Catchment Approach to Combating Soil Erosion in Thailand

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Introduction

Erosion is a major cause of soil degradation in the world. It is a natural phenomena but inappropriate land use can significantly accelerate the impacts of erosion processes. It decreases arable surface, reduce soil fertility, cause harmful effects like soil and water pollution, the silting of reservoirs and irrigated fields. Subject to threshold, erosion varies considerably from one farming system to another. Water erosion (sheet and gully erosion), tillage and wind erosion are the main types of erosion (Valentin, 2001). In the humid and semi-humid tropics, rain and tillage erosion are the most important, causing decreases in crop yields and the loss of valuable arable land. In Southeast Asia, erosion rates range from 2 to 54 t ha^{-1} yr^{-1} according to land use and farming practices.

Understanding and modelling rainfall and tillage erosion is very important in all developing countries. This is due to the need to ensure the sustainability of the agricultural system. Rainfall induced soil erosion has several impacts. These include sheet erosion, linear cutting, mass movement and chemical degradation (Zante *et al*, 2003). Linear cutting is often presented as the most significant source of erosion.

In Thailand, MSEC has analysed the emergence and impacts of rainfall erosion in a small catchment. The main objective is to develop land management systems to better control erosion and increase income of farmers by evaluating both the biophysical and socioeconomic dynamics in the study catchment. Two forms of soil erosion, namely, rainfall and tillage erosion are investigated. Further, the study demonstrated how rainfall and tillage erosion results in the emergence and development of gullies. Investigations into the typology and the functioning of gullies can provide solutions that allow the adaptation of agricultural techniques.

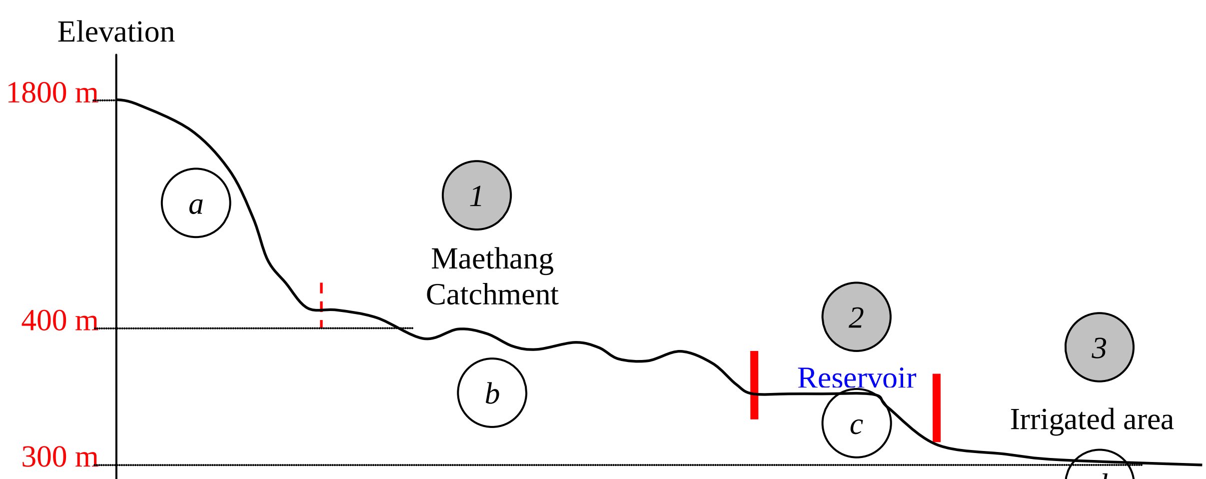
This report presents the accomplishments in 2003 and related results of the previous years.

Materials and Methods

Study Site

The study catchment is located in the province of Phrae in the north of Thailand, about 550 km. from Bangkok (Figure 1). It is not only the large plains of the province that are used for agricultural activity, but also the mountains (altitudes go from 250 to 1630 m), which are cleared and then used for agriculture. This is perfectly illustrated by the agricultural communities within the Mae Thang subwatershed, which can be sub-divided into three distinct zones (Figure 2).

Figure 1. Location of Mae Thang catchment (100km^2) and Huai Ma Nai catchment (93ha) in Northern Thailand



a. Forest with subsistence crops + cabbage & corn
b. Cash crop: corn, soybean and mungbean
c. Fish farming and recreation area
d. Rice during rainy season, mungbean in dry season

Figure 2. Principal areas of the large catchment of Mae Thang.

Zone 1, an upstream area called Mae Thang catchment occupies a surface area of 100

km^2 and can be separated into two sections. Section 1 is the mountainous upstream area. It is populated by recently established ethnic groups known as the Hmong and Malbri, who are increasingly subjected to Thai government influences. Traditionally, the Hmong and Malbri had until now a very small impact on the catchment. However, this is now changing. Actually there is village policy of large scale deforestation combined with the systematic use of inputs such as pesticides and manure. This is however, beyond the scope of the research activities presented in this report. Section 2 consists of the downstream area and is utilized by Thai Farmers (as opposed to Hmong and Malbri ethnic groups) for cash crops. Section 2 was completely deforested for crops including corn, soybean and mungbean. The use of manure and pesticides is systematic. Land management has a very strong impact on soil loss (rotations, tillage, crop managements).

Zone 2, consists of the Maethang reservoir which collects the entire flow of Mae Thang catchment. Runoff entering the reservoir contains a very high suspended load during the rainy season and pesticides and other residues from manures applied as soil amendments. The reservoir was constructed to contain water to be used for the irrigated agriculture downstream. However, it is also used for fish farming and recreation.

Zone 3, comprises the irrigated area downstream of the reservoir. The main crop is subsistence rice during the rainy season and mungbean during the dry season. Mungbean has beneficial impacts on the soil, allowing good nitrogen and phosphorus fixing (El-Hafiez Abl *et. al.*, 2002).

Due to the complex and interrelated characteristics of the Mae Thang catchment, the Management of Soil Erosion Consortium (MSEC) undertakes a project in this area to undertake research on soil erosion.

During 2003, the studies were done on three main areas:

1. Erosion in small catchment (93 ha) – Hydrological survey and soil losses.
2. Socio economic survey at larger watershed in irrigated area (Mae Thang Catchment $100km^2$)
3. Water quality and bathymetric survey in the reservoir.

Erosion in Small Catchment

The Huai Ma Nai catchment within the Mae Thang subwatershed has an area of 93 ha. Mae Thang sub-watershed used to be covered by mixed deciduous forest but a major portion is now degraded and used to grow many crops. Field crops such as soybean and mungbean are commonly grown with fruit trees planted in patches. In the lowland, the cropping sequence is mungbean/paddy rice/ soybean or corn. Farmers usually apply chemical fertilizer. The more detailed socioeconomic and biophysical characterization of the catchment has been described in earlier reports (Inthasothi *et al*, 2002).

Rainfall and runoff

The impact of rainfall erosion in the Huai Ma Nai catchment is very important with each rainy season resulting in significant soil loss. A comprehensive detailed

assessment of rainfall patterns within Huai Ma Nai catchment permits an evaluation of the multiple direct and indirect consequences of processes resulting in soil degradation.

Several methods are used to generate the average depth of rainfall over a given area. The method adopted in the study due to its simplicity, easily obtainable information requirements and positive results is the Thiessen Polygon method (Thiessen, 1911).

During a flood, sediments are transported by runoff. The size of these sediments are more or less large and are classified as suspended particles in water and as bed load which are transported to and settled at runoff measurement stations. By using a specific device to collect sediments during rising of water, results on soil losses Huai Ma Nai catchment are obtained.

The Huai Ma Nai catchment covers an area of 100ha. Initially, turbidity of the runoff was measured and used to calculate the proportion of the soil loss from the Huai Ma Nai catchment. This was combined by measuring the bed load transported during each runoff event. The resultant research output can be extrapolated to predict soil erosion losses from the Mae Thang catchment.

Runoff from the Huai Ma Nai catchment is as described earlier, monitored by five measurement stations. The main important station is the flume located at the outlet from the Huai Ma Nai catchment. The Huai Ma Nai catchment is divided into several sub-catchments each of which is monitored and controlled by a weir at which runoff is measured. The sub-catchment specific stations are called W1 for the Huai Mee catchment, W2 for the Huai Ma catchment, W3 for the Huai Bong catchment and W4 for the Huai Tong catchment.

It is always necessary to collect samples during the period to peak discharge as this period is associated with high turbidity. Subsequently, samples must be collected during the period of peak discharge (plateau) and again as discharge decreases to normal levels. Around twenty-five to thirty samples were preserved for analysis.

For each significant runoff event, it is also necessary to collect the bed load in each station. By combining the suspended and bed load sample weights, an estimate of soil loss can be made. The runoff measurement stations and flume provide information concerning the volume of runoff exported from the Huai Ma Nai catchment and total sediment losses. Climate information obtained from in-field rain gauges provides exact rainfall data at a sub-catchment level. By combining the above information, the portion of the rainfall lost as runoff and that infiltrating in the soil as well as soil losses (t.ha.yr^{-1}) can be determined.

Land use

Rainfall erosion is a direct result of raindrops impacting an exposed soil surface. Therefore, vegetative cover is a critical factor. Consequently, to undertake a detailed interpretation of runoff from each stream within the Huai Ma Nai catchment, it is necessary to have a detailed understanding of the land use.

