The Management of Soil Erosion Consortium Project: A Case of Integrated Natural Resource Management Research

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Abstract

The research project, funded by the Asian Development Bank, was conducted by a collaborative team under the Management of Soil Erosion Consortium (MSEC) in selected catchments in Indonesia, Lao PDR, Nepal, Philippines, Thailand, and Vietnam. In general, the catchments represent a resource management domain with biophysical and socio-economic characteristics common to the marginal sloping uplands. The participatory process has been employed since the establishment of the consortium. Consultation meetings and dialogues among various stakeholders including the NARES, IARCs, ARIs, NGOs, donors and farmers were undertaken to design the research program and its implementation. A network of 34 catchments and sub-catchments equipped for hydrology and soil erosion management research was established and now serves as a facility for conducting research on integrated land and water management. The research yielded outputs such as research methodology, tools, and guidelines to support decision-making and improved implementation. These include a decision support system (DSS) and soil erosion and hydrological models to simulate erosion and runoff under different scenarios. Dialogues with farmers identified variants of the hedgerow cropping technology combined with other options considered to generate additional income more quickly as potentially sustainable land management options. Originally designed as a longer-term project (12 years), IWMI has proposed a second phase to develop, adapt, and disseminate appropriate tools and methodologies to scale up the application of research results and technology options to larger catchments. This will better capture the interactions among the on- and off-site users of land and water resources, and more effectively resolve the competing demands of these users.

Introduction

Tropical Asia suffers from serious soil erosion caused by intense rainfall that occurs within only a few months of the year, and the topography of cultivated upper catchments (Figure 1). With nearly 60 percent of the total land surface covered by mountains and high plateaus, soil erosion remains a major problem to sustainable agricultural development in these marginal uplands (FAO, 1986). In addition to reducing agricultural productivity on site, erosion causes negative impacts off site (Figure 2).

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Figure 1. Soil erosion in Asia is severe because of intense rainfall and the steep topography of cultivated upper catchments.

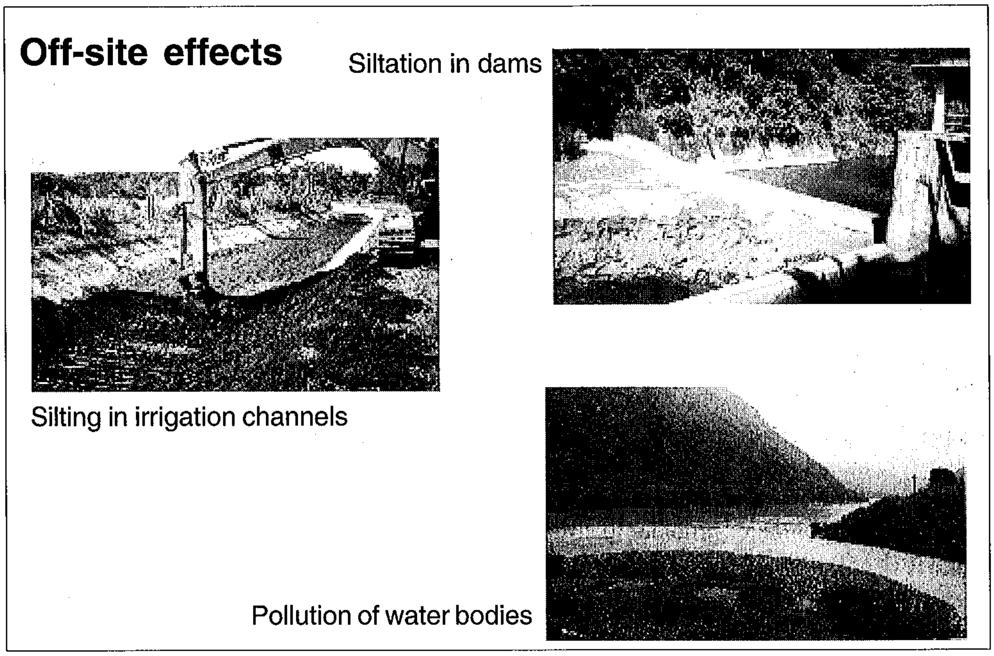

Figure 2. Downstream, soil erosion can cause siltation in irrigation canals and dams, and pollution of rivers.

The challenge is to recognize that land degradation, including soil erosion, is driven largely by socio-economic factors. Research on soil erosion has largely ignored the end-users, or has been based on small plot experiments of no relevance to the watershed situation. A new paradigm for research is required which ensures that the whole range of stakeholders, from land users to policy-makers is involved in the generation and promotion of improved land use practices (Greenland *et al.*, 1994). In Australia, Europe, and North America, integrated catchment management has been adopted widely as the most effective way to involve stakeholders, and to utilize scientific knowledge in the management of land and water resources. However, there is still a strong need for capacity development of the NARES, especially in Asia, who will be involved in this kind of research. This has led to the establishment of the Management of Soil Erosion Consortium (MSEC), which is one of four consortia in the soil, water and nutrient management (SWNM) system-wide initiative of the CGIAR

In late 1998, MSEC initiated a research project on soil erosion management in seven countries in Asia, namely, Indonesia, Laos, Nepal, Philippines, Sri Lanka, Thailand, and Vietnam with financial support from the Asian Development Bank (ADB). However, Sri Lanka was unable to continue its participation because of some organizational problems.

The project, "Catchment Approach to Managing Soil Erosion in Asia" (ADB-RETA 5803) was executed by the International Board for Soil Research and Management (IBSRAM) until March 2001 when the International Water Management Institute (IWMI) established a regional office in Bangkok, Thailand and consequently served as the Executing Agency. The Technical Assistance Agreement was signed on 17 September 1998 and the project was implemented for four years until 31 December 2002.

This report presents the accomplishments of the project during its first four years of implementation in six countries in Asia, namely, Indonesia, Laos, Nepal, Philippines, Thailand, and Vietnam. It highlights the research outputs as they relate to integrated natural resource management. It also summarizes its accomplishments in the other components of information dissemination and capacity building *vis à vis* the outputs expected. The project's strategy in governance and management is likewise presented.

Project Objectives and Expected Outputs

The project aimed to develop and promote sustainable and socially acceptable community-based land management options for sloping uplands through a participatory and interdisciplinary approach at a catchment level. The specific objectives are:

1. Develop sustainable and acceptable community-based land management options within a catchment framework;
2. Quantify and evaluate the biophysical, environmental, and socio-economic on- and off-site impacts of soil erosion;
3. Generate reliable information and scientifically-based guidelines to improve catchment management policies;
4. Enhance the capacity of NARES on integrated catchment management and soil erosion control.

The objectives have been set to address important issues as perceived by the major stakeholders, and the design process was carried out with their active involvement.

The project focused on three major components to address the stated objectives. These are:

- Catchment research to evaluate the effects of different land management practices on water and nutrient flows in selected representative catchments;
- Capacity building of participating NARES in research on integrated catchment management and soil erosion; and
- Dissemination of research results for enhanced adoption of land management technologies and for more accessible information as a concrete basis for decision-making.

The outputs from the project as indicated in the logical framework are summarized as follows:

- Decision support tools and guidelines based on a better understanding of the on- and off-site effects of soil erosion. This includes methodology for assessment of impacts and obtaining the participation of farmers and other stakeholders in the management of catchments which includes policies that will improve the management of catchments by the local government and the communities;
- Alternative technologies and land management systems that are socially and institutionally acceptable to the communities in the catchment areas;
- Information and communication strategies to effectively disseminate the results of the research to the farmers and other land users;
- Enhanced NARES capacity in integrated catchment management research through training and provision of research facilities; and
- Improved program management for catchment management research.

Project Implementation

The International Water Management Institute (IWMI) serves as the Executing Agency of the project. The key partners in the conduct of the study are the NARES of the six participating countries and IRD with the active participation of the farmers in the benchmark catchments. The collaborative team works under the Management of Soil Erosion Consortium (MSEC). MSEC is one of the four consortia established through the soil, water, and nutrient management (SWNM) initiative of the CGIAR, and employs an integrated, interdisciplinary, participatory, and community-based approach that involves all land users and stakeholders at a catchment scale. It focuses on the on- and off-site impacts of soil erosion and integrates biophysical and socioeconomic sciences to generate hard data and identify practical solutions that are acceptable to the various users. The following are the direct participants in the case study.

1. Centre for Soil and Agroclimate Research and Development (CSAR), Bogor, Indonesia
2. Soil Survey and Land Classification Centre (SSLCC), Vientiane, Lao PDR
3. Nepal Agricultural Research Council (NARC), Kathmandu, Nepal
4. Philippine Council for Agriculture, Forestry and Natural Resources Research and Development (PCARRD), Los Baños, Laguna, Philippines
5. Royal Forest Department (RFD), Bangkok, Thailand
6. National Institute for Soils and Fertilizers (NISF), Hanoi, Vietnam
7. Institute of Research for Development (IRD), France
8. Participating farmers

Other consortium partners are ICRISAT in India, ICRAF in Bogor, Indonesia, AIT in Thailand, SEARCA in Philippines, University of Bayreuth in Germany, ADB in Philippines and CRIDA in India.

