration) and this does enhance the soil moisture that supports dry season flow. But this is only one side of the hydrological story. Forests are also very effective pumps, extracting significantly more water out of the soil than other vegetation covers. The argument I have presented in this section is that the "sponge effect" needs to be considered alongside the "pump effect" in assessments of the impact of forest clearing on dry season water supply. More field data and further development of hydrological models will, no doubt, assist in assessing effects in particular locations but, in the meantime, an open mind appears warranted.

EROSION AND SEDIMENTATION

Forests are not only seen as important in terms of protecting water supply, they are also seen as playing an important part in securing water quality, particularly by reducing the amount of sedimentation that passes into the stream network. The issue of erosion and sedimentation is exceedingly complex and warrants a paper in its own right. However recent research suggests that, as with water supply, the protective role of forest may be somewhat overstated.

It is commonly assumed that there is no erosion under forest cover. This is not the case. As the discussion above indicates, significant levels of overland runoff can occur in forests and this can have a substantial erosive effect in terms of both sheet erosion and gullying (Forsyth, 2001; Pongboun et al., 2000). As Chomitz and Kumari (1998) point out “ground cover, rather than canopy, is the chief determinant of erosion” and in forested situations where the ground cover is sparse (or reduced by fire)[19] there can be considerable erosion, possibly enhanced by the fact that water droplet size may be increased by collection and consolidation of rainfall on the canopy (Hamilton, 1987). Importantly, it is also increasingly clear that forests have a limited impact on modifying overland flow in heavy storm events and there is growing evidence that such peak events make a disproportionately high—and perhaps even dominant—contribution to erosion and sedimentation (Douglas, 1999).

Of course, this is not to deny the significant potential for increased rates of erosion on cleared lands, especially in the early stages of cultivation when exposed soil is subject to heavy rainfall events. The work of Turkelboom et al., (1999) has also shown that down-slope movement of soil can be caused by the mechanics of tillage itself. But, once again, some questioning of widely held assumptions appears warranted. Forsyth”s detailed study of erosion in an upland village in Chiang Rai province suggests that, contrary to expectations, population growth does not necessarily lead to cultivation of steeper slopes (with greater potential for erosion) but leads to intensification of cultivation in less steep areas (Forsyth, 2001). His work forms part of an increasing body of evidence that the location, rather than extent, of forest clearing may play a crucial role in determining environmental outcomes in terms of both erosion and sedimentation. Moreover, even where forest clearing has taken place in supposedly more vulnerable areas, unacceptable levels of erosion are not an inevitable consequence, possibly due to the very high permeability of actively cultivated soils and rapid development of crop and weed cover. Notes from a recent survey of catchments in northern Thailand by the International Board for Soil Research and Management (in search of suitably degraded case-study sites) are illustrative:

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[19] In some areas of northern Thailand controlled “conservation” burning of undergrowth and groundcover is undertaken to promote growth of tree seedlings.

> In the [Huay Mae Kung] catchment no severe erosion problems could be observed even on extremely steep, cleared soils... In the lower part [of the catchment], cultivated plots on steep slopes showed a surprising stability of the topsoil and there was no evidence of erosion in these fields. (IBSRAM 1997)
>
> No severe soil erosion could be observed [in Mae Nga catchment] even on steep slopes under cultivation... There is no evidence of surface runoff or erosion in this catchment. (IBSRAM 1997)

Observations such as these have prompted increasing attention being given to non-agricultural sources of erosion and stream sedimentation. Research in northern Thailand and in other comparable regions suggests that roads and road building may have very significant impacts on catchment health. In relation to work undertaken in Chiang Mai province, Ziegler and Giambelluca (1997) suggest that "roads are responsible for a significant proportion of the increased erosion and sedimentation that is often attributed to agricultural activities in Sam Mun." Their *simulation* of sediment yield in a case-study sub-catchment suggests that it was negligible with 25 per cent of the catchment converted to various stages of upland agriculture but that the addition of a road "through a small lowland portion" of the catchment generated substantial sediment delivery during larger storm events.[20] Similarly, Douglas (1999) reports on a study in the Mae Taeng catchment that found that road length was "the most important single variable leading to increased run-off and sediment yield." Of course, roads are an intrinsic part of the process of deforestation (Chomitz, 1999) but identifying them as key sources of erosion and sedimentation leads to management and regulatory measures quite different to the farmer-based emphasis of many land and water conservation initiatives (Estrada and Posner, 2001).