Since 2001, a detailed analysis of land use within the Huai Ma Nai catchment has been done. This is essential to understand catchments dynamics. By analysing this information over several years the impact of vegetative cover as a means of soil protection can be identified. Initial results indicate that deforestation at Weir 3 (W3) and a change in crop type at Weir 2 (W2) from soybean to maize are very significant causes of increased soil loss.

Once complete, this work will allow the development of appropriate land use planning in terms of soil protection and cash cropping objectives. This provides a sustainable farming system.
A downstream impact of rainfall and tillage erosion is the significant sedimentation of Mae

Thang reservoir. It is estimated that 10% of the storage capacity of the reservoir has been lost in 8 years. In addition, sedimentation has resulted in a significant decline in water quality for downstream use.

Gully erosion

The main type of erosion in Mae Thang catchment is gully erosion which is a direct result of the deforestation process. Gullies dramatically alter the landscape and farmers must adapt their cultivation methods. What are the mechanisms of gully formation and what are the main causes of gully development? To answer the first question a detailed understanding of the typology of gullies is essential. As a result of this typology causes of gully development can be identified. One of the main problems associated with gullies is to understand their mains impacts. Once understood, various solutions for limiting gully formation and improving land management can be developed.

Gullies are formed due to the negative impacts of intensive agriculture on runoff dynamics in previously forested upland systems (Peersman and Ohler, 1999). Some studies have been undertaken to further understand and model gully formation (Sidorchuk, 1999). These studies have focused on predicting gully formation according to a dynamic model or through the use of a static model based on the final morphology of the gully. In addition, several papers have investigated the global impact of gullies on soil erosion (Peter *et al*, 1997). In general, gully would have impacts on the sediment losses for the soils, and deposits downstream in the reservoir.

However, a simple gully typology based on slope characteristics and zoning within a micro-catchment has not yet been fully developed. Determining the functions and typology of gullies is important to understand gully development and its erosive function.

The gully selected for analysis at the beginning of the 2003 rainy season is located at the Huai Ma sub-catchment associated with W2 (Figure 3). Rain gauge No. 6 provides exact rainfall data for the Huai Ma sub-catchment. The gully is in the form of a Y with a tree structure at the end of the two branches. In the 2003 rainy season, soybean was cultivated on the upstream part and maize on the downstream part. During October 2002 to October 2003, 1,391 mm of rainfall was recorded. The gully selected had several advantages including

1 The gully is representative of the gullies observed within the catchment and occurs on an old deforested field (30 years old) associated with a double cropping rotation and both manual and mechanized tillage
2 The gully is active with discharge observed after each major rainfall event,
3 The gully is associated with little vegetation establishment at outlet zone,

4 The size of the gully allows the installation of the material,
5 The gully is easily accessible.

Figure 3. Gully monitored during the 2003 rainy season in Huai Ma Nai catchment.

Socioeconomic Survey

The study is based on the production system which describes the combination of different production components or sub-systems, the production activities' diversity and purposes, and the production activities' management (special and temporal distribution, workload allocated) (Figure 4). The production system is defined both at human scale, the village community, and at land scale, the village land. The household is used as basic unit of assessment of the production activities and distribution within the village community (Lestrelin, 2003). The purpose is to characterize the production activities with diverse variables:

- How they are organized between them;
- Where they are located;
- Workload allocated;
- How many people they mobilize;
- How much money they get, if it is a cash activity;
- What amount of money allocated for this activity;
- Tools used.

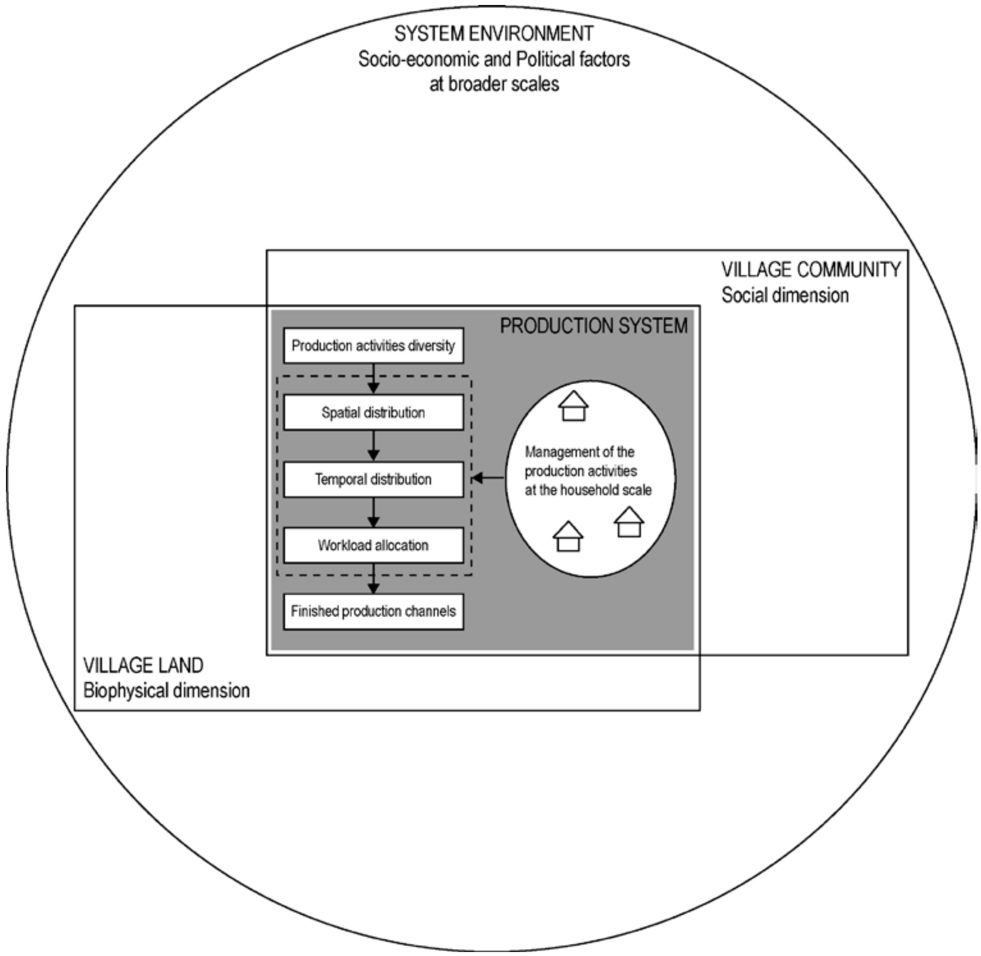


Figure 4. The production system showing the different levels interacting in the differentiation of the production systems (Lestrelin, 2003)

Most of these variables interact with each other. It will be important to know how these interactions happen and the consequent effects at the local level and extrapolated to the global level. If similar modifications emerge with the time in the production system, the reasons of these modifications are interesting to know and characterize. This change to new systems can have several influences on erosion and how to address it.

Scale of analysis

The study is based on a scale of analysis that goes from the global level to the local one. This allows the collection of different kinds of information as the same data would not be gathered from a national organization or at the village community. These information are useful to also cover the extent of the problems based on the influence of the global factors on the local scale.

Selection of the villages

Because a village is a production system in itself, several of them were selected. As the major concern is erosion and land management, the villages have to be linked hydrologically, representing the upstream-downstream continuum. This representation can describe the interaction between the activities in the upland which can cause erosion and affect the activities downstream.

Three villages were selected for the study. Ban Pong, with most of the residents cultivating in the small catchment of Huai Ma Nai represents the upper catchment. Representing the downstream area is the Ban Waieng village with 11 households producing fish in the Mae Thang reservoir. The discharge system of the watershed area of Huai Ma Nai runs to the Mae Thang reservoir. The village of Ban Huai Hung was the third village chosen because its residents do not have any activity in the upland and in the reservoir.

Development of the questionnaire

As mentioned earlier, the investigation is organized around the productive systems of the village community. To collect information on this subject, the questionnaire was based on the activities constituting the production system. Thus, the questionnaire was divided into six gropus of questions as follow:

1) General Information, which made it possible to characterize and differentiate the villages, identify the respondents and the focus of the survey.
2) Activity of production, which gives information on the type of activity carried out, when is the activity done, and the final product. The type of activity could be seasonal crop production, livestock raising, rice production, plantation crops, vegetable production, etc.
3) What is used to conduct the activity and obtain the final product. It is interesting to collect information on the way the product is obtained, chemicals used, etc. The answers can change with time because of global factor.
4) Distribution of this activity to get information about the field use for the activity, the site of the activity, area and number of plots used. The site could be in upper slope, lower slope, reservoir, etc.
5) Economic of production to know the inputs used, the products sold and the marketing channel.
6) Calendar of activities to know the organization of the productive activities and why they are organized as such.

Sampling and interview

Population samples were determined by the method of stratified sampling which consists of the subdivision of a heterogeneous population in sub-populations more homogeneous (mutually exclusive and collectively exhaustive). The households were primarily subdivided in groups, according to their land size. For the village with fields in the upland and the lowland, a second classification of the location of the field was done. It was planned to have 45 sample respondents from Ban Pong, 26 from Ban Waieng, and 27 from Ban Huai Hung. However, the final number was 20 from Ban Pong, 6 from Ban Waieng, and 15 from Ban Huai Hung. The number of samples from Ban Pong and Ban Huai Hung is sufficient, but the little information taken from Ban Waieng makes it difficult to make comparison with the two other villages.

Both direct interviews using the structured questionnaire and semi-direct interviews with open-ended questions were used. The questions were asked to get information relative to a time scale as follows:

- 2003 because is the year of realization of the investigation, to obtain recent information on the activities of the villagers.

