From Soil Research to Land and Water Management: Harmonizing People and Nature

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

Foreword

Soil erosion is considered a major cause of land degradation. While quite a few studies have been conducted to address the problem, results have not yielded technologies and management systems that are widely accepted and maintained to sustain upland development. This concern is the major rationale for the establishment of the Management of Soil Erosion Consortium (MSEC) and the conduct of the soil erosion management project funded by the Asian Development Bank (ADB).

The first four years of the project established a network of 34 catchments and sub-catchments for hydrology and soil erosion management research. With adequate instrumentation put in place and more capable national partners developed, the network provides a valuable tool for evaluating the impact of land use and land use change on soil erosion over a range of biophysical and socio-economic environments. The research conducted in this network and other activities implemented by the project yielded outputs and lessons learned which could provide strong support to development issues that concern integrated land and water resources management and development. Particularly important is the usefulness of the outputs to decision-makers, national research and extension systems, and the farmers themselves.

As MSEC is envisioned as a longer term project, IWMI is committed to source out support 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. This is to better capture the interactions among the on- and off-site users of land and water resources, to more effectively resolve the competing demands of 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 contribute to a more sustainable use of watershed resources.

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

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Preface

Land, water, forests, and other resources are often used in unsustainable ways resulting in the degradation of most of our watersheds. Fulfilling the short-term economic demand of the increasing rural population most often outweighs the concern for more sustainable use of these resources. This poses a challenge to developing and applying watershed management strategies that will be able to harmonize the use of watershed resources, particularly land and water, to produce the desired goods and services without any adverse effect on the environment.

Soil erosion is considered a major cause of land degradation. While quite a few studies have been conducted to address the problem, results have not yielded technologies and management systems that are widely accepted and maintained to sustain upland development.

In late 1998, the Management of Soil Erosion Consortium (MSEC) initiated a research project on land management for erosion- prone areas in the humid and sub-humid tropics of Asia. 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 of the land.

The project, "Catchment Approach to Managing Soil Erosion in Asia" (ADB-RETA 5803), and supported by the Asian Development Bank (ADB), has been conducted in six Asian countries, namely, Indonesia, Laos, Nepal, Philippines, Thailand, and Vietnam. It has aimed to develop and promote sustainable and socially acceptable community-based land management options for sloping uplands through a participatory and interdisciplinary approach at the level of a catchment. It 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 took over the supervision of the project.

From 7 to 11 December 2003, the MSEC partners convened at an assembly in Vientiane, Lao PDR. The 7th annual assembly was aimed to review the accomplishments of the first four years of MSEC, share information with other related research projects, and chart the future direction of the consortium. It was organized by the National Agriculture and Forestry Research Institute (NAFRI), the Institute of Research for Development (IRD), and IWMI. The program consisted of technical sessions which reported and discussed the scientific findings of MSEC and other related projects, a field trip, and the meeting of the MSEC Steering Committee.

More than 40 researchers and scientists representing 17 agencies and institutions from seven countries in Asia, namely, Indonesia, Laos, Nepal, Philippines, Thailand, Vietnam, and Sri Lanka participated in the meeting. It was officially opened by Dr. Bounthong Bouahom, Director General of NAFRI, who represented the Honorable Sitaheng Raphone, Vice Minister of the Lao Ministry of Agriculture and Forestry (MAF). Mr. D.J Bandaragoda and Dr. Giacomo Rambaldi gave messages on behalf of IWMI and ADB, respectively.

The technical sessions started with the sharing of experiences among institutions and projects that dealt with sloping lands management. The ASIALAND network on the management of sloping lands provided some lessons it has gained from more than 10 years of work in Southeast Asia, which started with experiments at the plot scale and is now moving to widespread promotion at the community level. The International Rice Research Institute (IRRI) presented upland rice production in the sloping areas of Laos. NAFRI shared its experiences in its two years of implementation of the Integrated Upland Agricultural Research Project (IUARP) which essentially focuses on methodology for integrated upland agricultural research and collaboration in Laos. IWMI provided its insights on watershed management and discussed its projects related to watershed management.

The rest of the technical sessions dealt with cross-country analysis of the results of the MSEC project. The papers targeted soil and soil erosion, soil erosion management, and assessment of impact.

