The Off-site Effect of Soil Erosion: A Case Study of the Mae Thang Reservoir in Northern Thailand

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Abstract

The Management of Soil Erosion Consortium (MSEC) initiated a catchment-scale study on soil erosion management in six countries in Asia, namely, Indonesia, Laos, Nepal, the Philippines, Thailand, and Vietnam. In Thailand, the study evaluates soil erosion in a small catchment within the Mae Thang Watershed through detailed measurement at the micro catchment scale and at a larger scale, through quantifying sediment accumulation in the Mae Thang Reservoir.

Four sub-catchments were delineated in the 93 ha catchment and equipped for hydrology and soil erosion studies. Rainfall, runoff, and erosion data were collected for each sub-catchment and computed to obtain yearly means. The change in land use was assessed from field surveys in the experimental catchment and from satellite images for the whole watershed. The amount of accumulated sediments was determined by calculating the difference between the designed water storage volume of the reservoir and the storage volume obtained from a bathymetric survey undertaken in June 2002.

Observations in 2001 and 2002 indicated an annual sediment yield of as high as 26 t $ha^{-1}year^{-1}$. Variation in sediment yields among the different sub-catchments was attributed to land use and rainfall characteristics between years. Soil erosion calculated from the larger Mae Thang Watershed by determining the sedimentation rate in the Mae Thang Reservoir showed a much higher soil loss of 51 t $ha^{-1} year^{-1}$. This rate of sediment discharge is significantly higher than the design estimate of 1.45 t ha^{-1} $year^{-1}$ and a reservoir life span of over 100 years. Notwithstanding this, the estimated sediment discharged into the Mae Thang Reservoir is similar to that estimated by Inthasothi et al. *(2000) using the USLE. Moreover, the study has shown a methodology which can further be refined to evaluate reservoir sedimentation and the off-site effect of soil erosion.*

Introduction

In late 1998, the Management of Soil Erosion Consortium (MSEC) initiated soil erosion management studies at a catchment scale in six countries in Asia, namely, Indonesia, Laos, Nepal, the Philippines, Thailand, and Vietnam. One objective of the project is to quantify and evaluate the biophysical, environmental, and socio-economic effects of soil erosion, both on- and off-site (Maglinao *et al.*, 2001). In addition to decreased on-site productivity, it is recognized

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that soil erosion leads to off-site consequences including flooding, decreases in groundwater recharge, and sedimentation and pollution of rivers and reservoirs by nutrients and pesticides. The sedimentation of reservoirs also reduces their life and irrigated service areas (Chanson and James, 1998).

In Thailand, the MSEC study site is located within the Mae Thang Watershed in Phrae Province, in the northern part of the country (Figure 1). The watershed covers an area of approximately 121 km^2 and drains to the Mae Thang Reservoir constructed downstream (Figure 2). Construction of the dam was started in 1987 and completed in 1995. Selected specifications and characteristics of the Mae Thang dam and reservoir are presented in Table 1.