- 2000 because it had appeared certain changes since the watershed area is studied by IWMI;
- 1990 to know the activities existing in the area before the realization of the reservoir.
- 1950 collect information on the past and high light dates of appearance of certain production activity because at this time normally, people don'y go yet in up land.

Construction of the data base and analysis

The tool used to build the data base was Microsoft Access because of its utility. MS Access is a basic relational format which allows a simple and fast treatment of the data under various formats (text, date, numerical...). Them text format for example can be treated in term of a number of occurrence (by carrying out a cross analysis of the attributes " type of activity " / " product use ", " cash " will be able to take value 35 because it appeared 35 times for the attribute " type of activity ", which is not possible with Excel.

Monitoring Dissolved Oxygen Depletion

Dissolved oxygen depletion in natural and artificial water reservoirs is a major environmental problem because of their importance to human settlement, in particular for irrigation, flood control, fishing and energy production. Critical conditions may arise when the dissolved oxygen concentration available to decompose organic matter falls below a minimum level ($[O_2] < 1$ mg.l^{-1}). Bacterially-mediated processes lead to the degradation of water quality through a cascade of redox reactions that involve NH_4^+ production, SO_4^{2-} / H_2S conversion or dissolved metal release from fine suspended matter. Several processes may account for oxygen depletion in freshwaters:

1. enhanced biological productivity resulting from high input of nutrients (eutrophication),
2. high organic matter supply generated by soil erosion and runoff in the drainage area
3. low water turnover

In-situ monitoring was performed using probes equipped with sensors that allow high resolution and low response time (<1 second) (Figure 5).

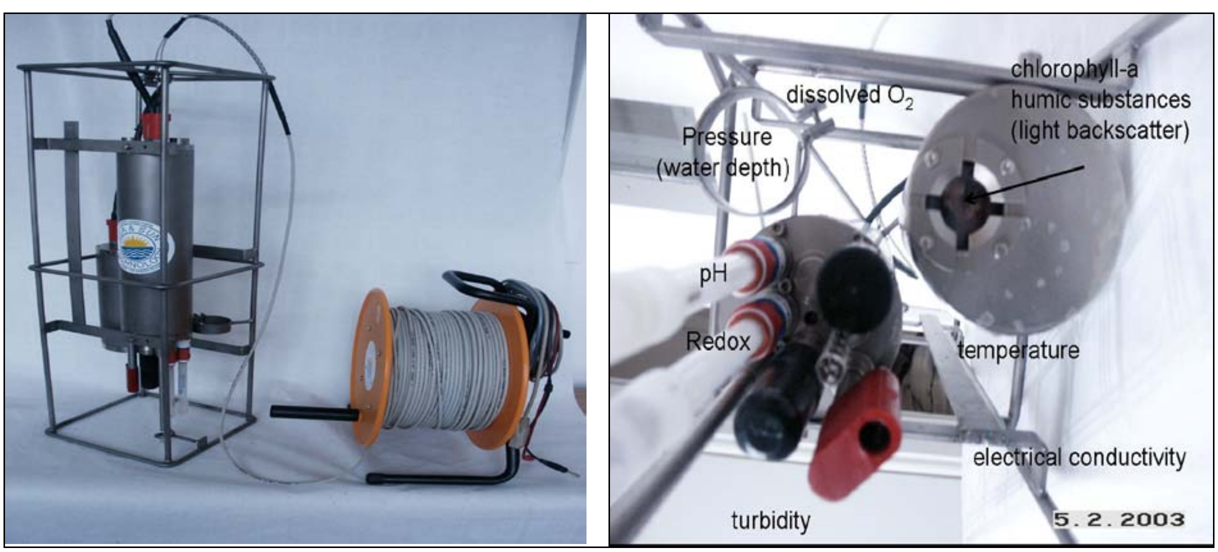


Figure 5. Multi-parameter probe used in Mae Thang reservoir.

Results and Discussion

Rainfall, Runoff and Erosion

Table 1 shows the rainfall over the catchment and subcatchments in the Thailand site in 2003 generated by the Thiessen polygon method. The annual rainfall in the catchment was 1107 mm from January to October (Huai Ma Nai automatic climate station, Cimel 407). This represents an approximate volume of 1 million $m^3.yr^{-1}$. A proportion of this volume was lost as runoff via the natural drainage network of the Huai Ma Nai. The rains in 2003, although less than those in 2001 and 2002 had comparable level of intensity (CV = <5%).

Table 1. Distribution of rainfall in the Huai Ma Nai catchment (Thiessen Polygon Method)

Rain Gauges	1	2	3	4	5	6	7	8	9	10	11	Climatic station		Surf (ha)	Rain fall volume (m3)
Rainfall (mm)	1124	1109	1129	1087	1134	1145	1101	1142	1145	1073	1100	994			
Huai Ma Nai	45	78	56	87	125	160	110	69	137	86	77	80	1109	93	**1033856**
Huai Mee	0	0	0	0	0	34	0	503	217	0	99	249	1102	12	**130036**
Huai Ma	0	0	0	0	0	527	0	0	355	0	253	0	1134	10	**108904**
Huai Bong	135	0	722	261	0	0	0	0	0	0	0	0	1118	3	**35781**
Huai Tong	34	499	0	0	0	0	0	11	0	0	0	507	1051	7	**74627**

The accurate determination of water level measured at each station provides a complete assessment of the runoff volumes for each sub-catchment. Total runoff from the Huai Ma Nai catchment is presented in Figure 6. Each peak corresponds to a runoff event. The sum of the runoff volumes over time gives the total volume of runoff exported by the catchment during the rainy season. This measurement is the second component (the first being rainfall) of the determination of the coefficient of run off*. This measures correlated with the measurement of turbidity provide information regarding the quantity of sediment ($t.ha.yr^{-1}$) exported by the catchment (Figure 7). The dynamics of the rain fall and runoff in the Huai Ma Nai catchment is presented in Table 2.

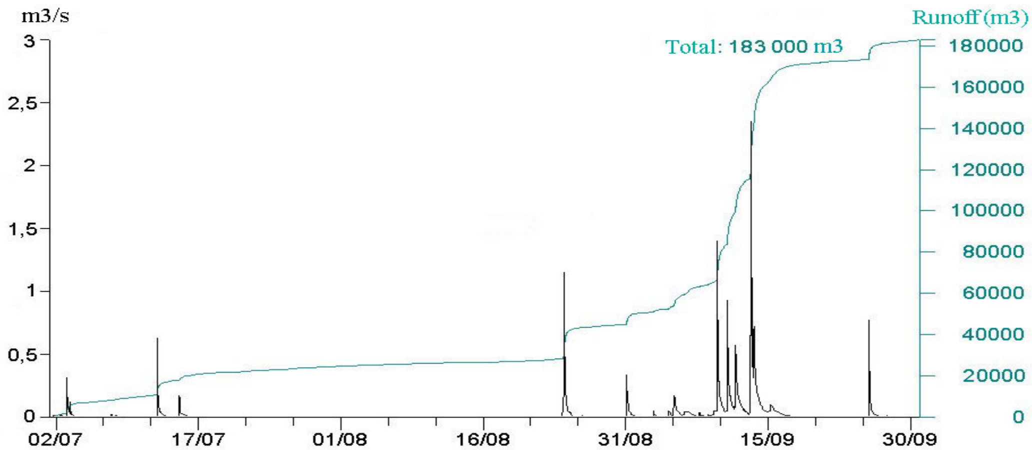


Figure 6. Assessment of runoff volumes from the Huai Ma Nai catchment (2003).

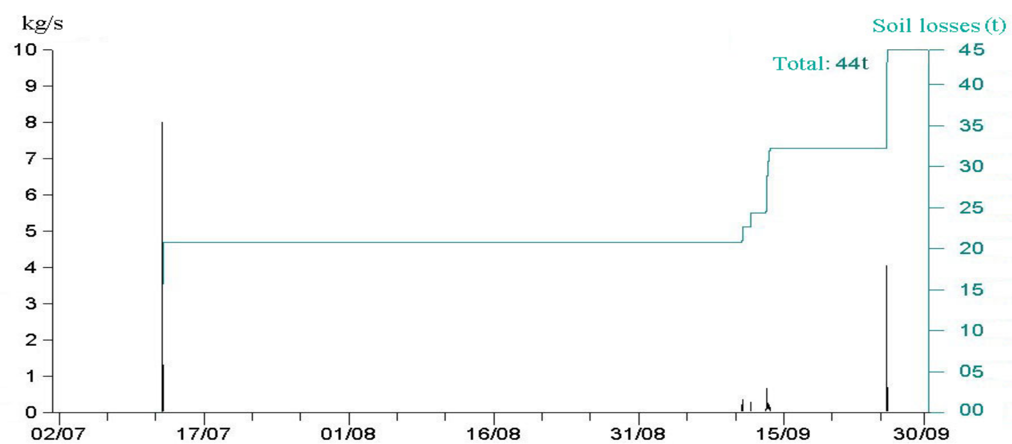


Figure 7. Assessment of sediment exported by the Huai Ma Nai catchment (2003).

Table 2. Dynamics of rainfall and runoff in the Huai Ma Nai catchment from 2001 to 2003.

	2001	*2002*	*2003*
Total rainfall (m^3)	486,500	306,300	192,500
Rainfall (mm) October – January	1159	1225	1016
intensity of rain (mm hr^{-1})	26.3	26.4	24.1
Coefficient of runoff	**45%**	**30%**	**20%**

The results indicate that the Huai Ma Nai catchment lost 44 t of soil during the 2003 rainy season. The Huai Ma Nai catchment occupies an area of 93 ha. Consequently, the average loss of soil from the Huai Ma Nai catchment is approximately 0.47 t ha yr^{-1}.