INRM Approaches

The case study supports the ultimate goal of sustainable watershed development through an approach that seeks to establish an enabling environment for the sustainable use of natural resources to address the twin objectives of resource conservation and food security. An organizational model that engages scientists and research institutions to tackle a common goal was employed. The model allowed the participation of those who can contribute, exploits synergies, and is mutually beneficial. Research planning was undertaken through consultation among concerned NARES, IARCs, NGOs, and farmers. A facilitator, a steering committee, and an annual assembly were essential to ensure the effective operation of the consortium. The NARES play the central role in the consortium, particularly in participatory research, but with a broad responsibility for underpinning applied and strategic research (Figures 3 and 4). IWMI serves as the consortium facilitator, and together with other international centers and advanced research institutes provides the scientific inputs in the strategic and basic research. The whole idea of the program is to take a bottom-up approach in research planning with iterative discussions between farmers, NARES, IARCs, and ARIs in the definition and implementation of the research undertaking.

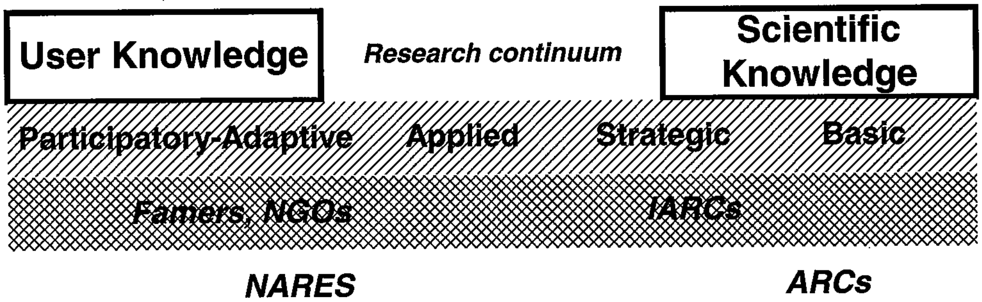

Figure 3. The research continuum showing the role of different groups in the irrplementation of MSEC research (Craswell and Maglinao, 2001)

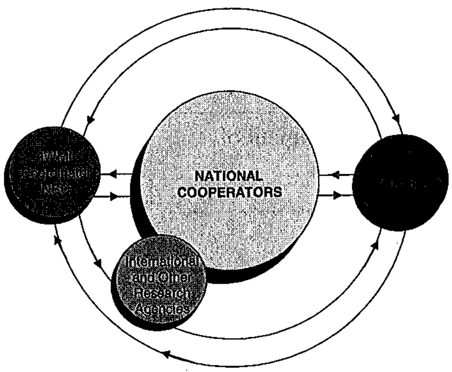

Figure 4. Schematic organization of a network/consortium

The overall procedure followed by the consortium in program planning and implementation is shown in Figure 5. Identification and selection of representative catchments in participating countries was conducted by an interdisciplinary team using carefully defined criteria and methodological guidelines (IBSRAM, 1997), based on visits and dialogues with local institutions, scientists, and farmers. Table 1 shows the basic information and other attributes of the benchmark sites. These catchments were equipped with proper instrumentation for data collection and monitoring (Figure 6).

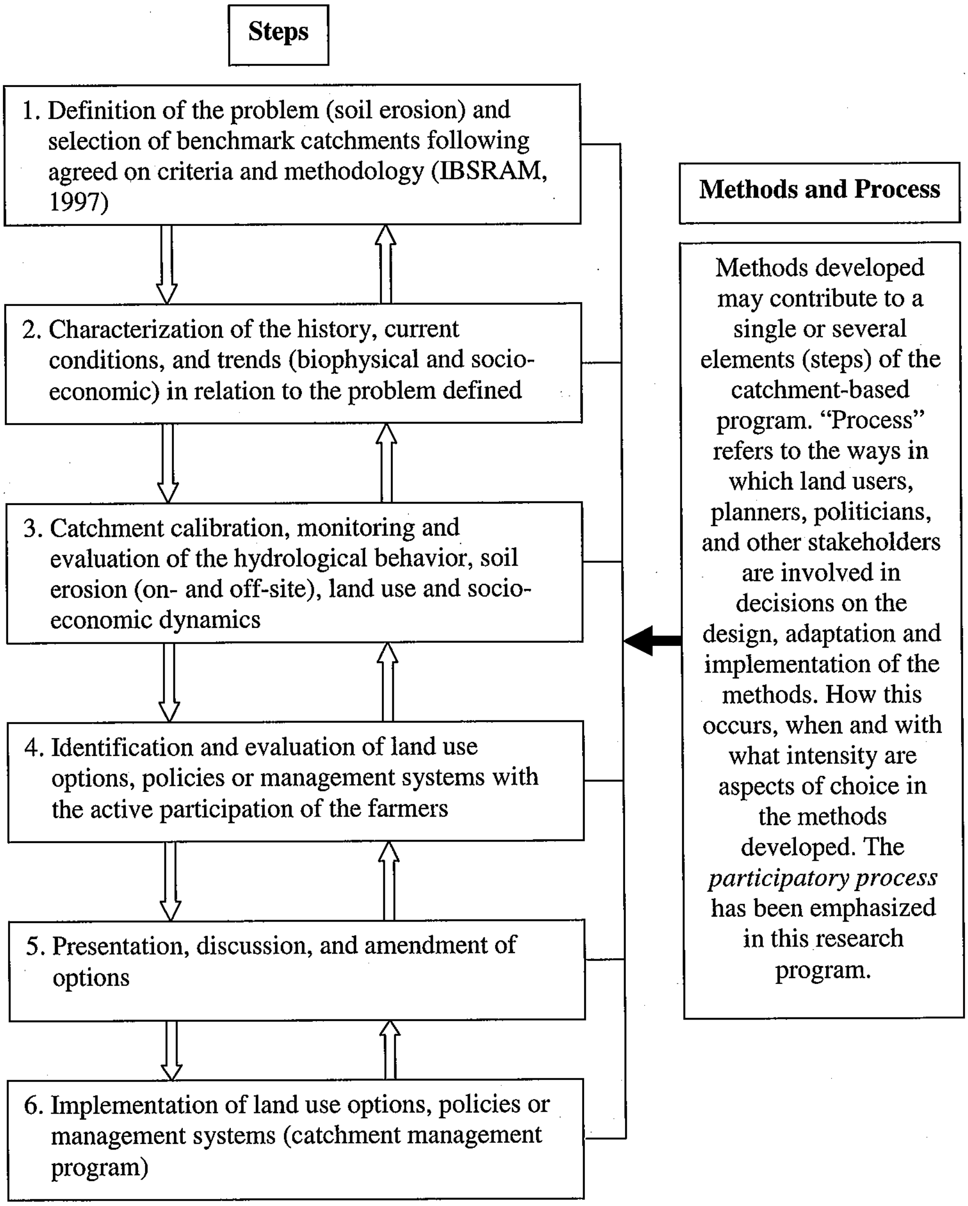

Figure 5. Steps followed in the catchment-based approach to managing soil erosion research

Table 1. Profile description of the MSEC catchments in participating countries

Country **Catchment name**	**Indonesia** **Babon**	**Laos** **Huay Pano**	**Nepal** **Masrang Khola**	**Philippines** **Mapawa**	**Thailand** **Huay Yai**	**Vietnam** **Dong Cao**
Province	Semarang	Luang Prabang	Chitwan District	Bukidnon	Phrae	Hoa Binh
Latitude	07°20'S	19°51'10"N	27°49' N	08°02'50"N	18°13'20"N	20°57'40"N
Longitude	110°E	102°10'45"E	85°32'30" E	125°56'35"E	100°23'40"E	105°29'10"E
Elevation (m)	390-510	400-700	650-1400	1,080-1,505	400-480	125-700
Catchment size (ha)	285	67	124	84	93	45
Slope (%)	15-75	30-80	40-100	15-60	12-50	40-60
Geology and landform	Basaltic lava	Shale; schist	Gneiss; schist	Basalt, pyroclastics	Siltstone, sandstone	Schist
Rainfall (mm)	2,500	1,403	2,200	2,537	1,077	1,500
Soils	Inceptisol	Ultisol; Entisol	Inceptisol; Alfisol	Ultisol, Inceptisol	Alfisol; Ultisol	Ultisol
Vegetation and land use	Rice, maize, rambutan	Forest, bush fallow; rice, maize, Job's tears	Forest, grasslands, rice maize, millet, potato	Forest plantation, open grassland, maize, potato	Soybean, mung bean, tamarind	Cassava, rice, maize, taro, peanut
Hydrology	Permanent flow	Permanent flow	Permanent flow	Intermittent flow	Intermittent flow	Permanent flow
<u>Population</u>						
- household (HH)	405	80	54	70	50	38
- persons	1,812	427	354	155	3,655	196
Ethnic group		Lao Theung (92%) Lao Lum(2%)	Gurung; Gharti; Brahmin, Chhetri/ Thakuri,	Talaandig	Thai	Kinh (40%); Muong
Land tenure	Owners, shareholders	State owned Land use right (28 HH)	With certificate of owership leased	Private owner	ThaiLand use title	Land use right
<u>Annual income (US$)</u>	372	296	415	1,200	627	774
- <u>on farm</u>	64%	70%		60%		96%
- crop	46%					57%
- animal	18%		59%			39%
- <u>off farm</u>	36%	30%		40%		4%
Dominant crops	Rambutan, lowland rice; upland crops	Upland rice, Job's tears	Maize, rice, millet, mustard, legumes	Vegetables, maize	Soybean, mung bean	Cassava, rice, maize, peanut
Agricultural practices	2 crops in one year	Shifting cultivation	2 or 3 crops a year	2 crops in one year	2 crops in one year	2-crops in one year
Relevant institutions	CSAR, CIRAD, BPTP; AIAT	NAFRI; IRD	NARC, ICIMOD	PCARRD, DA, DENR, NGO SANREM, CMU, ICRAF, SEARCA	RFD, RID; ICRISAT; AIT	MARD, NISF, VASI; ICRISAT