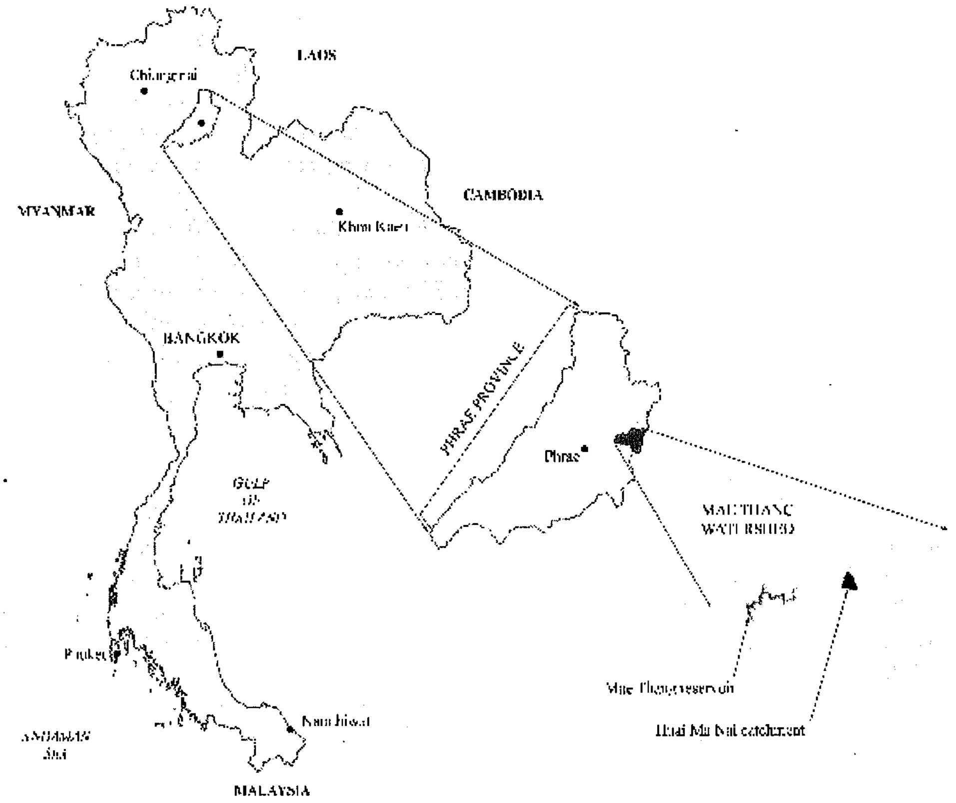


Figure 1. Location of the MSEC study site in Thailand

The Mae Thang Reservoir is expected to provide irrigation to about 3,520 ha of land, create a new recreation place, and provide a new ecological niche for fish production. Based on an annual sedimentation load of 17,585 t, in this respect the reservoir could be effective for more than 100 years (Royal Irrigation Department, 1996). This rate of sedimentation would result in the reduction in the active storage volume of the reservoir by about only 2.2 percent over 50 years and 4.4 percent over 100 years of operation. The life span of the reservoir and its service area are therefore not expected to be significantly affected.

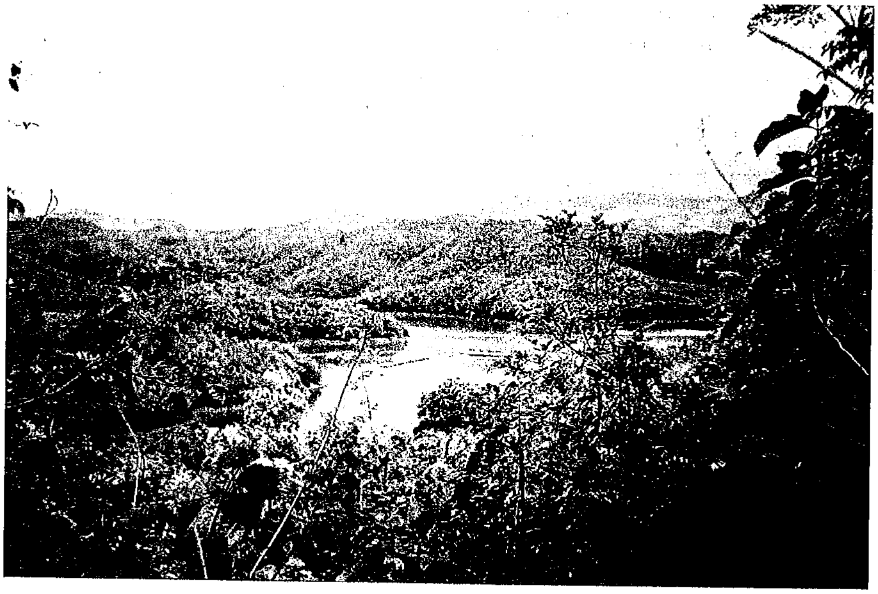


Figure 2. Overview of Mae Thang Watershed and Reservoir

Table 1. Selective specifications and characteristics of the Mae Thang dam and reservoir

Attribute	Value
Height (m)	46
Length (m)	225
Crest width (m)	9
Length of base (m)	190
Dam crest elevation (m above sea level)	255
Highest water level (m above sea level)	254
Storage level (m above sea level)	251
Volume of water at the highest level (m^3)	37 x 10^6
Volume of water at storage level (m^3)	32 x 10^6
Volume of water at the lower level (m^3)	1.2 x 10^6
Peak discharge (m^3 s^{-1})	310
Spillway (m above sea level)	251
Watershed area (km^2)	120
Annual average rainfall (mm)	1,377
Annual average discharge (m^3)	36.28 10^6
Reservoir area at the storage level (ha)	202
Reservoir area at the maximum level (ha)	220
Estimated sediment volume in 50 years (m^3)	1.22 10^3

However, with the growing problem of soil erosion as a result of rapid land use change in the watershed, this expectation may not be realized. In the past, the area used to be covered with mixed deciduous forest and teak. Now, most of the forests have been converted to intense cultivation. From 1995 to 2002, there was a decrease in the forest area from 87 to 51 percent and an increase in the area planted to annual crops (rice, maize, soybean, mung bean) from 11 to 34 percent (Table 2). Based on a study of 11 reservoirs in northeast Thailand, Lorsirirat and Tangtham (1996) showed that a 10 percent conversion of the forest to conventional cropping area can result in a 4 to 5 percent increase in annual sedimentation.