It is also important to distinguish between on-site *erosion* and the delivery of *sediment* to the stream network. Claims about downstream sediment impacts that are based on aggregated estimates of on-site erosion in upstream areas are likely to be vastly inflated due to the fact that there are numerous landscape filters and points of re-deposition that prevent the passage of sediment into the stream network (Chomitz and Kumari, 1998; Bruijnzeel, 1997). That this is a crucially important issue is highlighted by studies that demonstrate no evidence of a medium or long-term increase in levels of sediment in the northern Thai river system. Alford"s (1992) study suggests that there is significant year-to-year variation in sediment yield, matching year-to-year variation in stream flow, but that "[v]olumes of suspended sediment moving through the rivers of northern Thailand are among the lowest of all river systems worldwide." A similar review of data from Chom Thong by Enters suggests that sediment loads in the Ping River increased somewhat from the 1960s to the mid 1970s but declined again to the mid 1980s, despite ongoing deforestation. As with the study undertaken by Alford there is a clear correlation with short and medium term variation in stream flow suggesting "a sediment source within the stream channel ... rather than sheet erosion" (Enters, 1995).

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[20] See also Chomitz and Kumari (1998); Ziegler et al., (1999; 2001).

Finally, it is also necessary to acknowledge the benefits that may arise out of erosion in deforested landscapes. In particular, erosion of soil on up-slope fields can make a significant positive contribution to down-slope fertility and there is some evidence that this process is actively managed by farmers to assist, for example, in the formation of paddy fields (Turkelboom et al., 1999; Chomitz and Kumari, 1998). As Enters (1995) notes, “farmers are aware of the positive effects of light to moderate soil erosion and are able to use it to their advantage.” Even in-stream sediment can have benefits with dredging of riverine sediments playing an important part in the development of the northern Thai construction industry (Enters, 1995).

CONCLUSIONS

> It has been a saying in our people for many, many years that in order to get a regular, year-round long-term supply of water you need to cut down the largest trees around the village. I have seen it myself. It is only since we arrived in Thailand that we have heard people claim that this is not the case and it is the Thai extension workers who tell us this. (Mien villager quoted in Forsyth, 1999)

The main conclusions and implications from the discussion and data set out in this paper are summarised below.

- Analysis of rainfall and stream flow data suggests that substantial year-to-year fluctuation in rainfall produces substantial year-to-year fluctuation in stream flow. This short-term fluctuation is evident both in relation to wet *and* dry season stream flow. This short-term fluctuation in flow appears to be unrelated to any medium-term or long-term changes in land cover.

- Analysis of rainfall data suggests that there is no clear evidence of a long-term regional decline in rainfall, despite significant reductions in forest cover over this period.

- Numerous international hydrological studies, and some studies undertaken in Thailand, show that forest clearing has the effect of increasing *annual* stream flow, given that clearing forest lowers the percentage of rainfall that is lost to the atmosphere in the form of ET.

- A limited number of regional studies suggest that forests have *higher rates of infiltration than cultivated land covers* (though the actively cultivated portions of the cultivated landscape may have rates of infiltration similar to that of forests). Infiltration in cultivated landscapes is reduced by soil compaction and by the presence of hard surfaces such as roads, pathways and settlements. However, relatively accessible areas of forest (which are also probably the areas most likely to be cleared) also appear to be subject to a degree of compaction and reduced infiltration.

- Hydrological studies and modelling exercises suggest that the higher rates of run-off in cultivated landscapes tend to alter the seasonal *pattern* of stream flow with a greater percentage of annual stream flow occurring in the wet season.