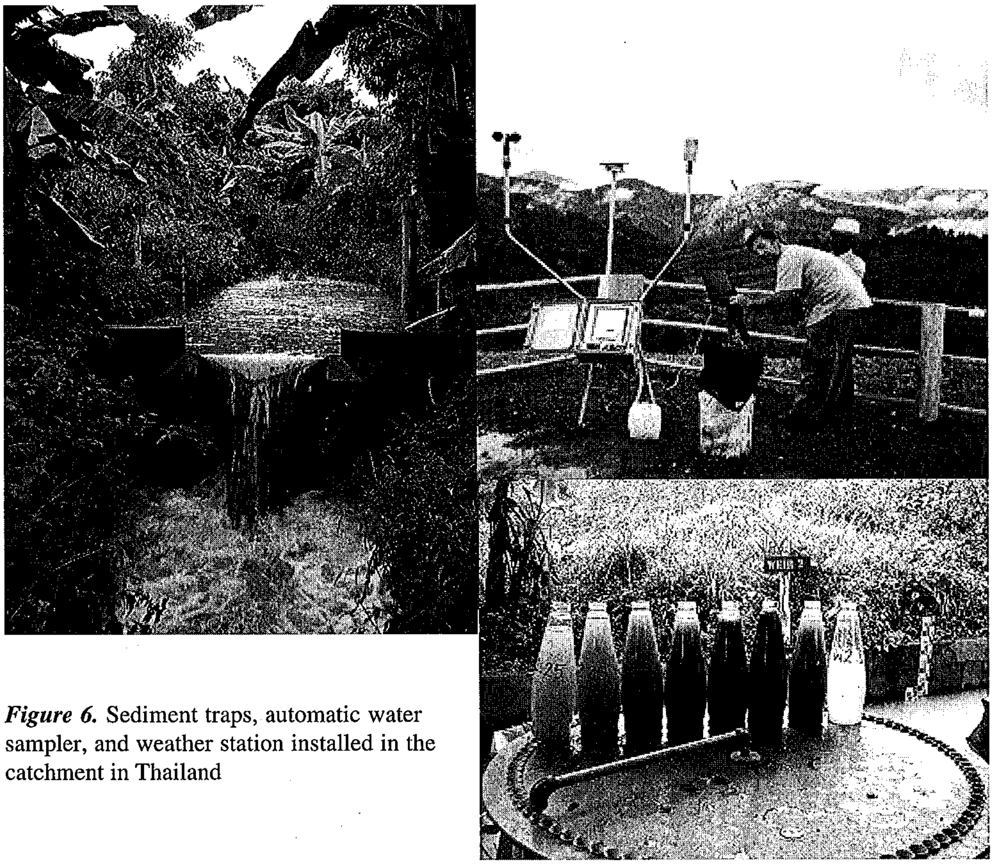

Figure 6. Sediment traps, automatic water sampler, and weather station installed in the catchment in Thailand

Rainfall, runoff, and sediment yields and other climatic data were monitored from the catchments and sub-catchments using the installed equipment. Erosion and runoff in each catchment were recorded both manually using staff gauges and automatically using automatic water level recorders. Samples were collected at time intervals from 2 minutes to 1 hour depending on water discharge peaks. Bedload sediments, i.e., the sediments trapped in the weirs, were collected and weighed after each main rainfall event or once at the end of the rainy season. Runoff and sediment yield data were computed to obtain yearly means. Runoff was derived from water depth after calibration curves were established in the field. Mean annual suspended sediment concentration was combined with water flux data to assess the annual suspended load, using data interpolation between the sampling periods.

Land use was assessed annually by field surveys. Land use types included: forest (Fo), annual crops (C), fallows or pastures (Fa). Crops associated with conservation practices (Cp) were mainly coffee and agroforestry techniques with annual crops. Teak, eucalyptus tree plantations, and orchards were placed in a single category (O). A preliminary evaluation of the off-site impacts of soil erosion was conducted in Thailand by studying the sedimentation of the reservoir downstream of the benchmark catchment.

The "best bet" land management options were identified and introduced through farmer consultations. With the farmers' participation in the selection process, it is expected that they will continue practicing the system, which in the long run will provide better income and less resource degradation. The introduced land management options are evaluated for their acceptability and sustainability, and a wider uptake at the community level is promoted to produce greater impact.

The participatory process in soil erosion management research on a catchment scale was employed since the establishment of the consortium and the design of the research program. A series of consultation meetings and dialogues among various stakeholders, including the NARES, IARCs, ARIs, NGOs, donors and farmer representatives, was undertaken to agree on the design of the research and the various partners that would be involved.

With the aim of promoting activities based on the principles of participation, interdisciplinarity, and collaboration, the NARES identified local institutions and project teams composed of researchers of different disciplines. Within the countries, collaboration among relevant partners has evolved. The organization of these teams from different institutions and disciplines has enhanced the participatory, interdisciplinary, and interinstitutional mechanisms that the consortium advocates. Generally, this arrangement is committed through formal agreements signed between and among institutions. It is intended that this arrangement should optimize the use of scarce resources and enhance the synergy of different experts and institutions.

Research Results

Relationships between Environmental Factors and Soil Erosion

The relation between environmental factors and runoff amount (R), bed load (BL), and suspended load (SL) was determined by correlation analysis. The environmental factors included annual precipitation (P), the precipitation ratio (Pr) between minimum monthly precipitation (Pn) and maximum monthly precipitation (Px), slope gradient (S), catchment area (Surf) and the areal percentage of each land use type.

Runoff and sediment yield were not significantly related to Surf (Table 2, Chaplot *et al*, 2002). Runoff coefficient (R) was highly correlated to orchard land use, O ($r = -0.87$) and slope angle, S ($r = 0.56$) and rainfall characteristics. Bed load (BL) was significantly correlated to the areal percentage of annual crops, C ($r = 0.83$). Suspended sediment load was mainly related to C ($r = 0.76$) and the ratio between minimum and maximum monthly precipitation Pr ($r = 0.61$). Under these sloping land conditions, the percentage of annual crops, not associated with conservation practices, appears to be the main factor controlling sediment yield, both in terms of suspended load and bed load, regardless of the size of the catchment. These results indicate that the area under annual crops seems to be the key parameter related to bed load and suspended load production. Surprisingly, no significant relation was found between runoff coefficient or sediment yield variables and the areal percentages of land occupied by forest or crops associated with conservation practices.

Figures 7 and 8 present the relationships between observed and predicted values for mean annual runoff, mean annual sediment load, and mean annual bed load. More than 70 percent of the variance was explained by Pr, C, and S in the case of runoff, and by Pr and C in the case of suspended sediment load. Less than half of the variance of bed load is explained by C ($r^2 = 0.41$). It is interesting to note that the bed load deviation errors could be ascribed to country conditions, suggesting some site specificity (Figure 9).

Table 2. Correlation coefficients between environmental factors, runoff and sediment yield variables (Chaplot *et al.*, 2002)

	Surf	P	Pm	*Pr*	S	C	Fa	Cp	O	Fo
R	0.04	-0.95*	-0.91*	0.95*	0.55*	0.25	0.53	0.21	-0.87*	0.39
BL	-0.29	-0.16	0.01	0.22	-0.37	0.83*	-0.4	-0.07	-0.27	0.04
SL	-0.08	-0.54	-0.3	0.61*	-0.28	0.76*	-0.37	0.43	-0.47	0.21
SC	0.33	0.35	0.2	-0.39	0.23	-0.04	0.18	-0.45	-0.05	0.21

Surf (ha) is the catchment area; P, the annual precipitation; Pm, the maximum monthly precipitation; Pr (%) the ratio between Pn, the minimum monthly precipitation and Pm; S (°), the slope; C, the areal percentage for annual crops; Fa, the areal percentage for fallows or pastures; Cp, the areal percentage for crops with conservation practices; O, the areal percentage for orchards; Fo, the areal percentage for forests; R, the runoff ratio; BL, the bedload; SL, the suspended sediment load; SC, the sediment concentration.