Table 2. Estimated land use of the Mae Thang Watershed

Land use (%)	1995	2002
Reservoir	1.15	1.15
Hill evergreen forest	-	11.56
Bare/open space	-	3.08
Disturbed forest	44.20	7.74
Mixed crops	-	0.78
Dry evergreen forest	-	1.88
Orchard	0.50	0.04
Mixed deciduous forest and bamboo	32.75	21.21
Evergreen forest	9.90	9.05
Shadows	-	3.56
Sparse vegetation on bare mountain	-	5.57
Crops(rice/maize/soybean in1995 and soybean/mung bean in 2002)	11.5	33.98
Total	**100.0**	**100.0**

The potential soil erosion estimated for the study site is as high as 50 t $ha^{-1}year^{-1}$ (Inthasothi *et al.* 2000). It is therefore necessary that soil erosion in the upper catchments is addressed in order to reduce the negative off-site impacts downstream. This study evaluates soil erosion in a small catchment within the Mae Thang Watershed and gives initial estimates of the total erosion based on the amount of sediment accumulation in the Mae Thang Reservoir.

Methodology

The Experimental Site

The Huay Yai Catchment, a 93.2 ha area, was selected as the experimental site for the study. It is located in the central part of the Mae Thang Watershed where more intensive agriculture is practiced. Farmers cultivating in the area live in villages outside of the catchment. The dominant farming system practiced is slash and burn with the crops in rotation being soybean, mung bean, and maize, but there are also some fruit trees, i.e. mango, tamarind, and jackfruit. New agricultural techniques are being introduced to decrease erosion and these include crop diversification and minimum tillage. These techniques allow for more stable and permanent farming systems with longer periods between slash-and-burn activities.

Evaluation of Soil Erosion

Four smaller sub-catchments were further delineated and equipped (Figure 3). Weirs and sediment traps were constructed at the outlet of each sub-catchment and automatic water level recorders, water samplers, and a weather station were also installed (Figure 4). Eleven manual rain gauges were distributed at appropriate locations within the catchment.

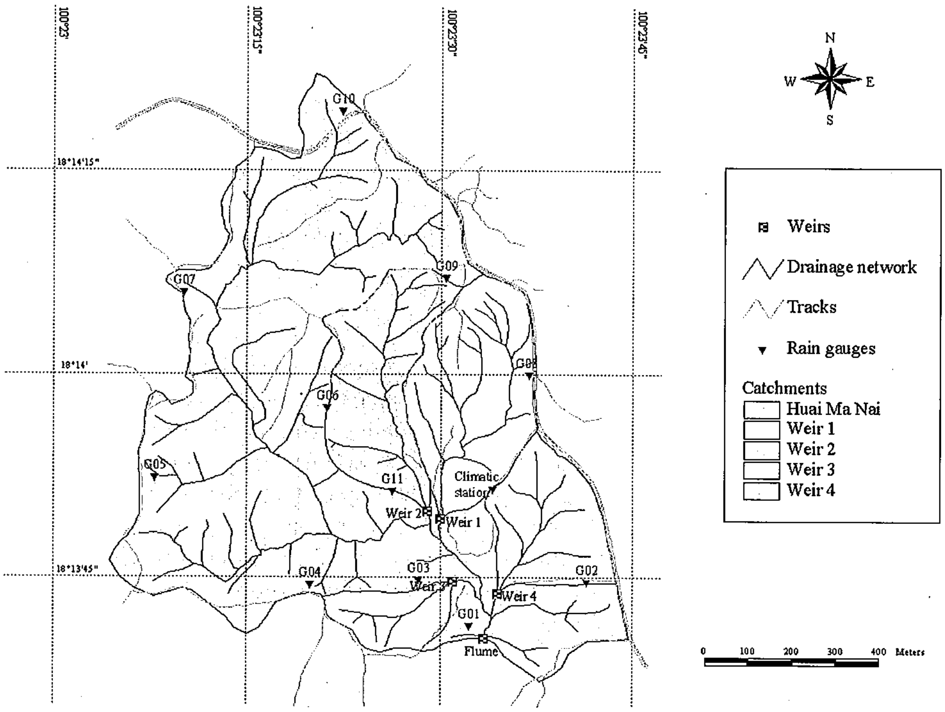


Figure 3. Different sub-catchments and the location of measuring structures at Huai Ma Nai