- Hydrological studies and modelling exercises suggest that while clearing of forest for agriculture may change the *pattern* of stream flow, the absolute level of dry season flow does not necessarily decline and it may increase. This arises from the fact that the level of annual flow is higher given the reduction in ET. The positive impact on dry season flow of reduced ET will be outweighed by the negative impact of reduced infiltration only when runoff reaches relatively high levels.
- Forest clearing probably does increase erosion in some cases, though there appear to be numerous landscape filters that prevent passage of a substantial proportion of eroded material into the stream network. Studies of stream sedimentation in the Ping River suggest no long-term increase in sediment load.

These conclusions have a number of important policy implications. First, some caution is warranted in relation to extensive tree-planting programs, either in the form of plantations, orchards or initiatives in watershed "rehabilitation." Increased tree cover is likely to reduce the annual water yield of upland catchments and, if the objective is to secure larger supplies in major downstream hydroelectric schemes, the initiatives are very likely to be counter-productive (Aylward, 2000). There is also a good chance that extensive tree-planting will reduce dry season flow, because the medium to long-term benefit in terms of enhanced infiltration may well be limited and strongly outweighed by short to medium increases in the level of water "lost" due to ET.[21] The popularity of pine plantations in some areas of northern Thailand (Oberhauser, 1997) is particular cause for concern given that a number of studies have indicated that such plantations can have a significant negative impact on both annual and dry season stream flow (Sahin and Hall, 1996; Vincent et al., 1995). Also, the fact that some of the bitterest catchment disputes about water supply have arisen in areas of extensive orchard establishment, perhaps should prompt some reconsideration of the common assumptions in northern Thailand about the contribution of increased tree-planting to environmental rehabilitation and agricultural sustainability.

Second, greater research and policy attention needs to be given to the issue of run-off in cleared areas. As Calder (1998) has written: "In general, the role of vegetation in determining the infiltration properties of soils, as it affects the hydrological functioning of catchments ... remains poorly understood." There is now considerable recognition of the role that farmers can play in conserving the forest itself but there appears to be relatively less public attention given to the current and potential role of farmers in maintaining forest *functions*—high infiltration rates in particular—in agricultural zones. Further research is required on rates of infiltration in cultivated areas and the effectiveness of local and introduced conservation measures—including the maintenance or establishment of forested "filter zones"—in limiting runoff. This research will assist in a more informed assessment of the trade-offs between the costs of soil conservation measures and the possible off-site benefits in terms of dry season water supply (see, for example Rao et al., 1996). It will also help in establishing whether or not key hydrological functions can be performed by strategically placed "filter strips" of forest, plantation or orchard. Ziegler et al., for example, found that "buffers" of

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[21] See, for example, Hamilton (1987); Vincent et al., (1995); Bruijnzeel (1997); Calder (1998); Chomitz and Kumari (1998); Niskanen (1998); and Harden and Mathews (2000).

relatively high infiltration land cover can *significantly reduce* the amount of overland flow that reaches the stream network (Ziegler et al., unpublished mss: 3; Giambelluca and Ziegler, 1996) Research on catchment scale run-off also suggests that an emphasis on soil and land cover management needs to be combined with much more attention to limiting the impacts of roads and pathways.

Finally there is a need to put the issue of contemporary rates of forest loss into hydrological perspective.[22] Despite the predominant emphasis on deforestation, rates of forest loss in northern Thailand have been *relatively modest in the last two decades,* with a reduction in forest cover from 52 per cent in 1982 to 44 per cent in 1995 and even suggestions of an increase in more recent years (Kaosa-ard, 2000: Table 1; Hutasing, 2000). While there are various reasons why even modest reductions in forest cover may be regrettable—for example in terms of loss of biodiversity and local amenity—the hydrological impacts of changes of this magnitude are likely to be negligible and insignificant in relation to the natural year-to-year variation in stream flow. Moreover, any minor reductions in dry season water supply that *may* have occurred as a result of the recent reduction in forest cover must also be considered in the context of the dramatic increases that have been taking place in *demand* for water during the dry season. This is a crucially important issue that I am addressing in a separate paper (Walker forthcoming) and here I will just note that there is good evidence that water conflicts are much more likely to be driven by large increases in water demand than by small changes in the pattern of supply possibly caused by land-use change. Here we return to the politics of water. As long as the focus of public debate is on water *supply,* the regulatory focus will be on those resident in the forested upland areas that are seen as being crucial in securing downstream flows. But if the water management focus is shifted to water *demand,* then regulatory attention must shift to the diverse sources of that demand that exist throughout the hydrological system—not just upland farmers but lowland farmers as well, along with industrialists and urban water consumers. This broader regulatory focus may well be unwelcome and it should come as no surprise that various hydrological arguments are mounted to maintain the geographically and socially restricted focus on regulating water supply. If this paper has raised some doubts about these arguments, it will have served its purpose well.