The analysis of the catchment can be more precise. As stated, the Huai Ma Nai catchment is sub-divided into four sub-catchments. The experimental set up allows the combined runoff volume from the sub-catchments to be cross-referenced with the runoff volume determined by the flume at the catchment outlet. Table 3 represents the data obtained during the 2003, rainy season (July 1^{st} to September 30^{th}, 2003). The comparatively high runoff values associated with the Huai Ma catchment are a result of the fact that the Huai Ma catchment was cultivated primarily for cash crops with no forest cover remaining or soil protection measures adopted.

Table 3. Rate of run off and soil loss in Huai Ma Nai catchment for 2003, rainy season.

	Huai Mee	**Huai Ma**	**Huai Bong**	**Huai Tong**	**Huai Ma Nai**
Surface (ha)	11.8	9.6	3.2	7.1	93.2
Rainfall (mm)	1102	1134	1118	1051	1109
Rain fall in volume (m^3)	130036	108864	35776	74621	1033588
Flow ($m^3.s^{-1}$)	36790	25831	14905	14196	182719
Run off coefficient (%)	**28.29**	**23.73**	**41.66**	**19.02**	**17.68**
Exported sediments (t)	15.11	7.59	0 *	1.586	44.24
Bedload (t)	3.78	12.368	3.912	3.279	0 *
Export by catchment (t)	18.89	19.958	3.912	4.865	44.24
Soil loss by catchment ($t.ha^{-1}$)	**1.60**	**2.08**	**1.22**	**0.69**	**0.47**

*: no measurements because of the installations which do not allow the analysis of these results.

Land Use and Dynamics of Runoff

The land use practices are a determinant of the degree of soil protection and thus soil erosion. By comparing land use with the coefficients of runoff, the impact of climate can be evaluated. Changes in land use since 2001 are presented in Figure 8. In 2001, the majority of the cultivated area was used for mungbean. In 2002, soybean occupied more than 90% of cultivated area. In 2003, there was a marked increase in the area cultivated to maize, the original cash crop of the catchment, with 58% of the cultivated land used for the crop. Soybean was cultivated on 34% of the agricultural area. Land use patterns for 2003 are presented in Figure 9 which allows the visualization and characterization of different small catchments of Huai Ma Nai.

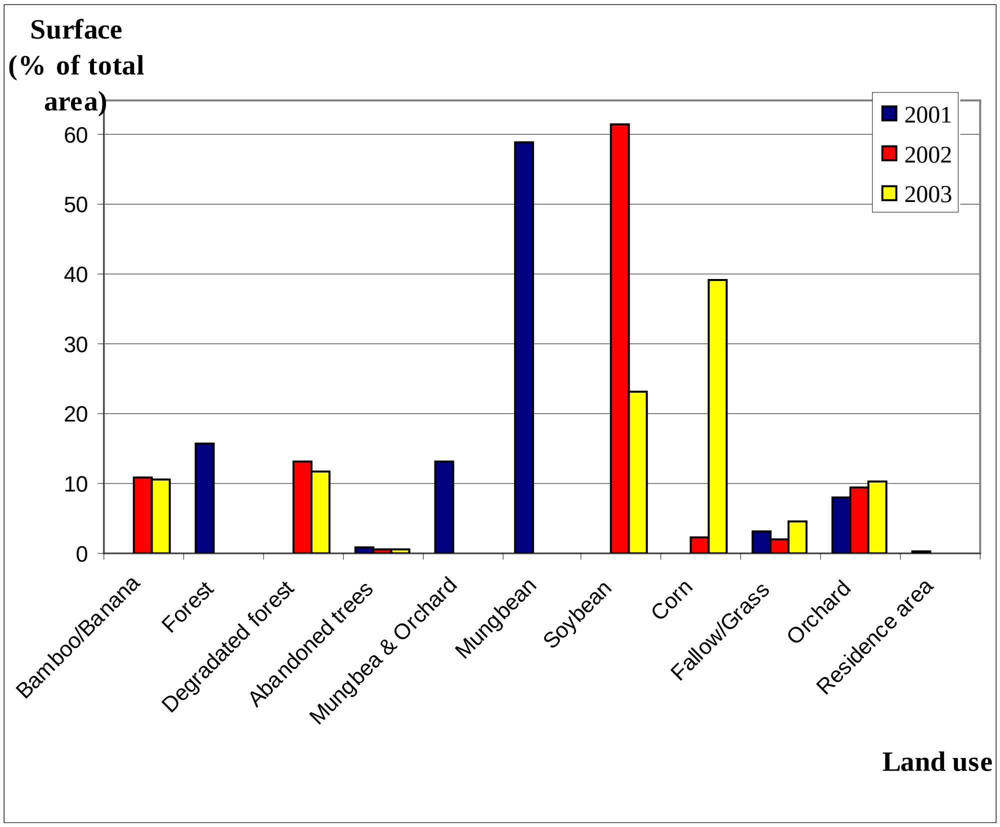


Figure 8. Changes in land use in the Huai Ma Nai catchment since 2001

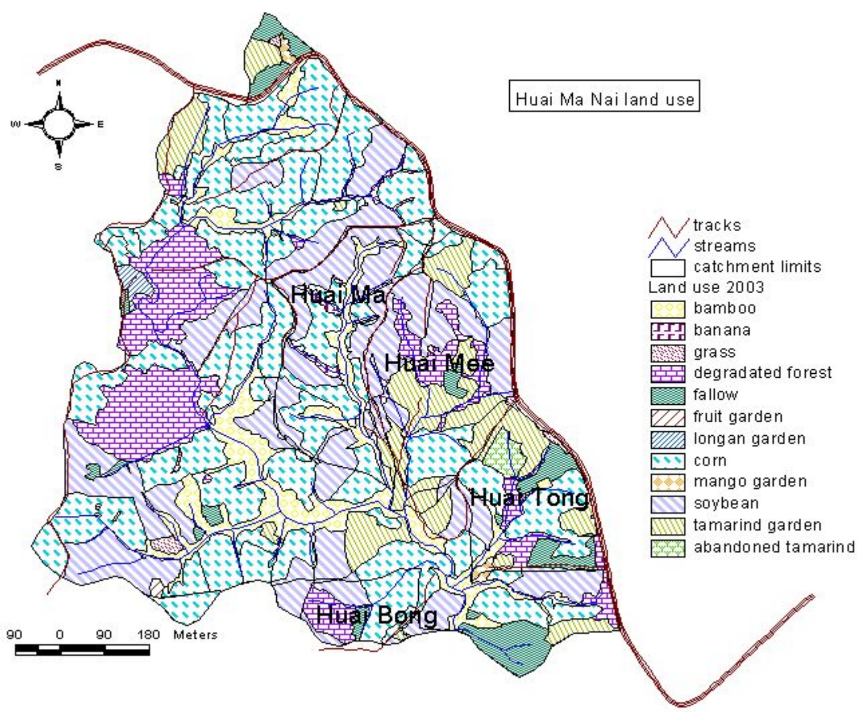


Figure 9. Land use of the Huai Ma Nai catchment in 2003 (Chatwatcharakul, 2003).

The rains in 2003 although weaker than those of 2001-2002 have a comparable level of intensity (CV = < 5 %). In addition, good vegetative growth and therefore surface cover resulted in high soil infiltration capacities. In this respect, the results indicate that maize is more effective than soybean cover and even more than the mungbean. The Manning coefficient and the coefficient of vegetative cover (expressed as a percentage of the soil surface) are good indicators of soil protection. The higher the coefficients are, the more resistant the system is against erosion (Table 4).

Table 4. Manning coefficients and vegetative cover as related to land use.

	Coefficient of Manning	Vegetative cover
Drill	0.20	70 %
Orchard	0.70	60 %
Fallows	0.04	50 %
Maize	0.09	35 %
Soybean	0.01	20 %

In contrast to soybean which is associated with low vegetative cover; fruit orchards provide a very good protection to soil. The soybean root system does not provide efficient resistance against the flow.

In terms of cash crops, maize is a better soil conservation crop due to a comparatively higher Manning's coefficient and percentage of vegetative cover due to inherent plant physiology. Good vegetative cover in the Huai Ma Nai catchment during the 2003 rainy season as a result of favourable climatic conditions resulted in minimal soil losses.

Best Bet Option

In terms of reducing soil losses, the current experimental system of tamarind in association with other cash crops appears to be promising. In addition, in certain fields, the cultivation methods adopted between the maize-mungbean rotations appear effective in reducing soil losses. Specifically, several farmers currently pull up the maize during harvest, use disc cultivator for tillage and then sow mungbean. Consequently, during the period of mungbean vegetative growth, the maize residue protects the soil surface from raindrop impacts, prevents surface sealing and maintains high infiltration rates. Upon decomposition and humification, the maize residue improves aggregate stability. In addition, the off field exportation of organic matter and associated nutrients is limited.

In comparison, the currently adopted soybean cultivation practices are conducive to accelerated soil losses. Prior to harvest, the soybean plant is allowed to die down resulting in vegetative cover decreasing to < 30%. In addition, at harvest, the whole plant including residue is exported from the field. Subsequently, the field is tilled and sown with the following rotation crop. This results in an exposed soil surface with no protection from raindrop impacts (Figure 10).