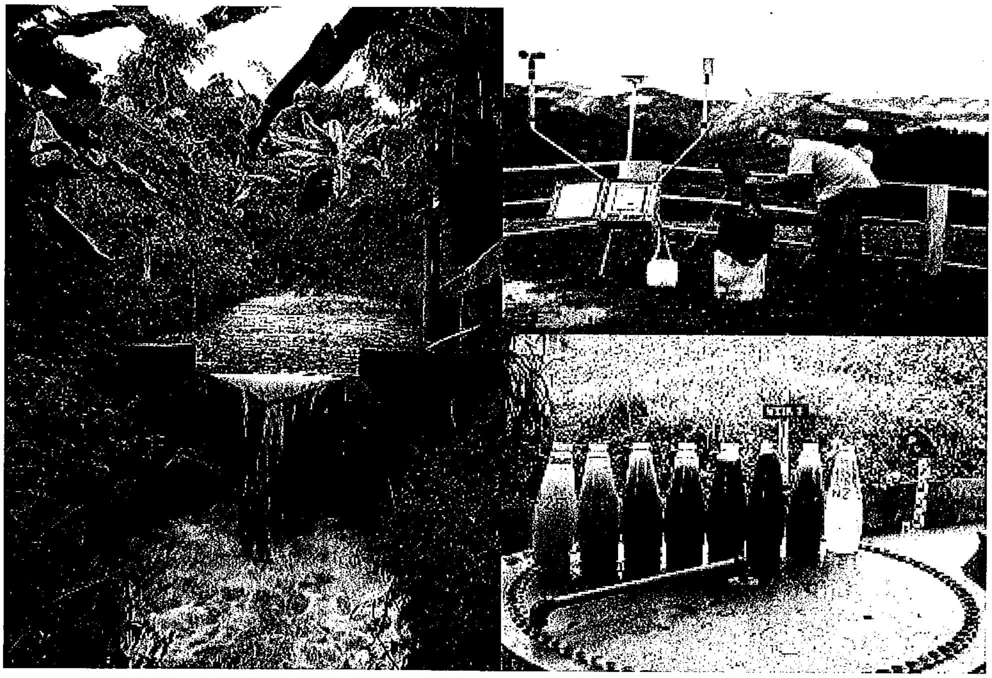


Figure 4. Sediment traps, automatic water sampler, and weather station installed in the catchment

Runoff and erosion data were collected at the outlet of each sub-catchment, both manually, using staff gauges and automatically, using the automatic water level recorders. Water level in the weirs was automatically recorded at a time step of three minutes. Water samples were collected during the main rainfall events to assess the sediment concentration and the amount of suspended sediments. Bedload, i.e. the sediment trapped in the weirs, was collected and weighed after each main rainfall event. Rainfall, runoff, and sediment yield data were computed to obtain yearly means. The change in land use was assessed from field surveys in the experimental catchment and from satellite images for the whole watershed.

Sedimentation in the Reservoir

The amount of sediment that had accumulated in the reservoir since the construction of the dam was determined by comparing the topographic map of the site before the reservoir was filled and the bathymetric map prepared by conducting a survey before the rainy season of June 2002. Topographic data before the filling of the reservoir were provided by the Royal Irrigation Department. Bathymetric mapping of the bottom of the reservoir was undertaken with the aid of a Global Positioning System (GPS, Garmin III+) and an echo sounder (Eagle III Sonar). Data gathering was achieved throughout the reservoir by using a fisherman's boat (Figure 5). The maps were prepared using the Surfer program (Bindford and Sloan, 2000). The reservoir bottom configuration is presented in Figure 6.