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[22] The study by Fox et al., (1995) for example, though framed within the broad discourse of forest loss, demonstrates that although there had been a significant decline in dense forest between 1954 and 1976 (76 to 57 per cent) between 1976 and 1989 *there was no further significant decline* (and it is also not clear how long before 1976 the decline halted) despite the arrival of a new group of immigrants and a 50 per cent increase in population density on cleared land during the latter period (Fox et al., 1995). Indeed if the categories of dense forest, sparse forest, plantation, fallow and tea are combined to give an estimate of the total non-actively-cultivated area the decline from 1954 to 1976 was from 90 per cent to 88 per cent with no further decline between 1976 and 1983 (Fox et al., 1995).

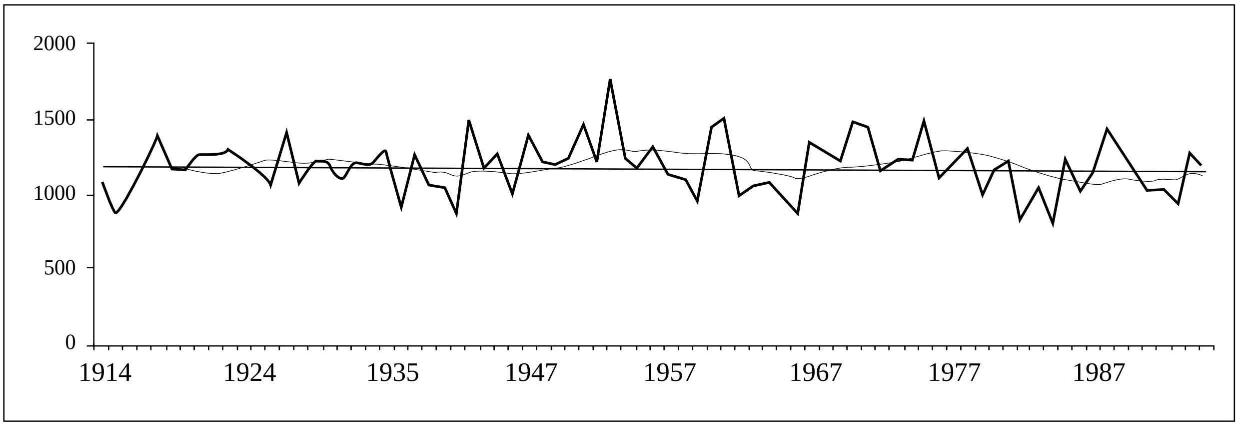

Figure 8a. Annual precipitation (millimetres) with long-term trend and 10-year moving average in Chiang Mai. **Source:** Royal Irrigation Department