*significant at the 5% level

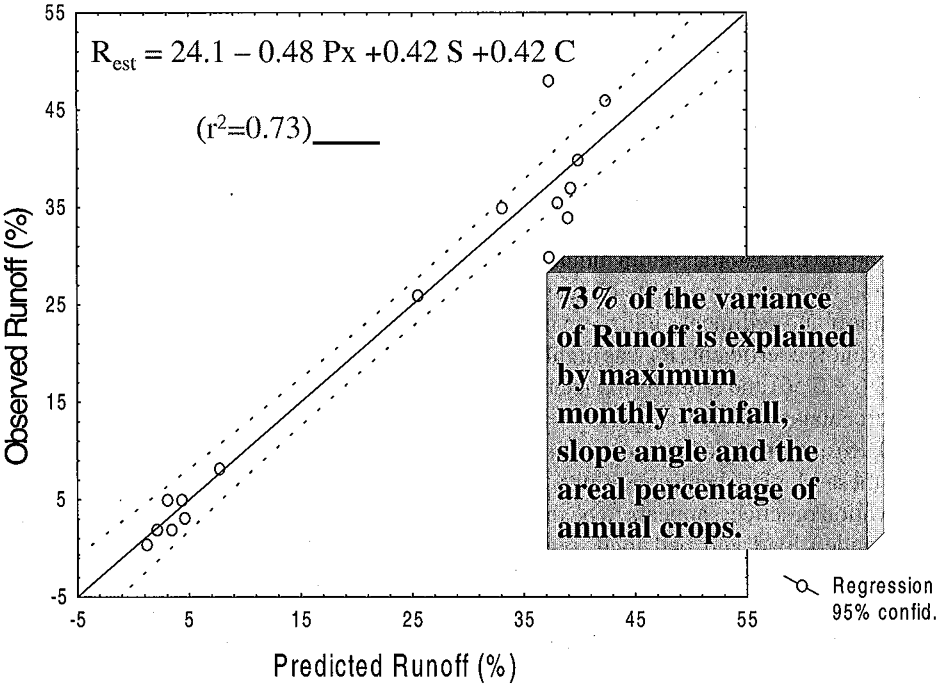

Figure 7. Observed mean annual runoff as a function of predicted runoff or a data set of 16 catchments in Southeast Asia (modified from Chaplot *et al.*, 2002)

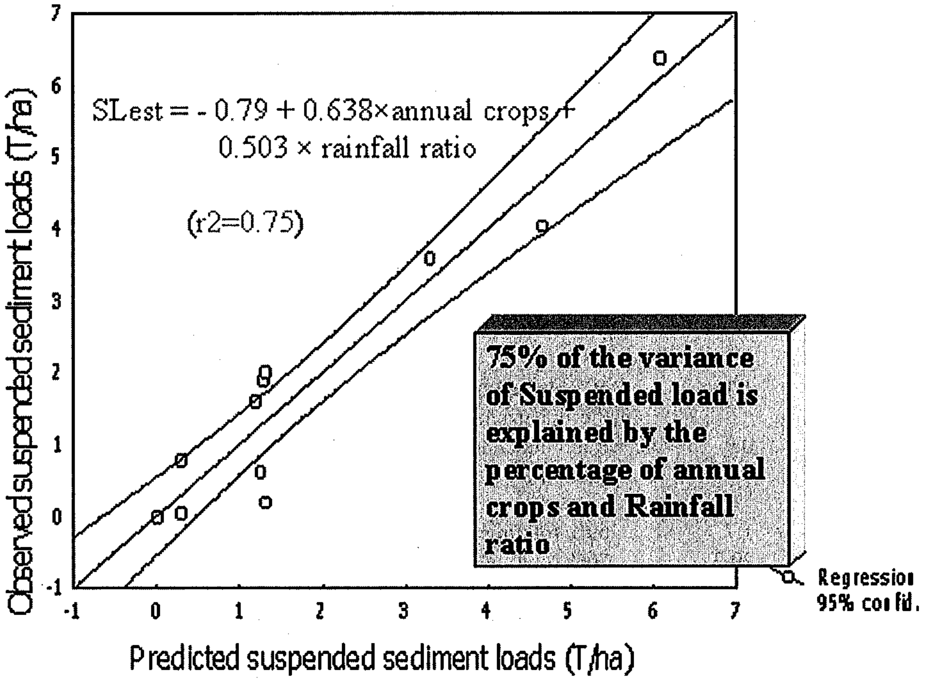

Figure 8. Observed mean annual suspended sediment load as a function of predicted suspended sediment load for a data set of 11 catchments in Southeast Asia (modified from Chaplot *et al.*, 2002)

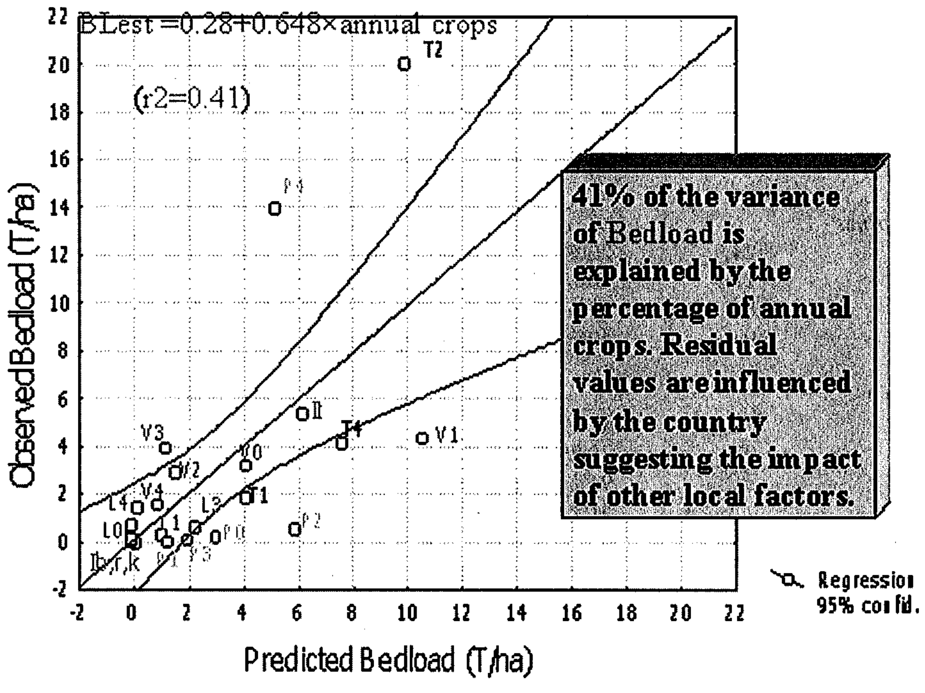

Figure 9. Observed mean annual bedload as a function of predicted bedload for a data set of 21 catchments in Southeast Asia (modified from Chaplot *et al.*,2002)

Soil Erosion and Land Use

Current land management practices had some effects on the degree of soil erosion in the different sub-catchments within the catchments. Except for the results obtained in Nepal, the areas more intensively cultivated to upland crops produced more soil loss than those grown to perennials or left under grass cover (Tables 3 and 4).