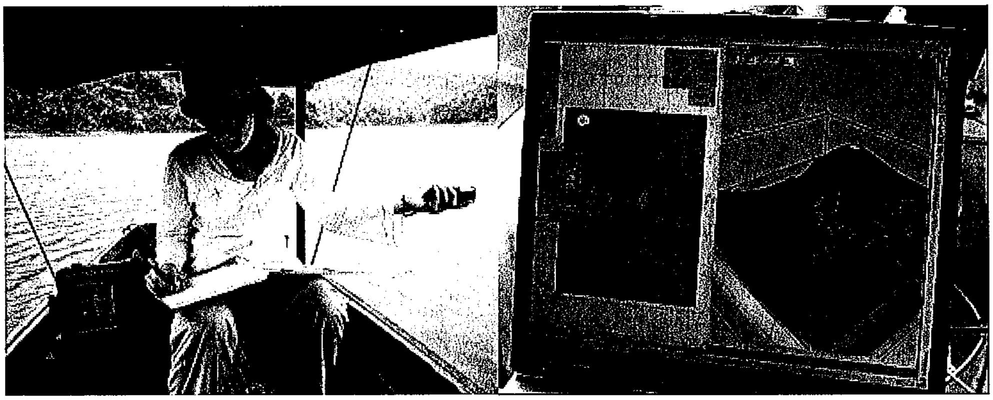


Figure 5. Bathymetric survey of the reservoir (left side) and result of echo sounder with Max Sea software

An echo sounder gives the depth of the water at a specific location recorded by the GPS. It also provides an estimate of the thickness of the sediments at the bottom. Using the Surfer program, the difference between the designed storage water volume of the reservoir and the volume of water calculated at the time of the survey represents the volume of sediments that has accumulated in the reservoir seven years after the start of its operation. Erosion from the whole catchment was then estimated from the average density of the sediments (1.4 t m^{-3}) measured in different locations of the catchment.

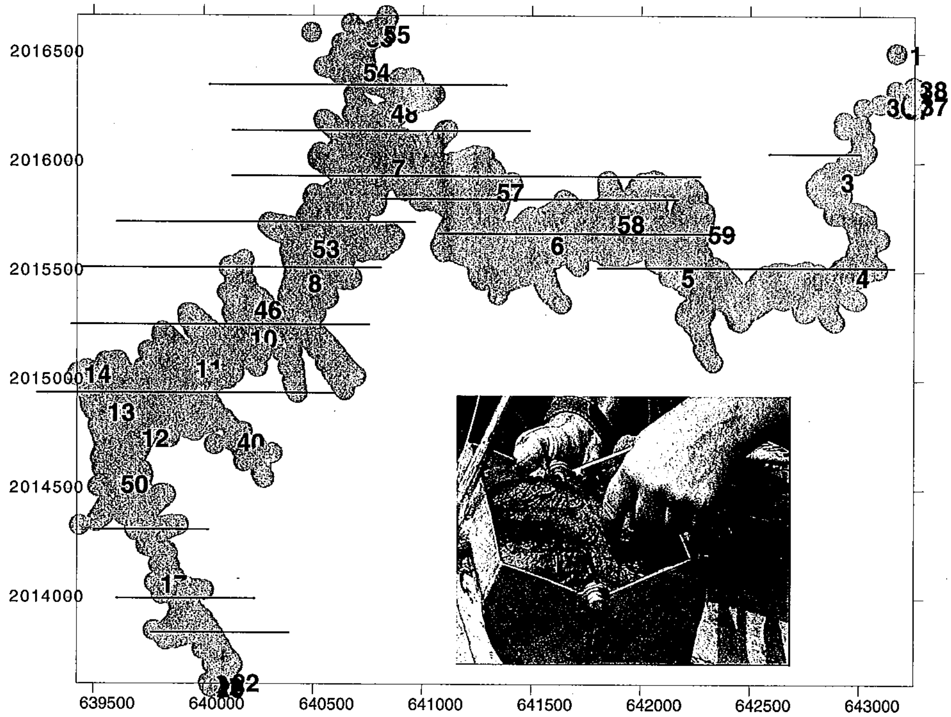


Figure 6. Reservoir configuration showing the location of transects and sediment sampling sites (coordinates in UTM)

Results and Discussion

Soil Erosion in the Small Catchment

Table 3 shows the land use, rainfall, runoff, and sediment yield data from the whole catchment and the different sub-catchments in 2001 and 2002. The first results showed a soil loss of as high as 26 t ha^{-1} $year^{-1}$. Annual sediment yields from the different sub-catchments were higher in 2001 than in 2002 except in W3 which had no yield in 2001 but yielded the most in 2002. The higher sediment yields in W1, W2, and W4 in 2001 could be attributed to the characteristics of the rainfall that occurred over the years. In 2002, total rainfall was lower and more widely distributed. In 2001, there was a strong event which accounted for more than 70 percent of the total runoff (Figure 7).