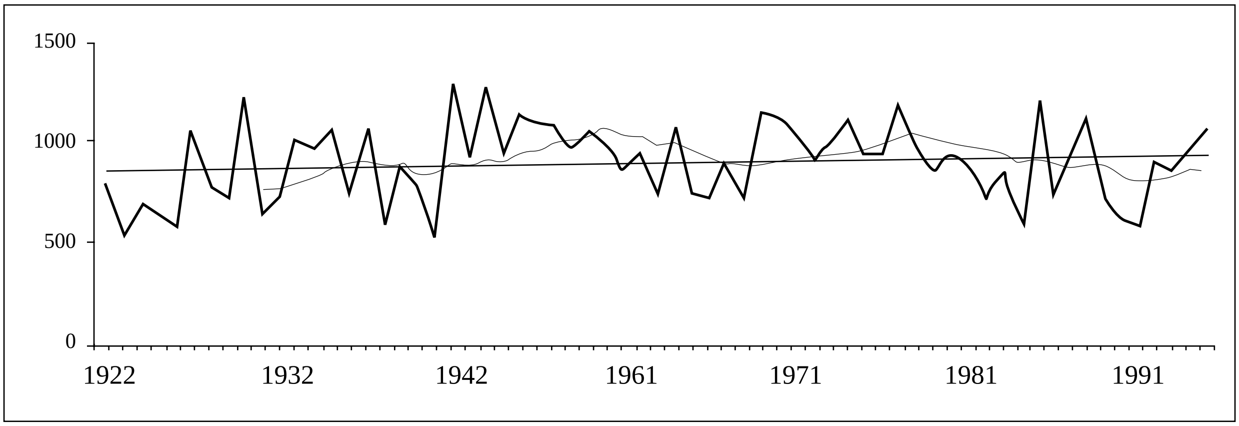

Figure 8b. Annual precipitation (millimetres) with long-term trend and 10-year moving average in Chom Thong. **Source:** Royal Irrigation Department

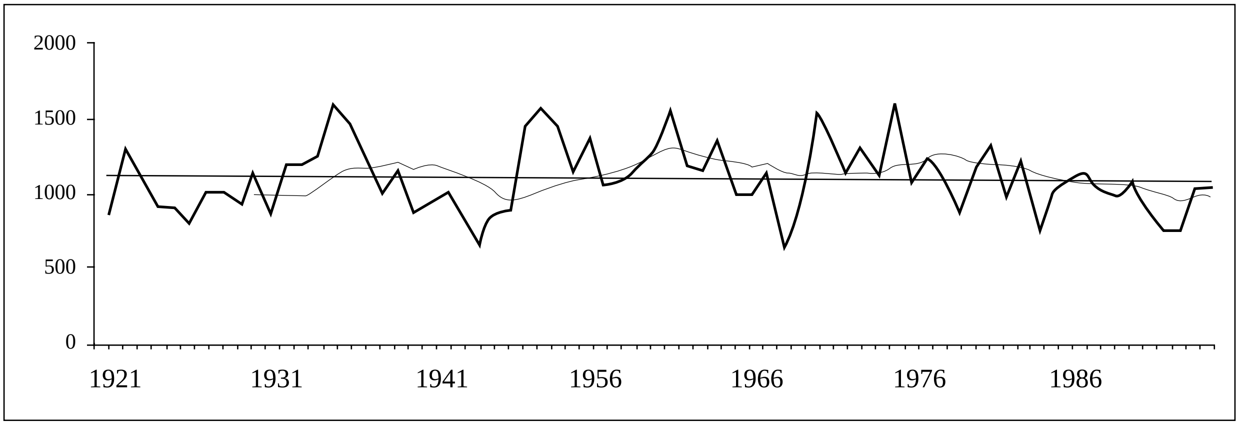

Figure 8c. Annual precipitation (millimetres) with long-term trend and 10-year moving average in Doi Saket. **Source:** Royal Irrigation Department