The field trip provided the participants with a clear description of the project site in Luang Prabang in northern Laos and the ongoing activities. The participants were divided into two groups to facilitate the visit and discussions. The two groups visited five sites within the catchment and discussed studies on improved fallow, improved fallow plus contour planting, slash and burn, and mulching and no tillage. Farmers were also involved during the trip and discussion with them provided additional feed-back about the project and their own expectations.

The MSEC Steering Committee met in the afternoon of the last day. The meeting primarily discussed the proceedings of the technical sessions and the field trip, the plans for the next year and beyond, project wind up and reporting arrangements, proposals for funding and the next annual meeting.

This publication documents the papers that were presented and discussed during the technical sessions.

The editors

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From Soil to Land and Water Resources Research: A Step Towards Integrated Watershed Management

D.J. Bandaragoda[1]

Watershed Management and Development

Watershed management has been invariably defined as "the approach or process of establishing an enabling environment for the sustainable use of natural resources, especially land and water resources, to address the twin objectives of resource conservation and food security". With the ultimate goal of sustaining the development of watersheds, the strategy has undergone changes through time.

In the past, watershed management had been strongly identified with forest management and rehabilitation, and the planners were preoccupied primarily with securing water supplies and/or minimizing downstream damage by sedimentation and flooding. Integrated watershed management and development has now evolved as a development intervention framework facilitating the sustainable utilization of natural resources and producing various services as required by the policies and priorities of the countries and the local population.

The International Water Management Institute (IWMI) has been implementing soil erosion management research and extension projects on sloping lands in Asia. The activities have evolved from a simple evaluation of soil conservation technologies to managing soil erosion at the catchment scale and the promotion of the technologies at the community level. It is believed that this direction is a step towards integrated land and water management and ultimately to a holistic approach to watershed development.

MSEC as a Catchment Research Project

Soil erosion is considered a major cause of land degradation and quite a few studies have been conducted to address the problem. The challenge for catchment research is to generate technologies and management systems that are widely accepted and sustainable over time. This has been the major task of the Management of Soil Erosion Consortium (MSEC) project with major funding support from the Asian Development Bank (ADB).

MSEC uses a network approach for the organization and implementation of soil erosion management research at the catchment level. The approach provides a mechanism for different scientists and research institutions to work together in a coordinated and participatory mode. As mentioned, the unit of analysis is the catchment level, to be able to capture both the on- and off-site effects of erosion. Research planning and implementation is undertaken through consultation among concerned NARES, IARCs, ARIs, NGOs, and farmers.

[1] Director, International Water Management Institute (IWMI), Southeast Asia Regional Office, Bangkok, Thailand

The NARES play the central role in the consortium, particularly in the participatory research, but with a broad responsibility for underpinning applied and strategic research as well. Typically in catchment research, partnerships play a vital role, and the efforts made so far in the MSEC project have shown their positive impact.

The Role of IWMI

In April 2001, the International Board for Soil Research and Management (IBSRAM) ceased to exist but its projects continue as part of IWMI's science program. The IBSRAM staff have become part of IWMI's new Southeast Asia Regional Office based at Kasetsart University in Bangkok, Thailand. This work includes the supervision of MSEC and serving as the executing agency for the ADB-RETA 5803 (Catchment Approach to Managing Soil Erosion in Asia).

IWMI greatly values the network tradition inherited from IBSRAM, and the opportunity of being able to collaborate with such experienced research partners. While IWMI serves as the consortium secretariat and facilitator, IWMI also has an important responsibility to ensure good quality research in MSEC's activities. To strengthen this relationship, IWMI has embarked on establishing appropriate institutional linkages with the partner countries, other international centers and advanced research institutions. At this point, I would like to mention the close partnership that we are further strengthening with IRD, the French Institute of Research for Development. IWMI is committed to supporting their work and anticipates a stronger synergism and complementation. In fact, we look forward to establishing sub-regional offices in Laos and Vietnam where the group is mainly concentrated, in addition to Thailand.

IWMI, being one of the 16 centers of the Consultative Group on International Agricultural Research (CGIAR), is basically a research organization. IWMI's mission is to improve water and land resources management for food, livelihoods and nature, and in this respect, IWMI conducts a worldwide research and capacity-building program to improve water and land resources through better technologies, policies, institutions, and management.