The higher sediment yield of W3 in 2002 compared to 2001 can be explained by the change in land use. In 2001, this sub-catchment had more than 90 percent tamarind and shrubs. Most of the tamarind trees were cut down in 2002 and soybean was planted, increasing the area planted to annual crops from 3 to 41 percent. In both years, a relatively higher rate of erosion was observed in W2 and W4, which are both predominantly cultivated to annual crops of soybean and mung bean. The above results indicate that soil loss is very much influenced by land use and rainfall characteristics.

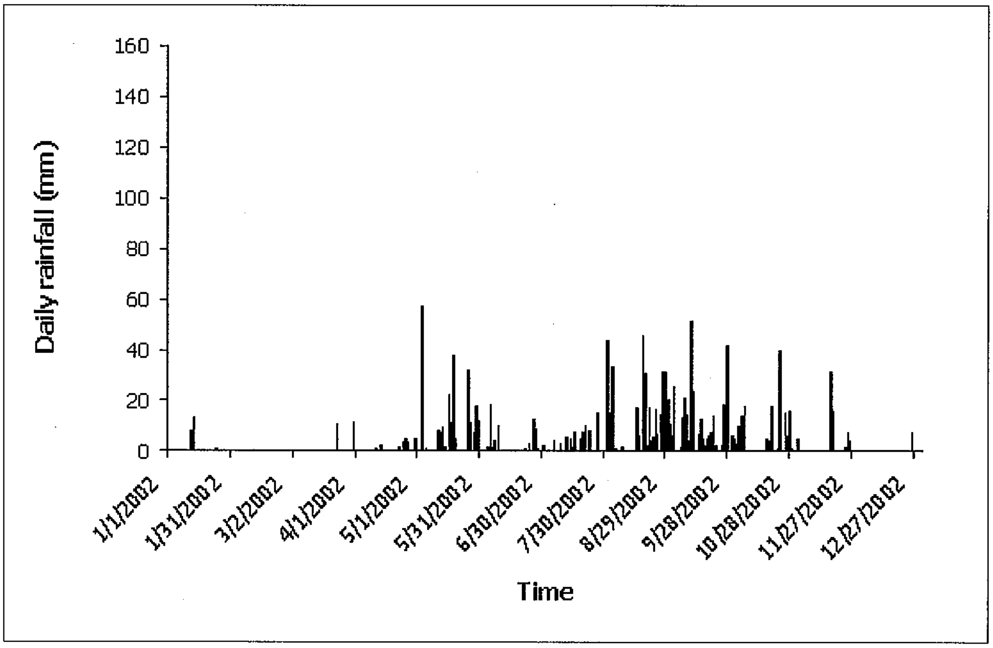
Table 3. Land use, rainfall, runoff, and sediment yield measured in the MSEC catchment and sub-catchments in 2001 and 2002

	2001					2002				
	W1	**W2**	**W3**	**W4**	**Whole**	**W1**	**W2**	**W3**	**W4**	**Whole**
Sub-catchment size (ha)	11.8	9.6	3.2	7.1	93.2	11.8	9.6	3.2	7.1	93.2
Land use (%)										
Annual crops	30	54	3	60	59	46	68	41	71	63
Fallow	10	10	2	10	4	7	1	0	8	3
Forest	30	26	3	15	23	11	26	0	15	23
Orchard	30	10	92	15	14	35	5	59	6	10
Rainfall (mm)					1,385					1,321
Runoff (x 10^3 m^3)	68	54	2	24	486	65	58	7	24	306
Runoff coefficient (%)	42	40	5	25	37	47	52	20	28	28
Sediment yield (t ha^{-1})										
Bedload	1.2	16.2	0.0	4.4		0.1	0.9	1.5	1.2	
Suspended load	2.3	5.2	0.0	4.2	2.6	0.7	0.9	2.3	1.9	2.7
Total	5.5	26.4	0.0	8.2		0.8	1.8	3.8	3.1	

A similar observation on the effect of land use on sediment yield was made by Chaplot *et al.* (2002). Using statistical models and the data from five MSEC countries, they found that soil erosion is heavily influenced by the rainfall characteristics and the percentage area of the catchment cultivated to annual crops.