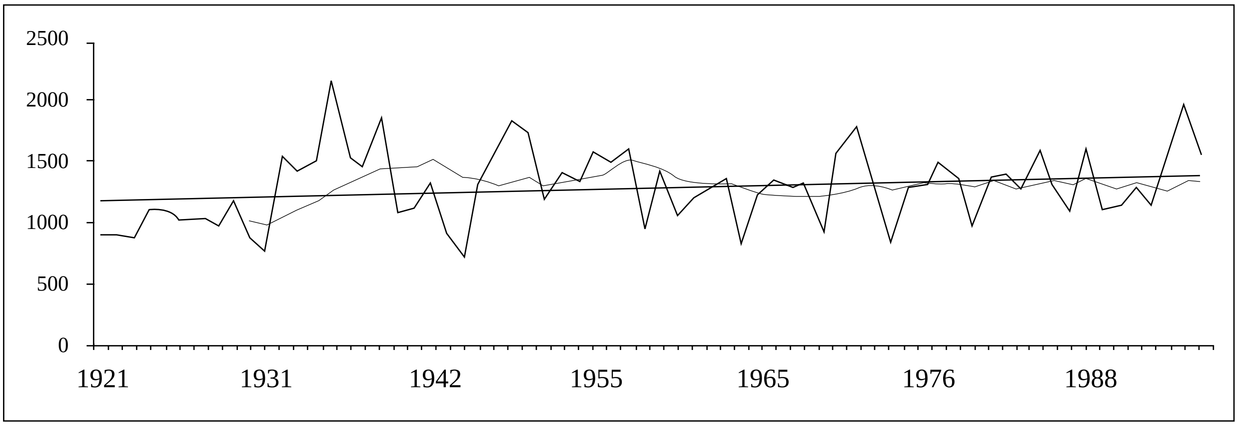

Figure 8d. Annual precipitation (millimetres) with long-term trend and 10-year moving average in Fang. **Source:** Royal Irrigation Department

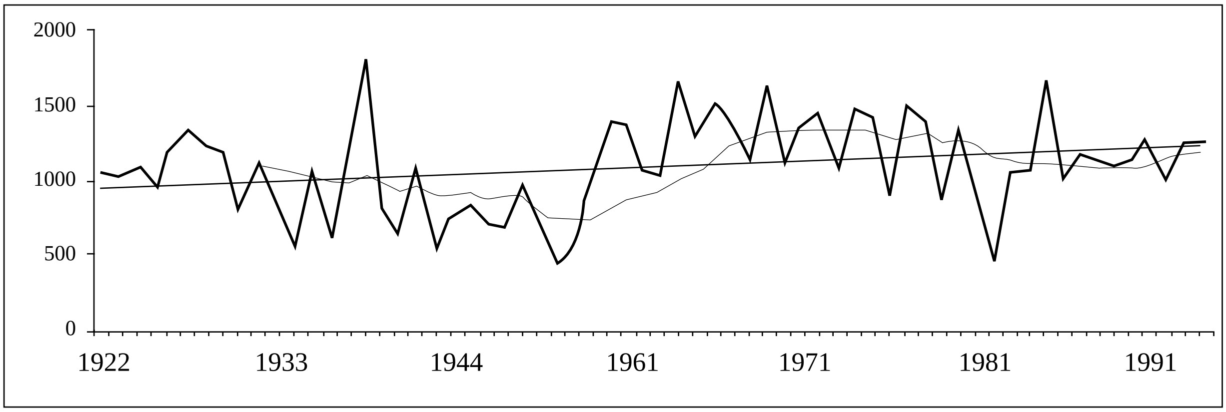

Figure 8e. Annual precipitation (millimetres) with long-term trend and 10-year moving average in Khun Yuam. **Source:** Royal Irrigation Department