IWMI has chosen five research themes as its key instruments to address the need for strategic priority setting in the institute and to assure thematic integration of the research agenda across physical locations. The five themes are:

1. Integrated Water Resource Management for Agriculture;
2. Sustainable Smallholder Land and Water Management Systems;
3. Sustainable Groundwater Management;
4. Water Resource Institutions and Policies; and
5. Water, Health and Environment

The MSEC activities are mainly associated with Theme 2. Research under this theme concentrates on identifying the promising smallholder innovations and evaluating them together with partners to understand how they work and what their impacts are. It seeks to understand the conditions under which the high potential smallholder practices are viable, and then support their uptake in developing countries and regions.

Looking Forward

The first phase of the ADB-supported MSEC project has ended. Under IWMI's management, the work on catchment management will remain as a major research concern, particularly in

Southeast Asia. And, as we envision a much bigger umbrella program on catchment research, we anticipate a much strengthened program with the integration of land and water management concerns. This integration is the very essence of IWMI's proposal for a second phase of MSEC submitted to ADB and other donors for funding consideration.

Notably, most CG centers like, CIAT, CIFOR, ICRAF, ICRISAT, IFPRI, IRRI, and IWMI have recognized the value of carrying out research on and in catchments. IWMI expects that the outputs of the present catchment research will provide valuable inputs to scale up the application of research results and technology options to much larger catchments and to the bigger river basins that we are involved in.

Very recently, the CGIAR approved the proposal on the Global Challenge Program on Water and Food which IWMI leads. The Global Challenge Program is a new initiative of the CG system that aims to catalyze effective and efficient improvements of water productivity in food production in a way that favors the poor and is gender-equitable and environmentally sustainable. At the basin level, water productivity needs to be understood in the widest possible sense – including crop, livestock, and fishery yields, wider ecosystem services and social impacts such as health, together with the systems of resource governance that ensure equitable distribution of these benefits. The program is structured according to a number of interacting modules, which are:

- Improving the efficiency of water use in agriculture, via increased crop water productivity;
- Management of upland watersheds for multiple functions;
- Management of aquatic ecosystems and wetlands;
- Policy and institutional aspects;
- Interaction among the four themes.

The second module bears the greatest relevance to watershed management. Upper catchments present a diffuse spectrum of challenges to improving the management and use of water. The complexity of the challenges can be summarized in three phrases that represent different facets of the problem, namely: water and livelihoods, catchment hydrology, and social organization. The major focus of the research will be on: 1) water and poverty in upland watersheds, 2) identifying the hydrological basis for improvement, 3) realizing the increased hydrological potential in upland watersheds, and 4) extrapolation and generalization.

We therefore expect that conducting research on and in a much larger catchment than we do currently will fully capture the interactions among the on- and off-site users of land and water resources and provide a more comprehensive basis to resolve the competing demands of these users. This supports IWMI's vision of *Improving Water and Land Resources Management for Food, Livelihoods and Nature.* We hope to have a very productive collaborative program with all of MSEC's partners in the years to come.

My strong wish is that this week-long activity will be able to generate valuable information and further interest in this aspect. I take this opportunity to thank the government of the Lao People's Democratic Republic and the Asian Development Bank for supporting this event and the MSEC program in general.

Thank you.

From Soil Research to Land and Water Management: Towards Harmonizing People and Nature

S. Raphone[1]

Distinguished guests, ladies and gentlemen,

First of all, allow me, on behalf of the Minister of Agriculture and Forestry to wish you a warm welcome to Lao PDR. It is a great pleasure for me that the Management of Soil Erosion Consortium, popularly known as MSEC, has chosen Vientiane to host its annual meeting. I would like to welcome particularly those who had a long journey from Nepal, Sri Lanka, Indonesia and the Philippines. I also cheerfully welcome our neighbors and friends from Thailand and Vietnam, as well as the delegates from the national agricultural research enters and from the International Water Management Institute. Welcome also to the delegates from the Asian Development Bank, IRD, CIRAD, and of course to my Laotian friends at NAFRI, the National Agriculture and Forestry Research Institute.