Harvesting and drying of soybean

Tillage before mungbean crop

Figure 10. Tillage operations and harvesting in the soybean – mungbean rotation

This study indicates that the cultivation practice primarily in terms of tillage and vegetative cover has a significant impact on the dynamics of soil erosion. Consequently, this will lead to the development of appropriate land management to improve soil protection and sustain livelihoods.

Gully Erosion

Characterization of the gully

The terminologies used in the study were those proposed by Planchon (1991). The gullies were defined in four terms in relation to the dynamics of erosion (Figure 11). The four terms are:

1. The *proto-rill* which indicates all the forms of incisions concentrated without incision marked on the soil. It is the initial tree structure of the gully.
2. The *rills* which dig the humus horizons by forming small rectilinear channels 5 to 10 cm deep and 10 cm wide. The vegetation is non-existent here. The bottom of the gully can be flat or in V-shaped. There are coarse silts present.
3. The *gullies* which dig the mineral horizons of the soil. The slope of the bottom remains parallel to the surface slope. The banks remain abrupt. The principal form is U-shaped, the bottom of the incision is strongly stony (many coarse elements with up to 10cm in diameter). There are crop residues deposited by the man. The flows in these gullies are still strongly related to the surface phenomena.
4. *Ravines* (or streams) are deep incisions reaching the parent rock. The bottom of the ravine is not all the time parallel to the surface slope. The distinction between a gully and a ravine is the depth of one meter. Perennial vegetation can be present in these deep incisions.

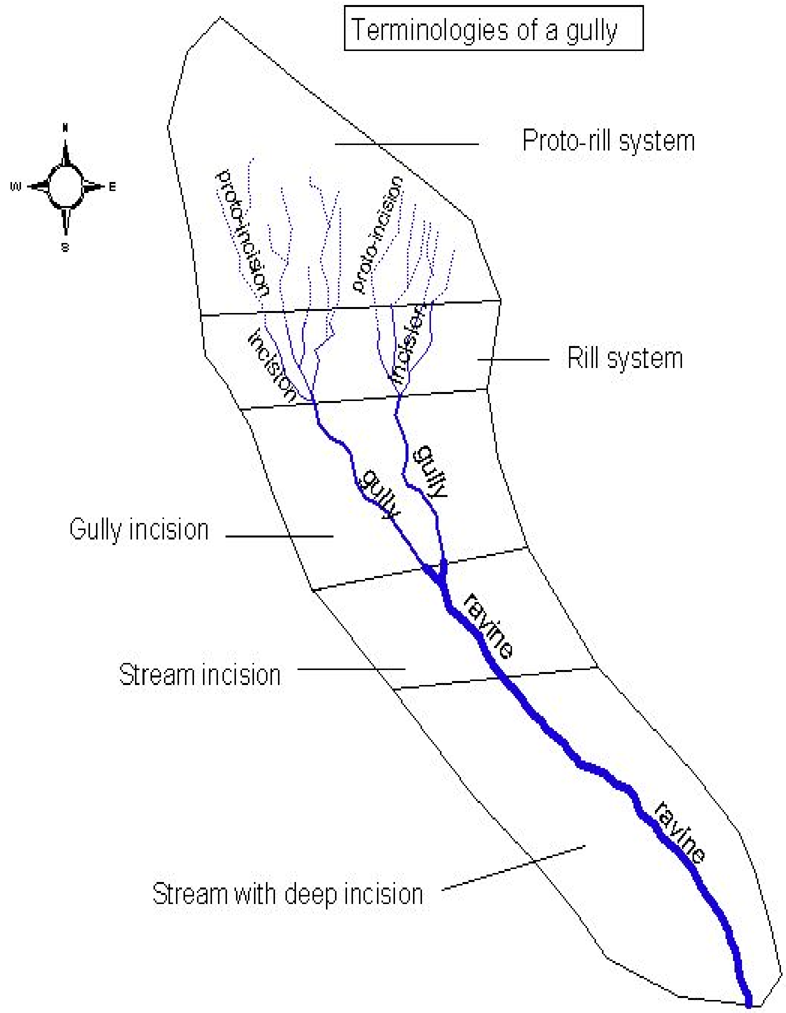


Figure 11. Diagram of terminologies applied to a gully.

Based on these terminologies, the toposequence of the studied gully in the catchment was defined (Figure 12). The toposequence allows understanding of the development of the gullies in a small catchment. The results of Bayer (2001) showed that the gullies are formed on slopes ranging between 30 and 35 % on bare soils. This phenomenon is a function of the interaction between different rain dynamics (intensity and duration), the slope and the particular characteristics of the soils and their surface. Because of these interactions, the dynamics of runoff and infiltration of water are very heterogeneous from one area to another in the same catchment. The variations are demonstrated in terms of compaction, size of the surface crusts, and stone rate (Janeau *et al*, 2003). The consequences are direct on the soil losses with a turbidity of 0 to 5.6 g l^{-1} and a detachability of the soils from 10 to 313 g m^{-2}.

On slopes lower than 25%, the loss of soil is mainly related to the splash effect (function of the kinetic energy of the rain and the slope) of rainfall. Splash effect allows a redistribution of the fine elements of the soil and progressive encrusting. The infiltration becomes lower. Beyond 25%, encrusting is much weaker. The crust is not hardened enough to protect the soil. The loss of soil is much more significant in this slope change. This area corresponds to the first upper quarter of the slope. It is the area where the gullies start.

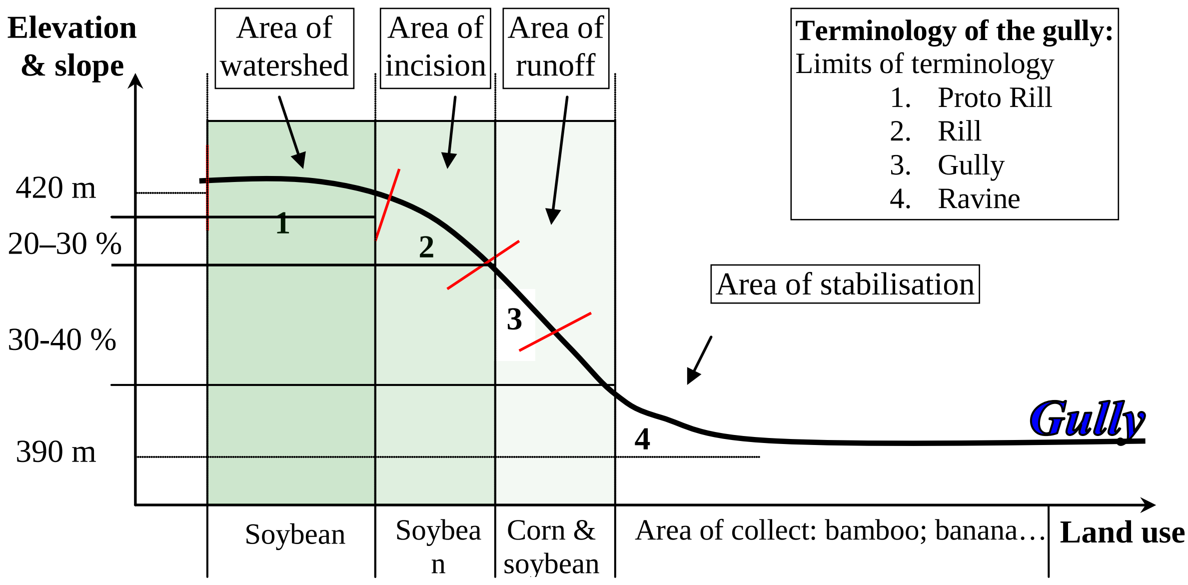


Figure 12. Toposequence of the gully studied in Huai Ma Nai catchment.

Gully development

The development of a gully was defined in four stages by Bergsman (1996). The initial stage consists of the concentration of a significant volume of water on a determinate area. This concentration leads directly to the incision development, then to a maturation stage when there is loss of soil particles. Finally, at the stage of stabilization, vegetation can be established. These four stages are not independent of each other and occur successively. So, the development of a gully can be related to the position in the landscape as follows:

1. An upstream area (which is the area of watershed) where rainfall and runoff are concentrated because of slope and the properties of the soil surface (Bergsman E, 1996);
2. An area of incision, where the incisions are initially formed. Their appearance is directly related to the slope (Bayer, 2001);
3. A development area (or drainage area) where the incision grows into gullies and then ravine. More volume of water can circulate here.
4. An area where the vegetation starts to grow and becomes more stabilized (Bergsman, 1996).

The topography of the gully area (2,496m^2, 104 m long and 24 m wide, visual limits of the gully) was determined using a level (Figure 13) and the data analyzed using "Surfer 7.0". Figure 14 presents the general topography of the studied gully.

Figure 13. Topographic measures with a level.