Table 3. Observed soil erosion rates in the sub-catchments 2001

Sub-catchment	Area (ha)	Land use	Soil loss (t ha^{-1})
Indonesia			
Tegalan	1.1	50% annual upland crops, coffee and nutmeg on the upper slopes	20.0
Rambutan	0.9	Rambutan and some bare plots	0.8
Kalisidi	20.0	Rambutan	1.0
Laos			
S1	1.7	69% rotating land, 31% teak	0.5
S2	29.3	76% rotating land, 6% upland rice	0.6
S3	19.8	80% rotating land, 12% forest	0.0
S4	27.7	61% rotating land, 11% Job's tears, 10% forest, 7% upland rice	2.1
S5	13.1	53% rotating land, 35% forest, 8% upland rice	2.8
		56% rotating land, 13% forest, 31% teak	
S6	2.5		2.0
Nepal	72.6		
W2		Mixed (45% upland, 5% lowland, 20%	0.1
	39.6	shrubs, 30% forest)	
W3		Mixed (60% upland, 10% shrubs, 30% forest)	0.1
	11.5	Mixed (23% upland, 2% lowland, 35%	
W4		shrubs, 40% forest)	0.1
	1.6	Upland cultivated (100%)	
W5			Traces
Philippines			
MC1	24.9	20% cultivated, 80% Falcata, grassland	0.1
MC2	17.9	40% cultivated, 60% grassland/forest	0.7
MC3	8.0	10% settlement, 15% cultivated, 75% natural grass	1.0
MC4	0.9	40% cultivated, 60% grassland	53.9
Thailand			
W1	11.6	47% soybean-mung bean, 47% tamarind	0.1
W2	9.8	78.2% soybean-mung bean, 13% shrubs	1.6
W3	3.2	94% tamaring, shrubs	1.0
W4	7.1	51% soybean-mung bean, 23% mango, tamarind	0.4
Vietnam			
W1	4.8	67% monoculture cassava, 33% natural grass	5.2
		24% cassava intercrop, 59% cassava	
W2	9.4	monoculture, 17% natural grass	4.3
		100% cassava intercrop	
W3	5.2	26% cassava intercrop, 74% natural grass	3.9
W4	12.4		2.0

Note: Period of observation:
Indonesia – March 2000 to February 2001
Laos – May to September 2001
Nepal – March to September 2001
Philippines – April 2000 to March 2001
Thailand – June to September 2001
Vietnam – January to August 2001

Table 4. Observed soil erosion rates in the sub-catchments, 2002

Sub-catchment	Area (ha)	Land use	Soil loss (t ha^{-1})
Indonesia			
Tegalan	1.1	50% annual upland crops, coffee and nutmeg on the upper slopes The upper slopes	10.2
Rambutan	0.9	95% rambutan, 5% shrubs	0.2
Kalisidi	13.0	Rambutan	7.8
Babon (flume)	285.0	All above + rice fields	6.1
Laos			
S1	19.6	49% annual crops, 36% fallow, 14% forest	0.5
S2	32.8	67% annual crops, 19% fallow, 12% forest	0.0
S3	51.4	27% annual crops, 48% fallow, 8% forest	0.9
S4	60.2	8% annual crops, 51% fallow, 32% forest	1.9
S5	63.0	2% annual crops, 51% fallow, 14% forest, 34% teak	0.0
S6	0.6	55% annual crops, 6% fallow, 30% forest	0.4
S7	0.6	79% annual crops, 21% forest	4.7
S8	0.6	40% annual crops, 60% forest	1.9
S9	0.7	24% annual crops, 63% fallow, 13% forest	0.1
Nepal			
W2	72.6	Mixed (45% upland, 5% lowland, 20% shrubs, 30% forest)	0.1
W3	39.6	Mixed (60% upland, 10% shrubs, 30% forest)	0.2
W4	11.5	Mixed (23% upland, 2% lowland, 35% shrubs, 40% forest)	0.4
		Upland cultivated (100%)	
W5	1.6		0.0
Whole (W1)	124.3		0.2
Philippines			
MC1	24.9	20% cultivated, 80% Falcata, grassland	0.0
MC2	17.9	40% cultivated, 60% grassland/forest	0.1
MC3	8.0	10% settlement, 15% cultivated, 75% natural grass	0.0
MC4	0.9	40% cultivated, 60% grassland	28.3
Whole	84.5		1.1
Thailand			
W1	11.8	47% soybean-mung bean, 47% tamarind	0.1
W2	9.6	68% soybean-mung bean, 13% shrubs	0.9
W3	3.2	59% tamarind, shrubs, 41% annual crops	1.5
W4	7.1	51% soybean-mung bean, 23% mango, tamarind	1.2
Whole (Flume)	93.2		2.5
Vietnam			
W1	3.7	67% monoculture cassava, 33% natural grass	1.3
W2	7.7	24% cassava intercrop, 59% cassava monoculture, 17% natural grass	1.9
W3	10.8	100% cassava intercrop	0.8
W4	7.2	26% cassava intercrop, 74% natural grass	0.6
Whole	45.5		0.5

In Indonesia, sediment yield was highest in the Tegalan sub-catchment dominated by upland annual crops yielding a soil loss of 20 t ha^{-1} in one year of observation. This is presumably because of minimal soil surface litter and little canopy cover of the catchment (Agus *et al.,* 2002, 2002a). On the other hand, the other sub-catchments (Rambutan and Kalisidi) planted to perennials (primarily rambutan), lost only about 1 t ha^{-1} of soil during the same period, yielding most sediment during the middle part of the rainy season (January).

In 2002, there was again a relatively higher erosion rate of 10 t ha^{-1} in the Tegalan sub-catchment. However, there was a significant reduction in the erosion rate compared with 2001. This could be attributed to the introduction of the fodder grass to reduce erosion and improve farmers' income through livestock integration. It should be noted that in 2002, more than 60 percent of the area adopted this intervention.

In the Philippines, the smallest sub-catchment (MC4), which has a higher percentage of cultivated area, gave the highest soil loss of 54 t ha^{-1}. The lowest soil loss of 0.1 t ha^{-1} was from the MC1 sub-catchment which has a lower percentage of cultivated land and a larger area covered with grasses. The MC3 sub-catchment, which has the lowest percentage of cultivated area but with 10 percent of settlements, yielded a higher soil loss. The relatively higher soil loss in this sub-catchment may be attributed to erosion from the foot trails and road network (Ilao *et al.*, 2002). Using a simulation model, Ziegler *et al.* (1999) showed that roads generate runoff sooner during a rainfall event, and have greater discharge values than other surfaces. Sediment transport was also greater. Footpaths emerged as important sources of accelerated runoff from agricultural fields that would otherwise require large amounts of rainfall to produce runoff.

In Vietnam, W1 (predominantly cassava monoculture with some natural grass) produced the largest soil loss of about 5.2 t ha^{-1}. The least was from W4 (predominantly natural grass and cassava intercropping) at 2.0 t ha^{-1}. The larger soil loss from W1 (primarily cassava monoculture) compared with W3 (all cassava intercropping) shows the effect of intercropping on soil losses. At its peak growth, cassava provides only about 47-56 percent soil cover, whereas mixed cropping or intercropping can increase this protective cover (Toan *et al.,* 2002). The effect of natural grass in the sub-catchments on soil losses was also evident. Natural grass enhances infiltration, reduces runoff and runoff velocity, and consequently reduces soil loss.

In Laos, the sub-catchment with the smallest proportion of rotating land and with some 8 percent of upland rice (S5) gave the highest soil loss of 2.8 t ha^{-1} (Phommassack *et al.,* 2002). No erosion was observed in the sub-catchment with the largest proportion of rotating land and about 12 percent forest (S3). In Nepal all sites gave very low soil losses in both years, irrespective of land use (Bhattarai *et al.*, 2002).

In Thailand, the observed soil losses in 2001 and 2002 were not alarming, being less than 2 t ha^{-1} (RFD/LDD, 2002). The increase in soil loss in W3 from 2001 to 2002 was attributed to 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 in 2002 and soybean was planted, increasing the area planted to annual crops from 3 to 41 percent. Another cause of variation in erosion can be the rainfall characteristics between years. In 2002, total rainfall was lower and more widely distributed. In 2001, there was a strong rainfall event which accounted for more than 70 percent of the total runoff (Janeau *et al.*, 2003).

Soil Erosion and Slope

Rainfall simulation studies in Thailand showed that the infiltration rate increased while the runoff coefficient decreased with slope gradient (Janeau *et al.*, 2003a). Moreover, sediment concentration and soil detachment decreased sharply with increasing slope indicating that soil erosion decreases with slope (Figure 10). These results conflict with the accepted belief that more runoff is generated from steeper slopes. It is suggested that for convex landforms, the steep mid-slope zone can act as an infiltration trap for runoff water from the upper gentler zone. This may have substantial impacts on flow volume generated from small watersheds and on water quality. As similar results are obtained under natural conditions in Laos, it can be concluded that they are valid for mountain soils with highly stable micro-aggregates. The data should encourage more research on the physical processes involved in soil erosion in steep slopes.