I would like to express my appreciation of this opportunity to make this keynote address. The subject of this meeting – From Soil Research to Land and Water Management: Towards Harmonizing People and Nature – reminds me of the long partnership between the Soil Survey and Land Classification Center, one of the institutes of NAFRI, and IBSRAM, the International Board for Soil Research and Management. When IBSRAM encountered difficulties last year, IWMI committed itself to continuing the ongoing programs. And we are very grateful for that commitment. This also gave us the opportunity to launch cooperation with this international center. For a long time, I have been in contact with IWMI, when its programs were still focused on irrigation, which is my personal background. I am glad that IWMI is now tackling the larger domain of land and water management. This is of great interest for us because as policy-makers, we do need sound research in this field, which is so crucial for the 21st century.

At the moment, the two programs that IWMI has implemented with NAFRI – the ASIALAND sloping lands and the Management of Soil Erosion Consortium programs deal with soil erosion and conservation. This effort is consistent with the government's strategic vision for the agricultural sector over the next 10 years. Our overriding objective is to alleviate poverty through the development of productive farming systems, not only in the valleys and flatlands but also in the sloping lands, thus improving the social and economic livelihoods of our rural and urban people. We must also conserve our natural resources, including soil, water, and biological diversity, not only for the benefit of Lao people but also for the rest of the world. As the subject of this meeting underscores, we are striving to harmonize people and their livelihoods with nature, nature being defined in terms of resources.

The Government of Lao PDR considers the agriculture and forestry sectors as the pivots of rural livelihood systems in its future long-term socio-economic development strategies and

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programs until 2020. Among the eight priority programmes of the government, one is dedicated to the stabilization of shifting cultivation. The rapidly declining duration of the fallow period leads to soil erosion. On site, soil erosion reduces the chemical fertility of the soil by nutrient and organic-matter depletion. It also damages the physical fertility by removing surface soil, reducing soil depth and water-holding capacity, and exposing gravel and rocks. These soil changes tend to reduce crop yields and hence farm income, and require increasing amounts of inputs to achieve certain yield levels. The off-site effects of erosion on the quality and seasonal availability of water can be very serious. Floods due to heavy rainfall and forest clearance can be particularly severe causing serious damage in the lowlands. Increased sediment, nutrient, and pollutant loads in streams degrade the quality of household water supplies and increase the risk to health. Siltation of dams and irrigation channels results in reduced security of water supply for irrigated crops and a shorter life span of reservoirs. As you may know, hydropower is very important for the economy of Lao PDR, which exports electricity. Because we are on the verge of building a new dam to increase our capacity, we are particularly interested in knowing more about the risks of reservoir siltation due to soil erosion in the upper catchments.

We need to rectify these negative on- and off-site impacts of soil erosion. The government of Lao PDR is devoting much effort in this direction. Between 1982 and 1989, approximately 280,000 families practiced shifting cultivation, and more than 300,000 ha were cleared and cropped under shifting cultivation annually, thus increasing soil degradation hazards. In 1998, with development efforts being targeted on sloping lands, the area under shifting cultivation had been halved to approximately 150,000 ha with 160,000 households. However, much still needs to be done in the northern and eastern sloping lands of our country, where the majority of shifting cultivators live. This is why we have planned to gradually reduce the areas of shifting cultivation to 30 percent in 2005 and fully eliminate them by 2010. During your field trip to Luang Prabang, you will have the opportunity to see the impacts of shifting cultivation and short fallow periods that result in soil degradation.

In this effort to improve the income of the farmers and to maintain our natural resources, NAFRI plays a crucial role. It undertakes integrated adaptive research on agriculture, forestry, and fisheries to provide valuable information to the government for further strategic development. Let me emphasize the word "integrated" because integration is the real key for more successful agricultural research where only the combination of several approaches, both biophysical and socio-economic can help tackle the development issues. In this respect, I am very pleased that IWMI has recently decided to participate in the Integrated Upland Agriculture Research Programme (IUARP) launched by NAFRI with other international agricultural research centers such as IRRI and CIAT. I am also glad that IWMI has posted in Vientiane five experts seconded by IRD, the French Institute for Research and Development, to conduct studies on soil erosion and land use change. The Government of Lao PDR pays major attention to capacity building and I would like to express my gratitude to your consortium for the training workshops that you organize regularly and for the practical training of many students in the field. Let me make a plea that your consortium enables Lao researchers to complete their academic training through MSc. and Ph.D programs.