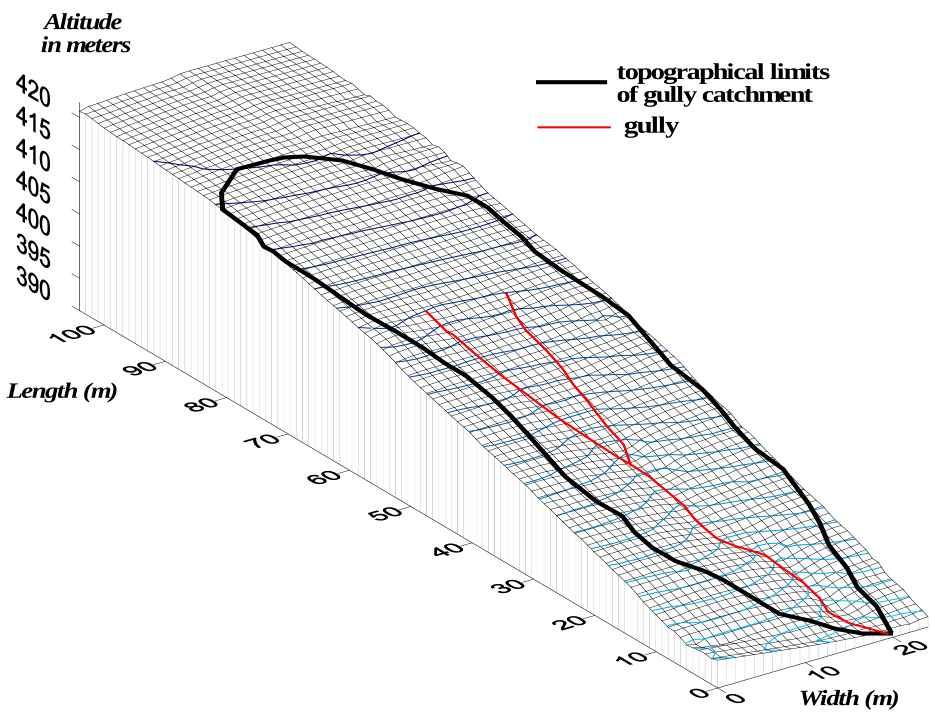


Figure 14. The gully catchment in Huai Ma Nai.

The general topography shows the main evolution of the gully, but during one rainy season the evolution is not very distinct. However, the loss of one outline in the middle of the graph can be observed. This element shows the incision development of the gully. To better appreciate the development of the gully, the surface roughness was measured using a distanciometer (Leica Disto. Pro, laser class 2-635). The result of the analysis is shown in Figure 15

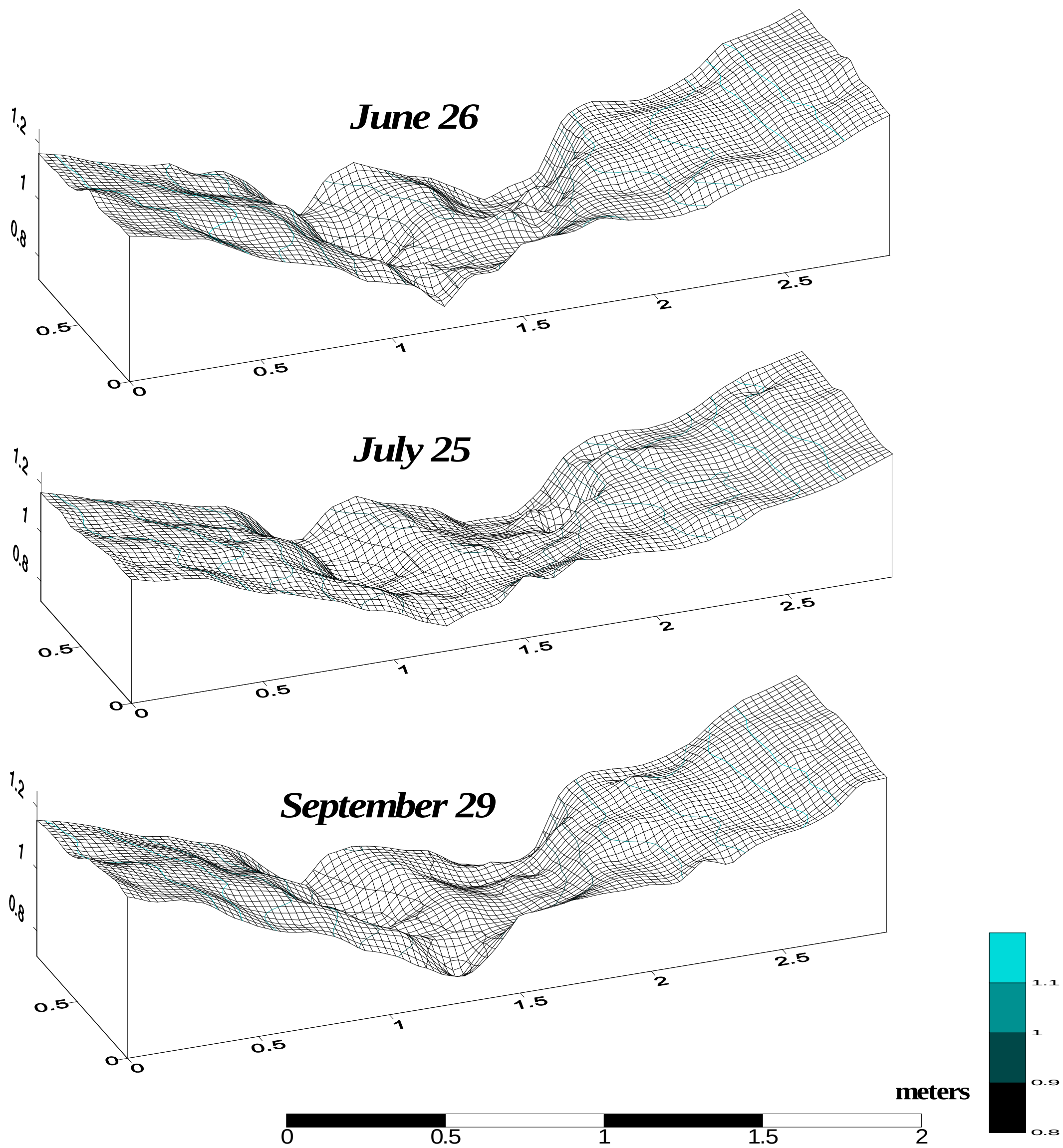


Figure 15. Gully evolution during 2003 rainy season in the incision area

Runoff and soil erosion

The loss of soil and fertility varied within the landscape (see Figure 11 for reference) where the soil characteristics and topography also vary. Figures 16 and 17 show the variation in bulk density and organic matter content, respectively, with depth at different locations in the toposequence. The watershed area has a hardened crust whose bulk density and consequently the porosity is low and infiltration is reduced. This is aggravated by the hardened layer at 15 cm depth. As the slope increases, bulk density decreases and the porosity increases. The maximum porosity is reached at the first part of the runoff area.

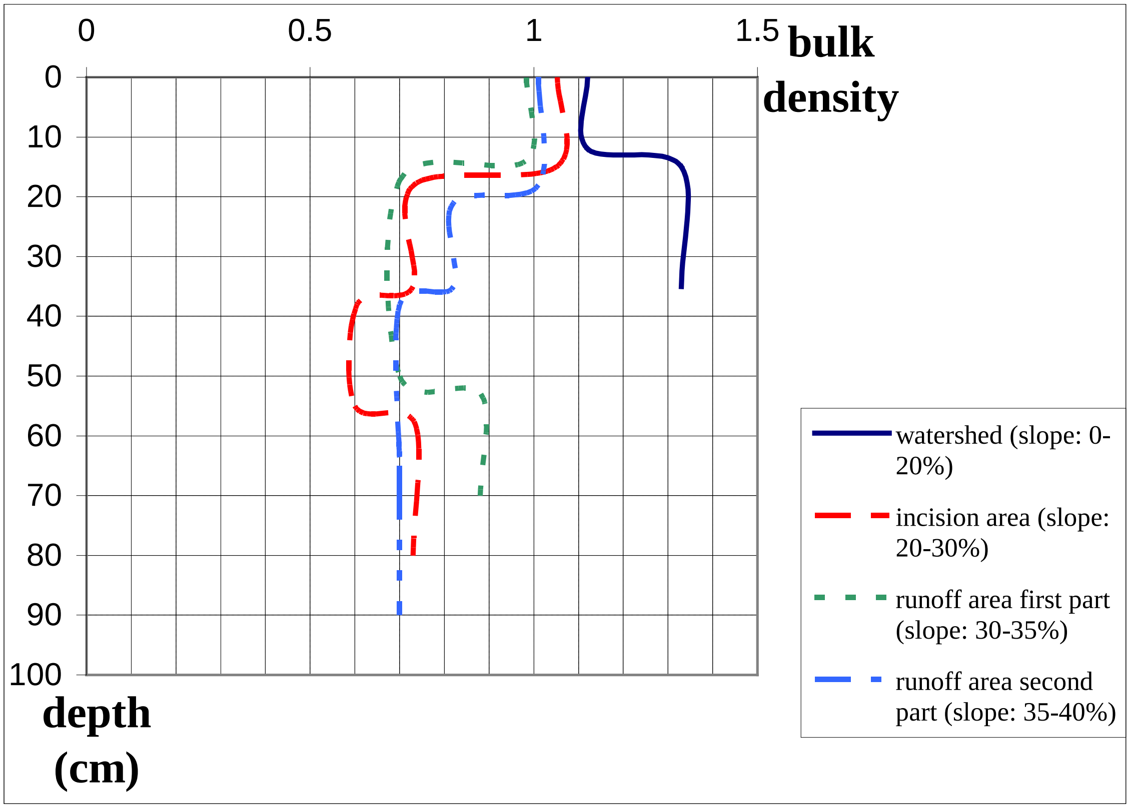


Figure 16. Bulk density of the soil according to the depth and the situation on the slope of the gully.

The analysis of the organic matter content gives an indication of the consequences of soil loss in the catchment. The organic matter is high in the tilled layer but it decreases with depth (Figure 17). The first part of the runoff area has 16 cm of arable soil, but organic matter becomes low further down. The development of the root system of crops becomes restricted. From an agronomic point of view, the incision area is the most fertile. The soil is deep and the organic matter decreases only gradually down the soil profile.