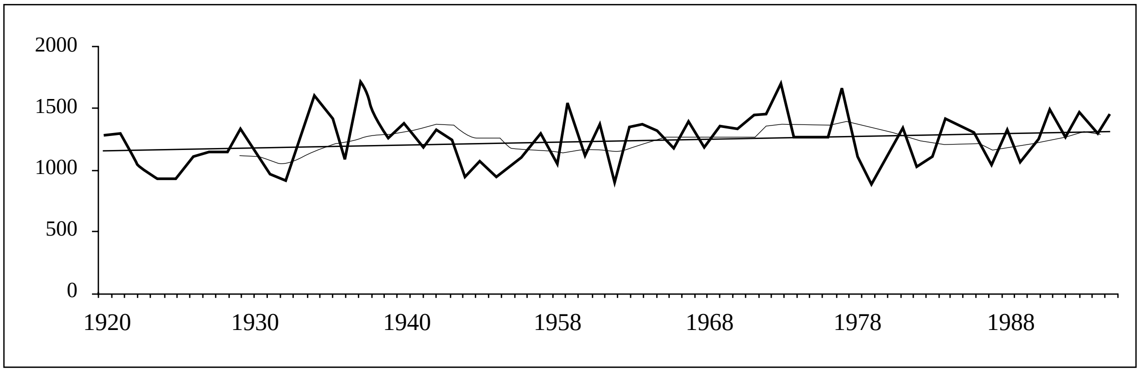

Figure 8f. Annual precipitation (millimetres) with long-term trend and 10-year moving average in Mae Hong Son. **Source:** Royal Irrigation Department

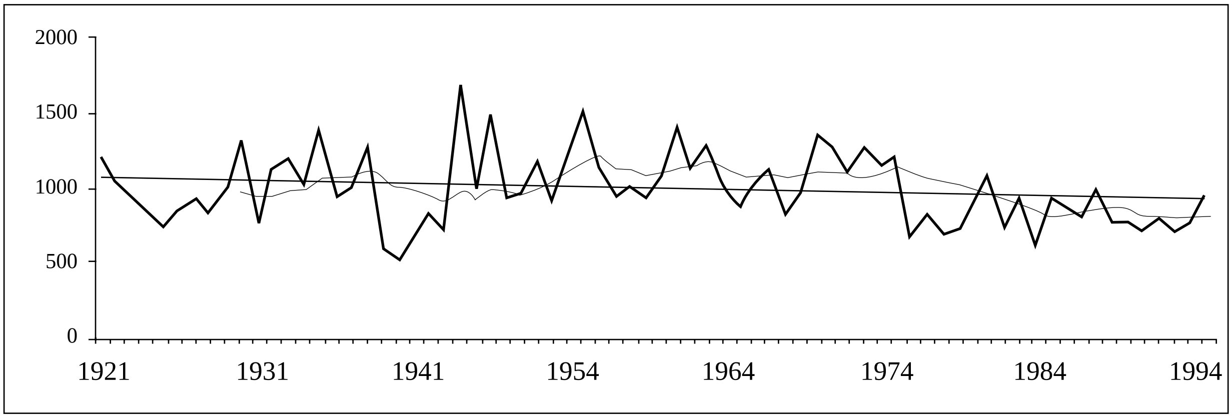

Figure 8g. Annual precipitation (millimetres) with long-term trend and 10-year moving average in Mae Rim.
Source: Royal Irrigation Department

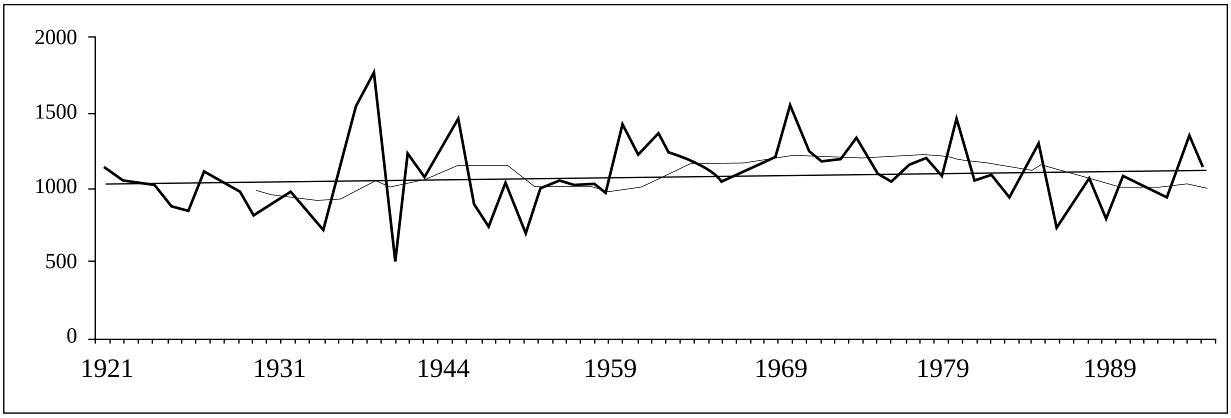

Figure 8h. Annual precipitation (millimetres) with long-term trend and 10-year moving average in Mae Sariang.
Source: Royal Irrigation Department