In the four days ahead of us, you will be dealing with soil erosion and conservation at the catchment scale. You will share your experiences gained in several countries and such exchanges are crucial because knowledge on soil erosion and conservation remains fragmented and not easily accessible to decision-makers. I am thus particularly pleased that the objectives of MSEC include the preparation of reliable information and guidelines for decision-makers.

This meeting is scheduled for four days involving presentations, discussion and a field trip. I would have been personally interested to attend this meeting and accompany you to the field but my agenda unfortunately does not allow it. I wish you all successful work and discussion during this annual meeting. I hope that it will be productive for the further progress of soil conservation and the welfare of the farmers in Asia.

It gives me great pleasure to declare this IWMI-ADB Project Annual Meeting and 7th MSEC Assembly officially open.

Sustainable Watershed Development: IWMI's Challenge in Asia and the Pacific

A.R. Maglinao[1]

Abstract

The Asia and Pacific region occupies about 23 percent of the world's land surface, about 72 percent of which (16 percent of the world's total) is occupied by 27 developing countries. Nearly 60 percent of the total land surface of the region is dominated by mountains and high plateaus where a large percentage of the population lives. A major portion of these areas is used for agriculture and has become seriously degraded and less productive. Thus, management strategies to improve the farmers' income and minimize or reverse the land degradation process are badly needed.

IWMI is very much concerned with programs that are related to watershed management. This is reflected in its mission of "improving water and land resources management for food, livelihoods and nature". In this regard, IWMI now implements three major programs that address land and water management at the level of catchments and river basins.

The Management of Soil Erosion Consortium (MSEC) makes use of the lessons learned from an earlier project on the management of sloping lands. It now intends to direct its focus from purely soil research to a broader theatre of integrated land and water management. The Comprehensive Assessment Program (CA) and the Global Challenge Program (CP) cover a much larger scope in terms of physical area and substantive coverage. All three programs aim not only to develop technological options for better land and water management, but also the mechanisms to best sustain the overall development progress. IWMI expects that through these programs, it will be able to contribute to improving food security and livelihoods, in harmony with nature.

Introduction

The Asia and Pacific region occupies about 23 percent of the world's land surface, about 72 percent of which (16 percent of the world's total) is occupied by 27 developing countries (Dent, 1990). Nearly 60 percent of the total land surface of the region is dominated by mountains and high plateaus (FAO, 1986). As of 1999, about 56 percent of the world's population lived in the region (World Bank, 2001). Population pressure has dramatically forced the proportion of this population to reside in uplands. The population of the tropical steep lands of Asia is estimated by the International Food Policy Research Institute (IFPRI) to be 263 million, many of whom live in poverty (Craswell and Maglinao, 2001).

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Agriculture is the economic mainstay for the majority of the people in the watersheds. However, the overall returns from agriculture are so low that they are not adequate to fulfill even subsistence requirements. Moreover, the farming practices employed are usually environmentally unsustainable resulting in deteriorating productivity of the watershed ecosystem. This degrading condition is causing adverse effects not only in the uplands but also in the adjoining lowlands that are home to another 25 percent of the world's population. Thus, there has been a strong need to reverse this downward process through the development and application of more sustainable watershed management innovations for upland development.

This paper presents a review of the present status of watershed development in Asia, the problems and constraints, and the suggested strategies to address these constraints. It likewise discusses the outputs of the Management of Soil Erosion Consortium (MSEC) project and other programs of the International Water Management Institute (IWMI) to support the global effort of reversing natural resource degradation.

Status of Watershed Management and Development in the Region

Watershed Management as an Approach

Watershed management has been defined as "the approach or process of establishing an enabling environment for the sustainable use of natural resources, especially land and water resources, to address the twin objectives of resource conservation and food security" (PCARRD, 1991; Koohafkan, 2001; Shivakoti and Neupane, 2001). With the ultimate goal of sustaining watershed development, the strategy has undergone changes through time.

In the past, watershed management was strongly identified with forest management and rehabilitation and was preoccupied primarily with securing water supplies and/or minimizing downstream damage by sedimentation and flooding emanating from "critical" watersheds (Koohafkan, 2001). Integrated watershed development and management has evolved as a development intervention framework facilitating sustainable utilization of natural resources and producing various services as required by the policies and priorities of the state and the local population (Jensen, 2001).