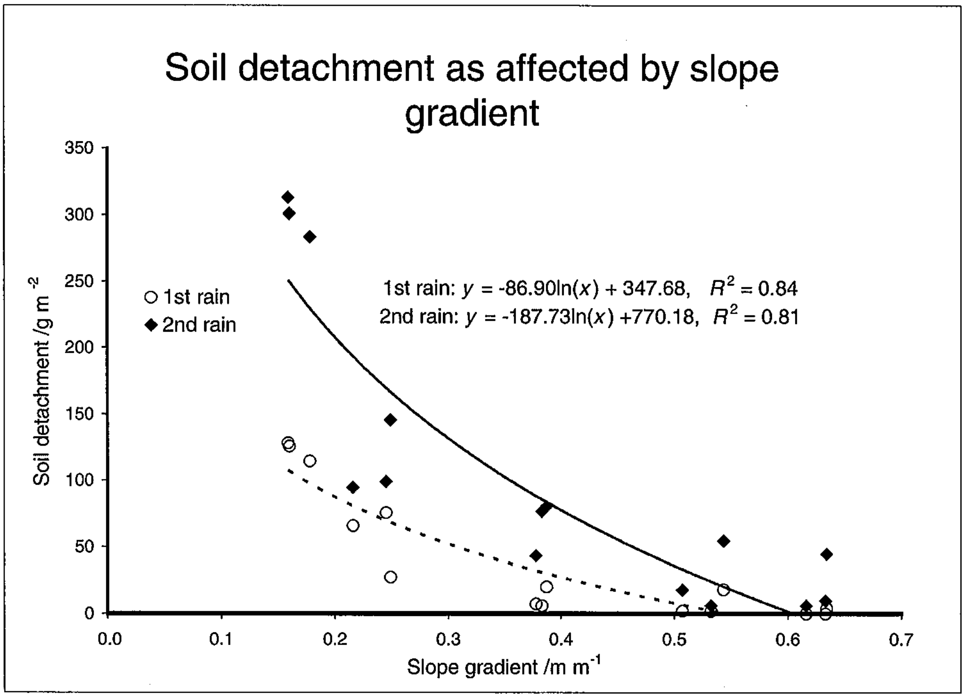

Figure 10. Soil detachment as affected by slope (Janeau *et al* 2003)

Tillage Erosion

Tillage erosion results from land preparation and repeated weeding operations. In northern Laos, in a field with a mean slope of 60 percent, soil losses due to tillage erosion are of the same order of magnitude as those due to water erosion (4-5 t ha^{-1} yr^{-1}) (Dupin *et al.*, 2002). These soil losses affect the most fertile soil layer. Soil clods detached by tillage operations accumulate in depressions or at field boundaries. Because of increasing weed pressure, tillage erosion is likely to become very serious, especially on the steeper slopes, because soil losses from tillage increase with slope (Figure 11). Other factors that affect tillage erosion are weed pressure, which causes an increase in the depth and number of tillage operations, and residues that trap aggregates and so reduce soil displacement.

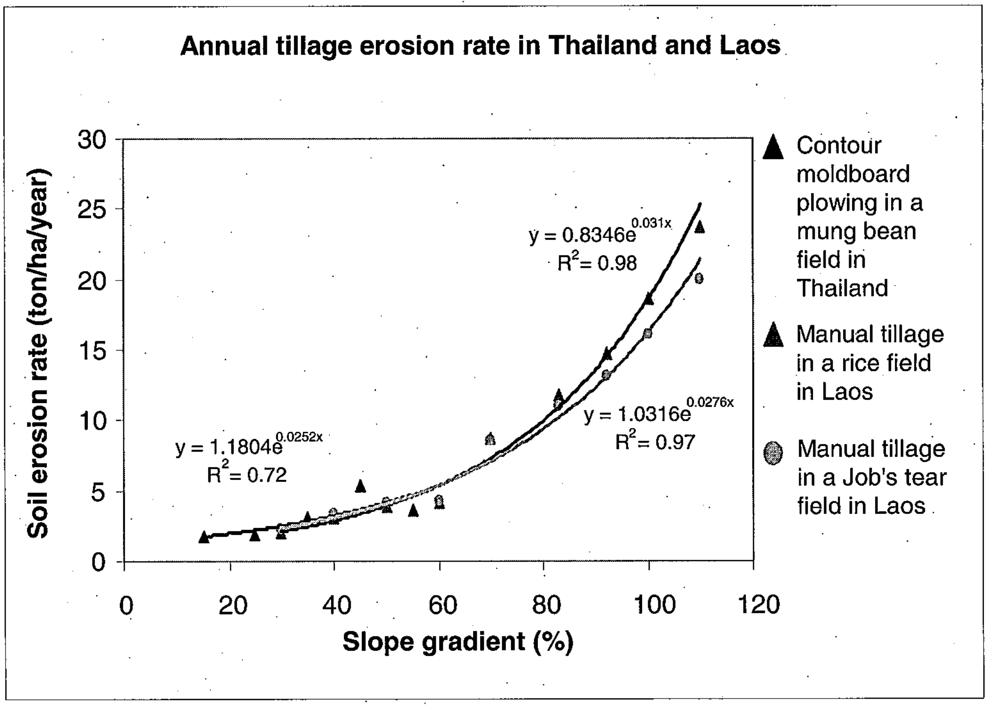

Figure 11. Tillage erosion as affected by slope

Alternative practices that limit weed infestation and the need for tillage operations need to be developed. Where a short fallow period is still possible, improved fallows of pigeon pea (*Cajanus cajan*) (or *Crotalaria, Leucaena, Gliricidia*) sown into the previous crop should be tested. This plant, which grows faster and provides more nutrients to the soil than fallow composed of natural species, can limit weed proliferation. Two other practices can also limit tillage erosion. The first is the no till system with cereals and a cover crop. The field is prepared without burning and without tillage. The cover crop reduces weed growth and the mulch provides nutrients. The second practice is contour planting, which hinders the movement of soil downslope, causing it to accumulate immediately above the crop line and associated weeds and residues. Provided there are sufficient obstacles along the crop rows, contour planting will induce the formation of micro-terraces.

Nutrient Loss and the On-site Cost of Soil Erosion

The on-site effect of soil erosion is generally reflected in a reduction of soil productivity through the loss of chemical, physical, and biological fertility. Erosion reduces soil depth, decreases water holding capacity and reduces chemical fertility through nutrient and organic matter loss. Table 5 shows the amount of nutrients lost in 2001 and 2002 at the study sites in Indonesia, Philippines, Vietnam, and Laos (Sukristiyonubowo *et al.*, 2002). In general, nutrient loss was lower in 2002 than in 2001, which is consistent with the lower rainfall in that year.

Table 5. Nutrient losses from different MSEC catchments in 2001 and 2002

Catchment	Nutrient loss (kg ha^{-1} year^{-1}) N		P		K	
	2000/01	2001/02	2000/01	2001/02	2000/01	2001/02
INDONESIA						
Tegalan	21.53	5.34	5.82	1.82	9.02	1.65
Rambutan	0.89	0.00	0.90	0.00	1.11	0.00
Kalisidi	9.24	0.03	0.21	0.13	5.97	0.08
Parshall flume	0.60	0.00	0.00	0.00	2.11	0.01
PHILIPPINES						
MC 1	0.50	0.00	0.00	0.00	0.50	0.00
MC 2	2.30	0.21	0.00	0.00	0.05	0.03
MC 3	4.80	0.00	0.00	0.00	0.19	0.00
MC 4	144.20	37.59	0.08	0.00	6.09	3.32
Whole	1.30	1.59	0.00	0.00	0.15	0.17
VIETNAM						
W 1	10.79	3.50	4.81	0.57	4.26	4.73
W 2	10.83	4.60	4.97	0.83	2.46	1.74
W 3	8.73	1.60	3.99	0.39	2.68	1.41
W 4	4.03	1.10	2.25	0.31	1.38	0.83
MW	3.55	0.90	1.94	0.22	2.58	0.75
LAOS						
S 0	0.03	0.00	0.00	0.00	0.00	0.00
S 1	4.74	1.25	0.90	0.20	0.82	0.12
S 2	5.12	0.06	0.93	0.01	0.79	0.00
S 3	12.51	3.31	1.91	0.15	0.76	0.01
S 4	16.27	2.58	2.73	0.12	0.98	0.07

One method of estimating the on-site cost of soil erosion is to calculate the equivalent cost of replacing nutrients lost by erosion. On this basis, the on-site cost of erosion varies among countries depending on soil loss and the cost of fertilizers. In 2002, the cost of lost nutrients was highest in the MC4 sub-catchment in the Philippines at US\$27 ha^{-1} yr^{-1} (Table 6).

This was followed by the sub-catchments W1 in Vietnam and Tegalan in Indonesia. The MC4 sub-catchment had the highest N loss and the second highest K loss. W1 in Vietnam gave the highest K loss, while Tegalan in Indonesia had the highest P loss.

Table 6. Nutrient loss and on-site cost of erosion at different MSEC catchments in 2002

Catchment	Soil loss	Nutrient loss (kg ha^{-1} yr^{-1})			On-site cost
	(t ha^{-1} yr^{-1})	N	P	K	(US$)
INDONESIA					
Tegalan	10.20	5.34	1.82	1.65	8.48
Rambutan	0.20	0.00	0.00	0.00	0.01
Kalisidi	7.80	0.03	0.13	0.08	0.34
Parshall flume	6.10	0.00	0.00	0.01	0.02
PHILIPPINES					
MC 1	0.00	0.00	0.00	0.00	0.00
MC 2	0.08	0.21	0.00	0.03	0.16
MC 3	0.00	0.00	0.00	0.00	0.00
MC 4	24.70	37.59	0.00	3.32	27.10
Whole	1.07	1.59	0.00	0.17	1.18
VIETNAM					
W 1	4.40	3.50	0.57	4.73	9.54
W 2	3.90	4.60	0.83	1.74	6.53
W 3	2.90	1.60	0.39	1.41	3.55
W 4	1.60	1.10	0.31	0.83	2.31
MW	1.90	0.90	0.22	0.75	1.93
LAOS					
S 0	0.58	0.00	0.00	0.00	0.00
S 1	0.72	1.25	0.20	0.12	0.44
S 2	0.59	0.06	0.01	0.00	0.02
S 3	1.47	3.31	0.15	0.01	0.95
S 4	6.83	2.58	0.12	0.07	0.76

Analysis for 2001 showed the same trend with a cost of US$52 ha^{-1} yr^{-1}, also in the Philippines (Biltonen, 2002). In general, it can be seen that the cost of soil erosion is a small fraction of annual income, which varies from US$296 to 1,200 per year (Table 1). Compared with the high cost of labor for erosion control, the costs of erosion are relatively small, and will probably be insufficient to motivate farmers to adopt conservation measures.