Reservoir Siltation and Soil Erosion

Surfer diagrams of the bottom of the Mae Thang Reservoir before its operation in 1995 and seven years after are presented in Figure 8. The storage volume of the reservoir as designed was calculated to be 31 mcm. A storage volume of 27.85 mcm was calculated at the time of the bathymetric survey in 2002. Based on these figures, there was a loss of 10 percent in the storage volume and this could represent the volume of sediments that had accumulated at the bottom. Further calculations resulted in an average erosion rate in the Mae Thang Watershed of 51 t ha^{-1} $year^{-1}$. With this rate of erosion and sedimentation, the life of the reservoir would not be more than 70 years. The rate may be an overestimation but the value is close to that presented by Inthasothi *et al.* (2000) (Table 4).



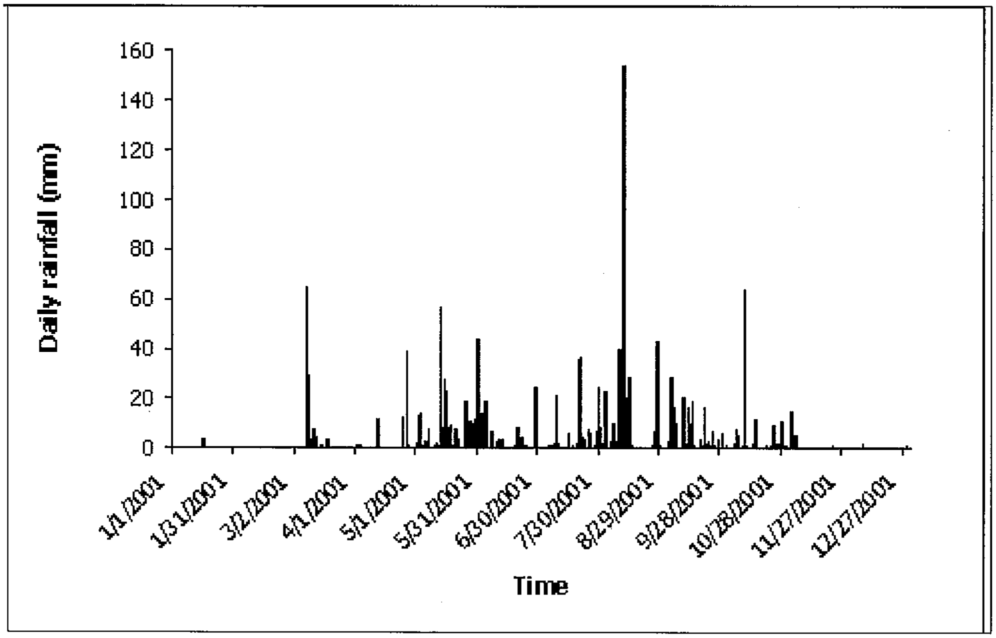


Figure 7. Daily rainfall in the catchment during 2001 (a) and 2002 (b)