The Food and Agriculture Organization of the United Nations (FAO) has initiated a review and assessment of watershed management strategies and approaches to determine the present status of watershed management development, identify any major gaps, and formulate guidelines for future development projects/programs (Tennyson, 2002). Comparing the major issues and constraints in watershed management as described in 1986 with the current situation in 2002, the study showed significant progress in some aspects of the approach (Table 1).

Table 1. Major issues and constraints on watershed management and their status as of 2002

Issues and constraints	Current status
Policy, legislation and regulations	• Watershed management becomes an integral part of upland development • Existing legislative and regulatory measures now emphasize more on empowerment than enforcement • Coherent policies to coordinate and promote watershed management still inadequate
Institutions and organizations	• Implementation of watershed management activities has shifted from a single department to a multi-agency responsibility • Well trained watershed management staff at all levels still inadequate
Problem identification, program planning andproject implementation	• Rapid rural appraisal method has been developed and used globally • Social and cultural issues are now an integral part of planning • Scope of watershed management activities still needs to be clearly defined especially when it is integrated with rural development • Economic analysis models remain inadequate • Absence of operational guidelines for development of programs that will resolve conflicts between project objectives and administrative organizations
Monitoring and evaluation	• Performance monitoring and evaluation has improved with the identification of verifiable indicators in project design • Social and cultural factors are also included in monitoring and evaluation
Training and education	• Professionals and technicians now have a broad perspective in watershed management • Learning institutions have modified curricula to fit local conditions • Training has emphasized building the capacities of field workers • Conservation of natural resources is taught, to varying degrees, in elementary and secondary schools throughout the world • Human resources training for local people still inadequate
Research and demonstration	• Relationships between technical and social benefits of watershed management still poorly understood • Understanding of causes and effects of watershed degradation in highly populated watersheds is still inadequate • Demonstration watersheds have fallen out of favor for various reasons • Effective linkages between appropriate research, demonstration, extension, and education organizations still lacking
Awareness	• Public awareness campaigns are now an integral part of conservation education • NGOs are more involved in all aspects of watershed management
Extension	• Training of extension workers is commonplace in many countries • Extension networks still remain one of the weakest links in watershed management activities • Weak linkages between extension, research, and training
People's participation	• Considerable progress has been made in the participatory process • Legal, institutional, and organizational approaches for involving local residents in project planning and implementation still not satisfactory • User rights, land tenure, crop rights are changing to benefit rural people
Investments	• Donors and governments are aware that to achieve success, long-term commitment is required • The advent of payment to upland dwellers for environmental services provided to lowlanders is a forward step.

With time, the scope of watershed management has broadened from the initial concept of technical management for water resources to an integrated discipline, which includes the application of biological, technical, social, and economic principles to maintain the productivity of the headwater and lowland areas by scientific management of the soil, plant, and water resources. Watershed management, which includes the participation of all the relevant key actors, has become widely accepted as the approach best suited for the sustainable management of water resources in the upland areas.

Development of Watersheds

While there have been some positive signs resulting from the paradigm shift, the sustainable development of watersheds has not progressed very much. The problem of land degradation, most especially that caused by soil erosion by water, continues to be a major constraint in sustaining upland development in the region. The seriousness of the problem is illustrated by the increasingly perilous condition of upland farming, the enormous discharge of suspended sediments in rivers, and the worsening poverty situations. Obviously, the extensive soil erosion that occurs when steep land areas are continuously cultivated has significant impacts, both on- and off-site.

A major on-site impact is the selective loss of the surface soil layer that contains much of the reserves of plant nutrients, which accelerates nutrient mining (Hashim *et al.*, 1998). Data from experiments in the region have shown nutrient losses via erosion (from farmers' practice plots) to be as high as 194 kg ha^{-1} $year^{-1}$ for N, 32 kg ha^{-1} $year^{-1}$ for P, and 36 kg ha^{-1} $year^{-1}$ for K. A recent report from erosion studies conducted in Asia by IWMI showed that soil losses as high as 54 t ha^{-1} $year^{-1}$ have been observed. This is way above the tolerable soil loss of 2 t ha^{-1} $year^{-1}$ (Maglinao and Penning de Vries, 2002). Replacing the amount of nutrients lost by soil erosion with external fertilizer inputs would cost as much as US$68 ha^{-1} $year^{-1}$ (Agus and Sukristiyonubowo, 2002). Such rates of soil and nutrient losses would make farming unsustainable particularly in areas where the common subsistence crops provide little cash income for purchased external inputs.