Off-site Impacts of Soil Erosion

An evaluation of the off-site impacts of soil erosion was conducted by identifying potential economic activities downstream that could be affected by the erosion occurring in the upper catchments. A simple evaluation of the off-site effect of erosion was carried out at the Philippine site by estimating the cost of dredging the irrigation canals and diversion of the Manupali River Irrigation System (Ilao *et al.*, 2002). A total of 84 685 m^3 of sediments has been estimated to have been transported into the system since 1995. Assuming that 0.5 percent comes from the Mapawa site, it was estimated to have contributed 423 m^3 of sediments to the irrigation system or an equivalent of US$250 in terms of the cost of dredging.

In Thailand, the sedimentation of the reservoir downstream was also evaluated. 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 operation of the reservoir, and the bathymetric map prepared by conducting a survey before the rainy season of June 2002. The maps were prepared using the Surfer program (Bindford and Sloan, 2000).

Siltation in the Mae Thang reservoir at the study site in Thailand showed a 10 percent reduction in its storage volume after seven years of operation (Janeau *et al.* 2003). The soil erosion rate calculated from the volume of sediments that have accumulated in the reservoir was 51 t ha^{-1} yr^{-1}. At this rate of erosion and sedimentation, the life of the reservoir would not be more than 70 years (Table 7). The rate may be an overestimation, but the value is close to that presented by Inthasothi *et al.* (2000).

Table 7. Estimated erosion and sedimentation rates at different scale studies (Janeau *et al.*, 2003)

	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}) catchment scale (t ha^{-1} yr^{-1})	1.45 17,585	50 605,000	51.2 620,000	26.4 321,860
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}

In addition to the effect on the life of the reservoir and its irrigation service area, erosion in the upper catchments may also cause an accumulation of heavy metals and other toxic substances in the reservoir. Granulometric and chemical (heavy metals) analysis made on lake sediment samples showed no significant pollution. However, fish farming may be affected particularly during the first heavy rains due to the accumulation of pesticides used in the watershed (Boonsaner *et al.* 2002).

Innovative Land Management Options

The recommended land management options were identified in consultation with the farmers and introduced in 2001 and 2002. In most instances, the options introduced in the catchments were variants of the contour hedgerow farming combined with improved soil fertility management and animal production (Table 8).

Table 8. Land management options introduced in the different catchments

Country	Catchment	Best bet options
Indonesia	Babon	Combination of fodder grass planted on alternate terraces of land currently used for annual upland crops and cattle fattening
Laos	Lak Sip	Contour cropping with contour barriers of perennial crops as from experience of ASIALAND network; direct seeding through mulch (cover crop killed by herbicide); improved fallow land management using legumes
Nepal	Masrang Khola	Sloping agricultural land technology adopted from the Philippines
Philippines	Mapawa	Use of natural vegetative strips (NVS) and some agroforestry crops as hedgerows; fertilizer management will be incorporated with the technology. Other options include planting pasture legumes during idle periods and tiger grass and bamboo along creeks
Thailand	Huay Ma Nai	Hillside ditch farming system
Vietnam	Dong Cao	Use of vetiver grass and *Tephrosia candida* as hedgerows and improved variety of cassava in the alleys

In the Philippines, natural vegetative strips (NVS) being promoted by ICRAF were introduced in 2002 with emphasis on soil fertility management as suggested by the farmers. This has been done using native grasses and some agroforestry crops as hedgerows (Figure 12). It is worth noting that several farmers have already adopted this technique as a result of the promotion activity by ICRAF in the area. Adoption seems to be affected by the farmers' tenure system. About half of the landowners, but no tenant farmers, have adopted some conservation measures so far (Duque *et al.*, 2001). The major reason for the lack of adoption by farmers interested in the practice is the cost of establishment.

Figure 12. Corn plants on the alleys of the NVS in MC2 in Mapawa Catchment in the Philippines

In Indonesia, the conversion of arable land into fodder banks of elephant grass (*Pennisetum purpureum*) combined with livestock production was first implemented in November 2001, and completed in 2002 by the procurement of cattle. The grass was planted on alternate terraces of land currently used for annual upland crops. In terms of the severity of erosion, the area planted to annual upland crops needs priority attention. The fodder grass is expected to reduce erosion and serve as feed for the livestock. The identification of this option was based on the lesson learned that farmers' adoption and improvement of conservation measures is determined by the economic contribution of the measure to the household economy. Farmers are attracted to a practice only if the practice promises an economic benefit, and so this consideration must be put forward in the participatory technology selection process.

In Vietnam, *Tephrosia candida* and vetiver grass (*Chrysopogon zizanioides*) have been used since 2001 as hedgerows combined with the use of a high-yielding variety of cassava. Possibly as a result of a nearby demonstration site on alley cropping, the farmers believe that the system will reduce runoff and soil loss, add organic matter, and improve soil fertility through the addition of hedgerow trimmings.

In Lao PDR, the traditional practice of slash and burn has been closely monitored over a period of two years, and "improved" options are currently under observation. These include (i) improved fallow involving later intercropping of pigeon pea and *Crotalaria*, (ii) contour planting of Jobs' tears (*Coix lachryma*-jobi) with pigeon pea, or *Crotalaria* and pineapple (*Ananus comosus*), and (iii) no tillage with the use of herbicides. In terms of soil erosion, these options yielded 0.4, 2.5, and 0.6 t ha^{-1} of soil loss respectively, compared with 5.7 t ha^{-1} from the traditional slash and burn system (Table 9). The cultivation of upland rice and Job's tears also required more labor (210 days ha^{-1}) in the slash and burn system compared with 171, 182, and 138 days ha^{-1} for improved fallow, contour planting, and no tillage, respectively (Table 10).

Table 9. Impact of innovative farming technologies on bedload, suspended load, and total sediment yields, Houay Pano Catchment, Laos. Traditional system includes fallow land with slash and burned fields (NAFRI, 2002)

Traditional and innovative farming systems	Catchment area ha	Bedload $t\ ha^{-1}$	Suspended load $t\ ha^{-1}$	Total sediment yields $t\ ha^{-1}$
Slash & burn (control)	0.62	4.74	0.99	5.74
Improved fallow	0.64	0.4	0.01	0.42
Improved fallow + contour planting	0.567	1.95	0.56	2.51
Mulch & no tillage	0.727	0.11	0.47	0.58

Table 10. Normalized labor required (days ha^{-1}) for the cultivation of upland rice and Jobs' tears, Houay Pano, Laos, 2002 (NAFRI, 2002)

Operation	Slash and Burn	Improved fallow	Contour planting & Improved Fallow	No tillage
Field preparation	41	43	71	29
Burning	1	1	1	
Second clearing	26	57	29	63
First weeding	36	28	18	21
Second weeding	38	2	6	
TILLAGE SUB-TOTAL	142	131	125	113
Herbicide				5
Transport/planting pineapple			**26**	
Planting main cereal crop	43	34	33	21
Planting cover crop		42	**30**	**6**
Harvest and transport	25	6	24	4
GRAND TOTAL	210	171	182	138

The Network and Consortium Arrangement

As presented earlier, MSEC employs the networking arrangement in implementing its research on erosion management. Networking has been established not only in terms of institutions and expertise but also in the benchmark catchments where the studies are carried out. Networking can overcome the high cost of conducting catchment research.

The project has established a network of 34 catchments and sub-catchments for hydrology and soil erosion management research. With the instrumentation put in place, the network provides a valuable tool for evaluating the impact of land use and land use changes on soil erosion over a range of biophysical and socio-economic environments. It provides benchmark information for evaluating the acceptability and sustainability of technology options for catchment development. It can also provide the basis for scaling up and promoting the uptake of such options to, at least, the level of the communities.

An active network of institutions and projects working together to address the problem of soil erosion and land management has been put in place. The network has facilitated exchange of information and expertise on catchment research and development and developed agreed standards and methodologies for this research. These common approaches will enable more comparative studies and enhance the potential for rapid advances in knowledge on viable erosion management strategies.