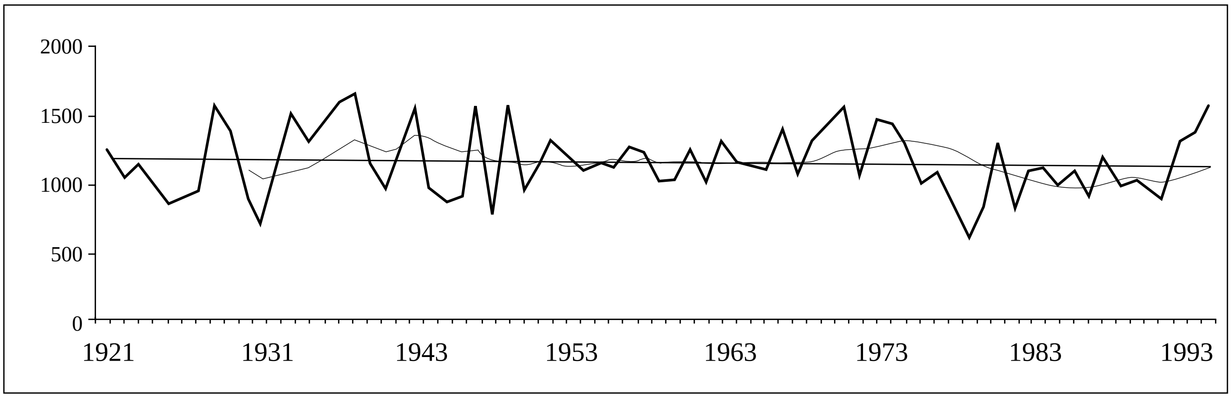

Figure 8i. Annual precipitation (millimetres) with long-term trend and 10-year moving average in Mae Taeng.
Source: Royal Irrigation Department

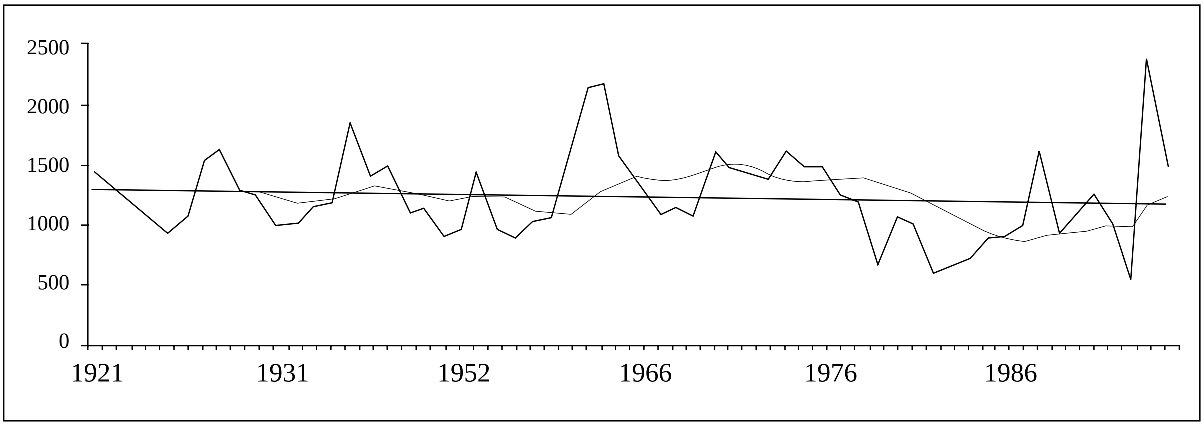

Figure 8j. Annual precipitation (millimetres) with long-term trend and 10-year moving average in Samoeng. **Source:** Royal Irrigation Department

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