The second part of the runoff area also looks to be a good area. It presents a good evolution of the organic matter rate along the soil profile, almost similar to that in the incision area, despite a lower average amount. These have some influence on the yield of crops. Figure 18 compares the average yields of soybean in the different toposequence.

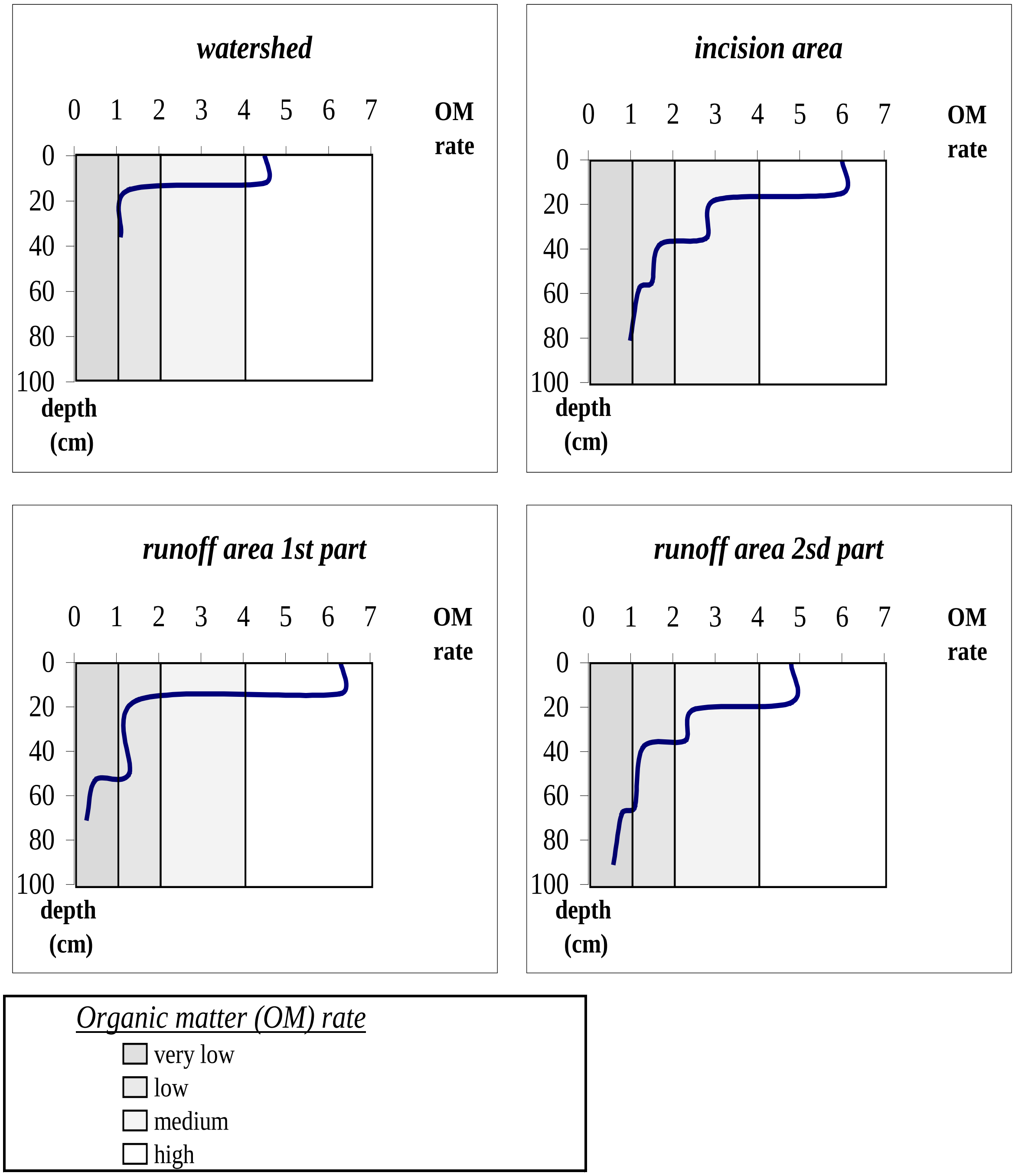


Figure 17. Organic matter rate of the soil according to the depth and the situation on the slope of the gully.

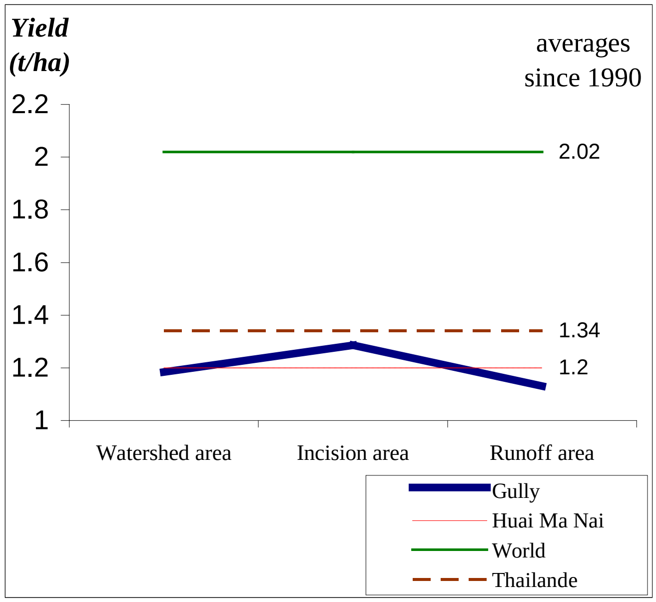


Figure 18. Comparative yields of soybean in the toposequence

The soybean average yield in Thailand is 1.34 t ha^{-1}. This is relatively low compared to the world average of 2.02 t ha^{-1}. In the Huai Ma Nai catchment, the average yield of soybean is lower at 1.2 t ha^{-1}. The major reason could be the problem of soil erosion.

The bulk density also varied within the gully itself. Figure 19 shows that the highest bulk density occurs at the center of the gully. It is where the porosity is lowest. The side of the gully is the least dense which creates an increase in the detachability of the soil particles.

Socio-Economic Dynamics

At this time, the data are still being processed, but it is evident that the production systems of each village are really not the same. The village of Ban Pong had a specific configuration. The houses are very close to one another, and most of them are built Thai style on wooden stilts and closed by concrete. Most of the villagers have land in the upland. They have been encouraged to plant fruit trees to prevent erosion but because of the canopy, they could no plant annual cash crops. They therefore cut the trees.

In Ban Weiang, the houses are also closely spaced, but most of them are of European style. Most of them have TV and computer. Some farmers grow fish in the reservoir and operate restaurants. The villagers say that they do not have good soil and most of the farmers of this village have some of their family members work in factories near Bangkok.

In Huai Hung, the houses are like in Ban Pong but witch much more space to allow them to have a garden where they can grow fruit trees and vegetables for their consumption. Most of the women make dresses for middlemen or for small shops near Phrae. This village is near the end of the irrigated area and with the water from the reservoir, they can crop more than before. In the past, most of the villagers went to work as hired labour in other districts.