The consortium provides an effective mechanism to organize many activities covering a large geographical area. It provided venues for exchange of experiences between countries, which contribute their experience to other countries. This network between and among researchers, has contributed greatly in developing methodologies by combining experiences from different countries. The network also broadened the view of researchers and enhanced researcher experience via the visiting of other centers in the network.

With stronger and continuing partnerships among stakeholders, particularly the farmers, it is believed that the network and consortium arrangement will bear fruit in the longer term. IWMI will continue to employ this approach and the promising outputs will further be validated at different scales of application and expanded to a much wider area for greater impact.

Scaling Up for Greater Impact

The established network of 34 catchments and sub-catchments for hydrology and soil erosion management research provides a valuable tool for evaluating the impact of land use and land use changes on soil erosion over a range of biophysical and socioeconomic environments. It provides benchmark information for evaluating the acceptability and sustainability of technology options for catchment development. It can also provide a basis for scaling up and promoting the uptake of such options to at least the level of communities.

The development of simple models that can be used even by those without much knowledge of computer or modelling science is one way of addressing this. The PCARES (Predicting Catchment Runoff and Soil Erosion for Sustainability) model was first developed in the Philippines for very steep slope conditions to simulate overland flow and soil erosion for each erosive rainfall event (Paningbatan *et al.*, 2001). This was further refined by AIT in Bangkok, and called the MSEC Version 1 model for dynamic soil erosion (Eiumnoh *et al.* 2002). The latest version, named PLER (Predict and Localize Erosion and Runoff) model, combines the first two versions and has now addressed the problem of fixed runoff coefficients by integrating soil infiltration capacity in the model (Bricquet *et al.*, 2002). The model is able to simulate soil erosion and sedimentation patterns within a given catchment (<100 ha), provided data on climate, soil type, topography and land use are fed into the system. Modelling outputs include static and dynamic scenarios of the distribution and intensity of erosion, sediment storage, and flux (Figures 13 and 14).

IWMI has incorporated impact assessment in its strategic plan and is embedding it in its research project cycle. An initial evaluation of the impact of the project was conducted by analyzing the benefits derived from its outputs by the collaborating NARES and participating farmers. The project may very well serve as a case study for impact assessment, which will support the scaling up process.

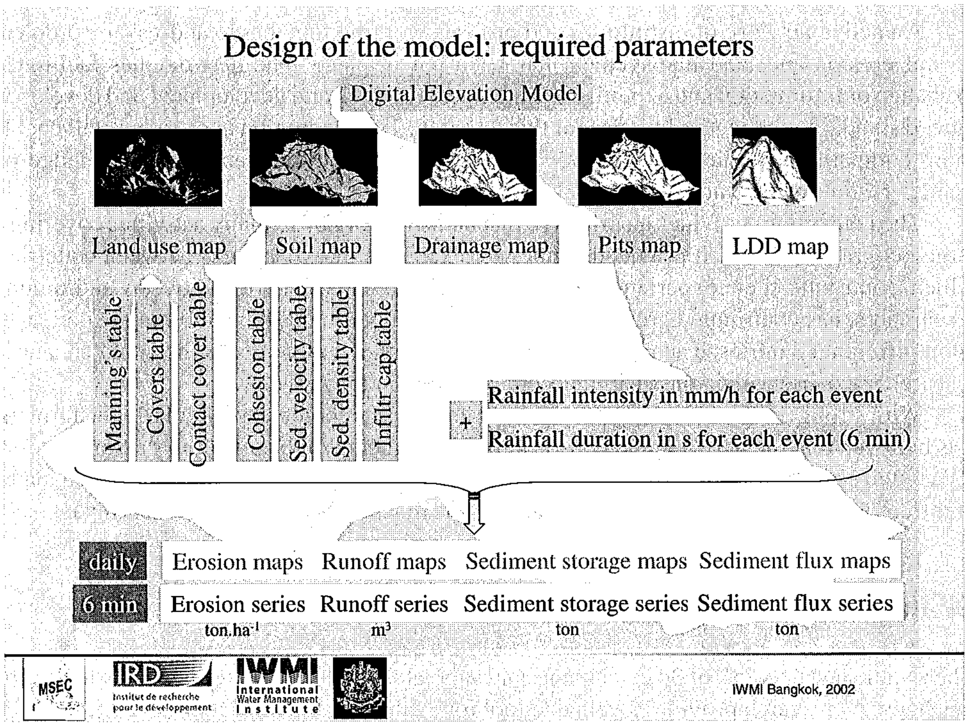

Figure 13. Flowchart of PLER (Predict and Localize Erosion and Runoff) model (Bricquet *et al.*, 2002)

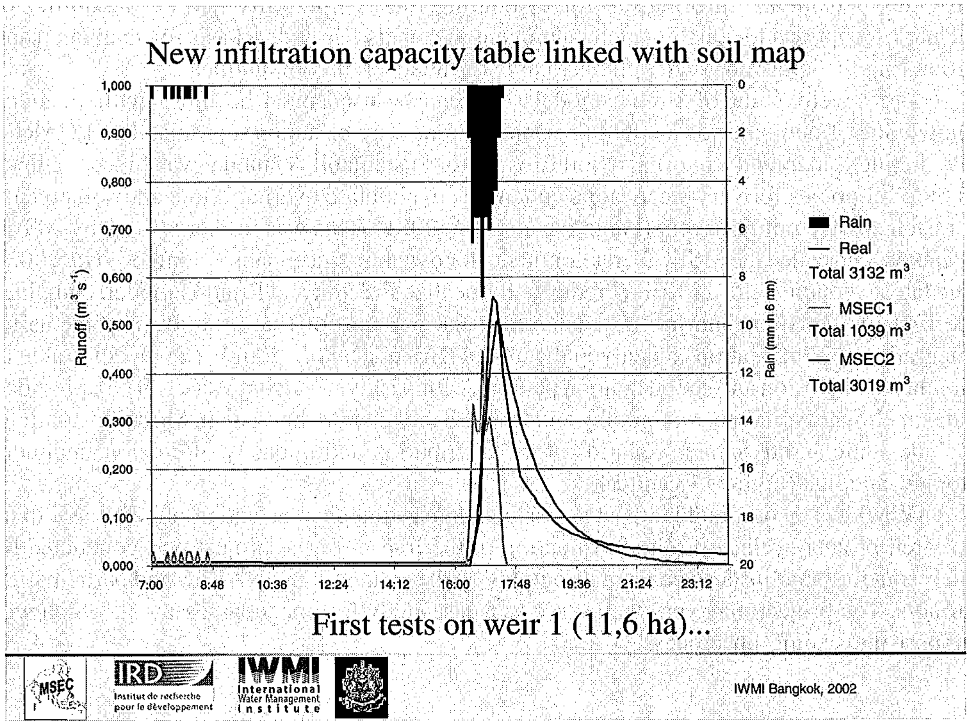

Figure 14. Comparison between observed and predicted runoff in one sub-catchment in Thailand

Next Steps/Challenges

Consultations and meetings with various stakeholders have taken much time, and the start of full-scale implementation of the project has been greatly delayed. A memorandum of understanding (MOU) with the NARES is still needed to formalize the implementation of the project in the participating countries. It also takes time for some partners to internalize the principles of participation, interdisciplinarity, and integration.

The project has a steering committee to provide direction and guidance for the operation of the network or the consortium. However, there is still concern on the effectiveness of the committee in providing the expected inputs. The committee meets at most only twice a year, and consequently continuity is usually a problem. The members of the committee are usually the national coordinators who are busy with their other responsibilities in their own institutions. Several suggestions have been forwarded to strengthen these committees. Smaller cluster groups or task forces have been created to look into the more specific issues of research, capacity building, and information dissemination.

Communication between IWMI and the NARES and among the NARES themselves has been a perennial concern. Exchange of information and monitoring is critical in this kind of research, which implements new methodologies and involves a number of partners. Thus, communication between and among partners needs to be further strengthened. Transaction costs have initially been very significant.

MSEC has been envisaged as a long-term project, and IWMI is committed to outsourcing the support needed to continue its planned activities. A second phase of the project has been proposed to develop, adapt, and disseminate appropriate tools and methodologies on how to scale up the application of research results and technology options to larger catchments. The aim is to better capture the interactions among the on- and off-site users of the land and water resources, to more effectively resolve competing demands by these users, and to identify and use impact assessment indicators for project monitoring. With the application of these tools and methodologies, the promotion and uptake of promising smallholder water and land management systems is expected to be enhanced and to contribute to more sustainable use of watershed resources.

IWMI expects that the lessons learned from the case study can be fruitfully used in carrying out research activities in the upper catchments as part of the Global Challenge Programme on Water and Food, which IWMI leads. It will also use the experiences of other related program on catchment management. This integrated approach, which considers the biophysical, socio-economic, policy, and even political environments, could be the best workable system to sustain upland development.

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Cover Photograph: Gullies formed on cultivated steep slopes, Houay Pano catchment, Lao PDR, photo. A. de Rouw.