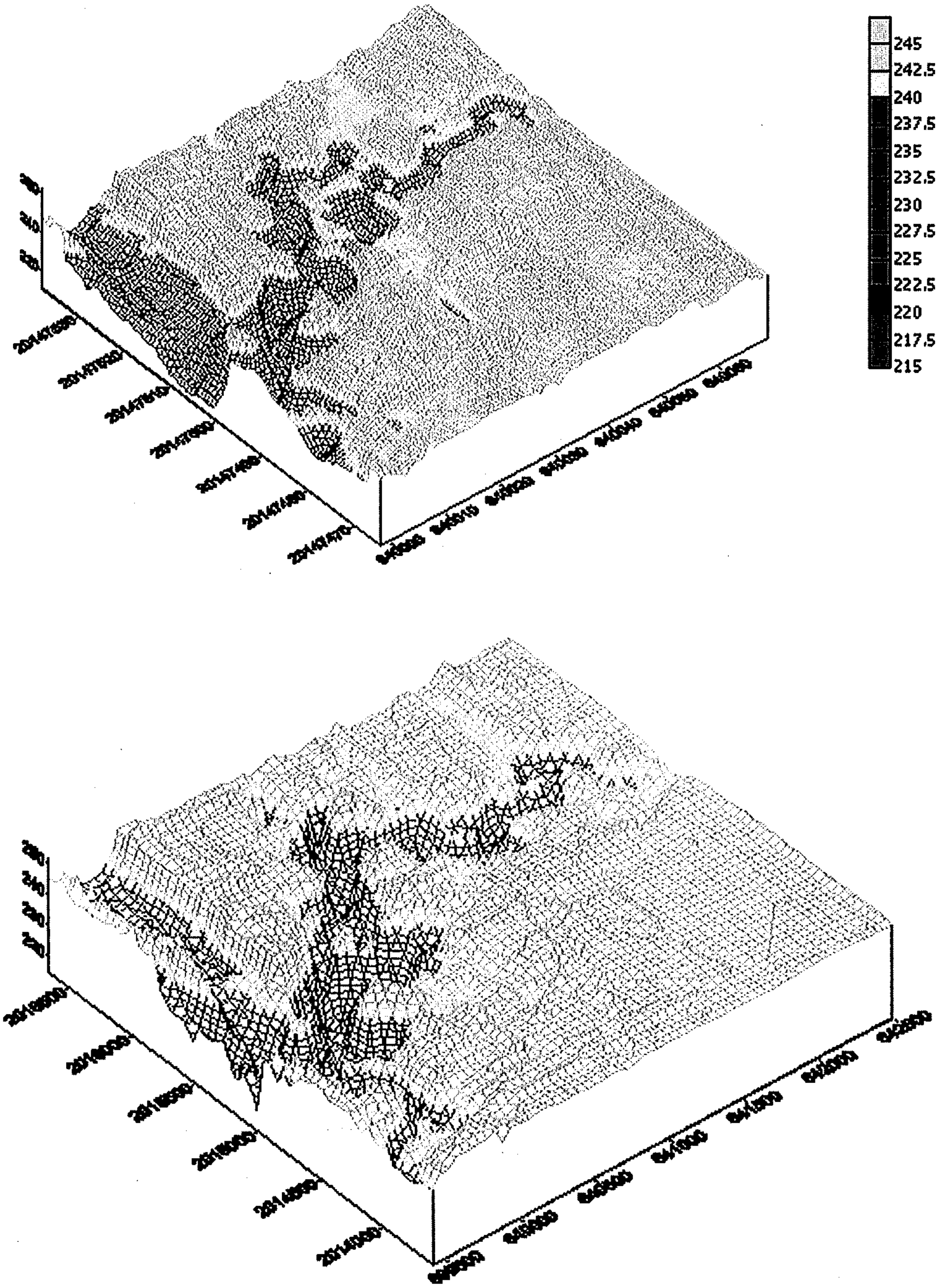


Figure 8. Surfer diagram of the reservoir bottom in 1995 (above) and in 2002 (below)

Table 4. Estimated erosion at different scale studies

	Royal Irrigation Department	Inthasothi *et al.* 2000	Survey June 2002 (7 years	MSEC catchment (93.2 ha)
Average soil loss (t ha^{-1} yr^{-1})	1.45	50	51.2	26.4
At the catchment scale (t yr^{-1})	17 585	605 000	620 000	321 860
Water storage volume lost (m^3 yr^{-1})	13 400	432 142	442 857	229 900
Expected life span (yr)	>100	72	70	>100

Surface area of the Mae Thang Watershed = 12,100 ha
Reservoir storage volume = 31,000,000 m^3
Sediment density = 1.4 t m^{-3}

Conclusion

In northern Thailand, the study evaluates soil erosion in a small catchment within the Mae Thang Watershed by detailed measurements at the micro catchment scale and on a larger scale, by determining the sediment accumulation in the Mae Thang Reservoir. Observations in 2001 and 2002 show an annual sediment yield of as high as 26 t $ha^{-1}year^{-1}$. Variation in sediment yields among the different sub-catchments can be attributed to land use and to rainfall characteristics between years.

Soil erosion calculated from the larger Mae Thang Watershed by determining the sedimentation rate in the Mae Thang Reservoir showed a more serious situation. A soil loss of 51 t ha^{-1} $year^{-1}$ will fill the dam with sediments in about 70 years. This is very high compared with the earlier estimate of 1.45 t ha^{-1} $year^{-1}$ and a reservoir life span of over 100 years. Nevertheless, this figure is close to what has been estimated by Inthasothi *et al.* (2000) using the Universal Soil Loss Equation (USLE). Moreover, the study has shown a methodology which can further be refined to evaluate reservoir sedimentation. Chemical analysis of the sediments will likewise be useful in determining the other off-site effects of soil erosion.

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