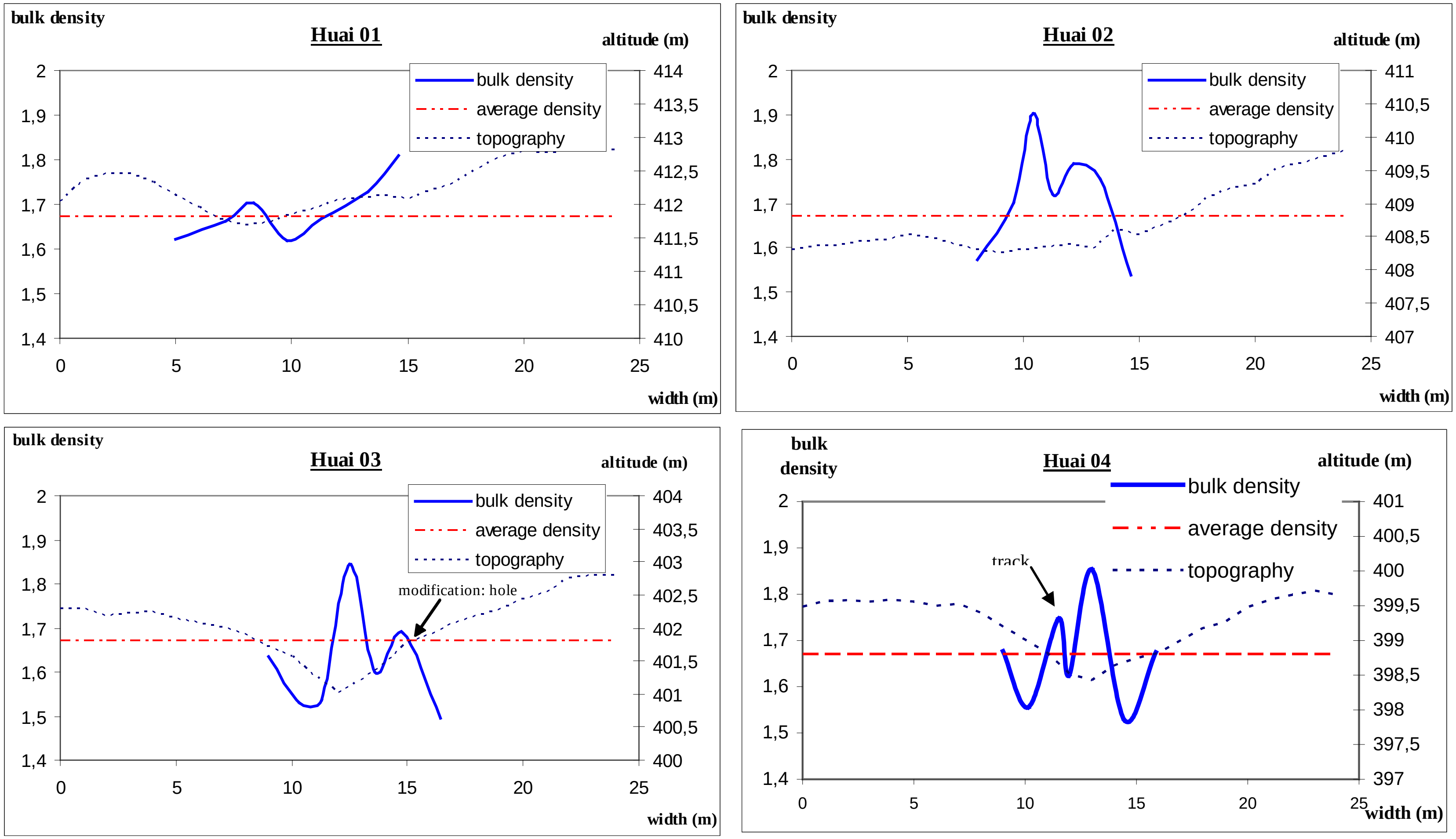


Figure 19. Bulk density of the surface horizons around the gully according to various areas.

The activity in the lowland is mainly cultivation of corn because of the presence of Monsanto Company which moved from the North-East to the North because of the well developed irrigated system. Monsanto works with the cooperative and the agricultural bank. They arrive in Phrae province since few years and progressively farmer crop more and more corn.

Corn is planted at the same month as soybean, so there is a change appears in the organization of the agrarian activity with the decrease in the area for soy bean. And for those who cultivate in the upland, they can have more money to spend for the seeds they need.

Monitoring Dissolved Oxygen Depletion

In the freshwater reservoir of Northern Thailand, preliminary investigations with specific multi parameter probe provide a first-order evidence of severe O_2 depletion below the thermocline in isolated sections of the reservoir that can be related with high surface productivity and limited bottom - surface water exchange. Control of the extent of dissolved metal release in the water column through chemical analysis of water sample aliquots is in progress.

During 2003, monitoring of temperature (T°C), electrical conductivity (EC), chlorophyll-a concentration, redox (Eh), pH, dissolved oxygen concentration (O2), turbidity and light backscatter in the water column of the Maethang reservoir near its outlet. Figure 20 shows the results in September 2003.

General Conclusion

The rainy season in 2003 was quite good with a total rainfall of 959 mm between 15th April and 1st November (1200 mm in 2002). There were very few big events, only 12 events with rainfall higher than 20 mm per day. The rain was well distributed within the months with only few days without rain. Biggest events came late in the season, in September – October. From an agronomic point of view, it was excellent for the crops, water being available during the growing period. Farmers had higher yields this year than last year.

Consequently, there were few runoff events with less amount of water measured at the different stations. The maximum discharge recorded at the flume was 2.35 m^3 s^{-1}, comparable with 2.65 m^3 s^{-1}in 2002 and 2.47 m^3 s^{-1} in 2001. In terms of total volume, 2003 is the lowest with only 193 000 m^3, compared with 295 000 m^3 in 2002 and 478 000 m^3 in 2001. The situation is similar for the other stations. For example, at the Weir 2, the discharge was 27 100 m^3 in 2003 compared with 47000 m^3 in 2002 and 57 100 m^3 in 2001.

The main reason for these changes, if the rainfall distribution is not taken into account, could be the changes in the crops. This year, many farmers decided to abandon soybean and go to maize. Corn is more effective to protect the soil from rain impact (cover crop is much higher than soybean) and, better, the cropping period is longer than that of soybean. About 60% of the land cropped last year with soybean was cropped this year with maize. Consequently, when some farmers harvested soybean, there was still maize on many fields which reduced rainfall erosion and runoff. The assessment of erosion was easier this year with improved equipment, especially the automatic water samplers.

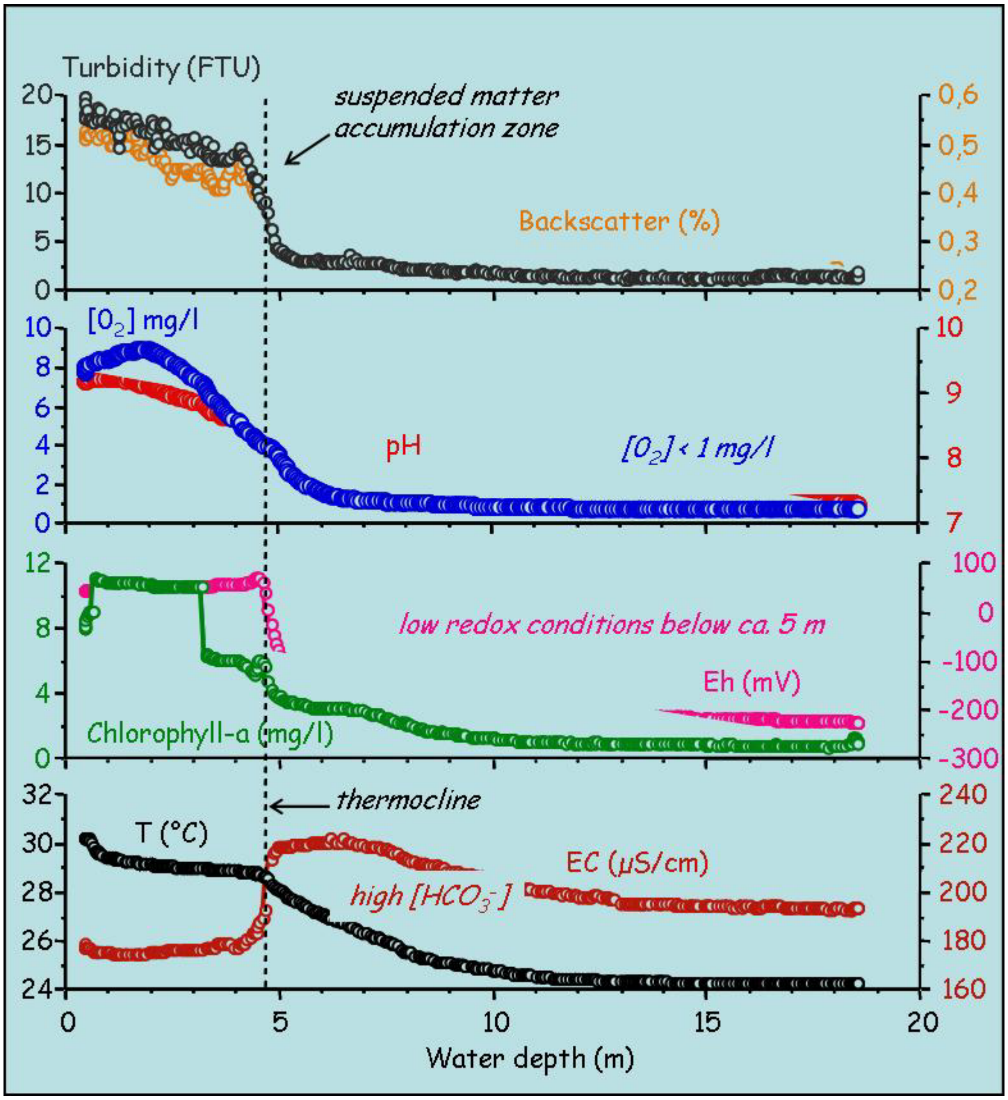


Figure 20. Data obtained with multi parameter probe in September 2003.

A socio-economic survey was started at the lower part of the watershed, particularly in the irrigated area, during the year. It is very important to evaluate the impact of the dam construction on the population and how they use the new resource available.

Another activity started during the year was the study on water quality. The methodology and techniques involved in that survey will generate large amount of data. The determination of water quantity and quality is crucial for the farmers and policy makers. The new association with others teams like medical and anthropologist will give a broader view of the off-site impacts of a watershed.

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Training

This year, two French students joined the programme for their thesis (MsC), and the assistant Warinya Thothong left for AIT for a Masters degree in watershed management. The French students, Jean Philippe Luc and Caroline Boulais, come from a school of agronomy in tropical countries. They spent 4 months in Phrae province to collect data and other information they needed. During the two months they stayed in the office in Bangkok, they wrote the notes and reports. Most of the annual report come from their work.

In October, training on data management and interpretation was conducted in Bangkok. Twenty-five participants from the MSEC countries joined this workshop. The main objectives of the workshop were:

- Improve data management.
- Improve the use of hydrological tools.
- Establish water and sediment balance, with focus on minimum data set
- Integrate socio economic components.

The main expected outputs were an appropriate use of the hydrological software used in MSEC (Hydras 3), an improved understanding of the collected and observed data, and finally a more attractive and intelligible improved presentation of results.

The different resource persons gave a deep comprehension of the database system, how hard it is to build a proper database, and how important it is to know the units we express results.
All participants were enthusiastic about the training. An evaluation was conducted at the end of the week to estimate the impact of those training. A workshop diner was organised on the Chao Praya River

The close collaboration with NPWPCD will continue and the execution of a new MoU will formalize this relationship.