The total annual sediment outflow from Asian countries to the oceans is more than seven billion tonnes. This represents an enormous net loss of fertile topsoil and nutrients, and is higher than outflows from other regions of the world. Based on nutrient content alone, valued at US$3.00 t^{-1}, this amounts to an annual economic loss of US$22 billion. This represents a major loss of nutrients and a drain on the economies of the countries of the region.

Off-site impacts are complex and difficult to assess quantitatively (Enters, 1998). However, observations show that cultivation of sloping lands significantly increases runoff (Craswell *et al.*, 1998) and hence may affect the regularity and seasonality of stream flows. In terms of sedimentation downstream, Carpina *et al.* (2001) showed significant amounts of soil being deposited in irrigation canals generating increased cost in desilting them.

The average land per capita in Asia is less than 0.15 ha, lower than any other region in the world. The Asian Development Bank (ADB, 1997) has estimated that during the last 30 years, one-third of the agricultural land has been degraded. It further indicated that degradation and loss of natural resources is progressing at a high rate, and that this is already affecting the opportunities of countries to produce food or the capacity of people in poor areas to generate income. Soil erosion is considered Asia's most widespread natural resource problem.

According to recent estimates by Penning de Vries (1998), East and South Asia will not be self-sufficient in food by the 2040 if land degradation continues at a high rate. In contrast to other regions of the world, the Asian region is a danger zone in relation to food security.

Issues on the Sustainable Development of Watersheds

The Concept of Sustainability

Serageldin (1996) conducted a comprehensive discussion on the definition of sustainability. He considered a two-step approach in developing an operational definition of sustainable development. The first step is to set in place a systematic way of testing the economic, environmental, and social sustainability of a specific proposal, in our case, watershed development. It uses a triangular framework, which considers the interaction of these three factors (Figure 1). In terms of economic and financial sustainability, one should consider growth, capital maintenance, and efficient use of resources and investments.

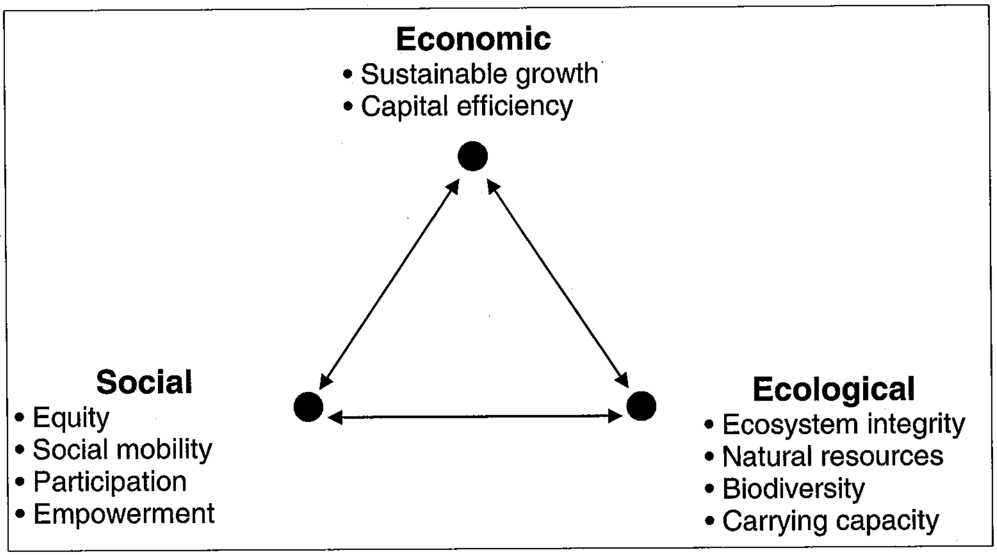

Figure 1. Triangular framework for environmentally sustainable development (Serageldin, 1996).

Ecosystem integrity, carrying capacity, and conservation of natural resources, including biodiversity are the aspects related to ecological sustainability. This is the domain of biologists and the physical scientists. On the social side, equity, social mobility, social cohesion, participation, empowerment, cultural identity, and institutional development are considered.

The next step is to consider sustainability as an "opportunity". From this concept, sustainability is *to leave future generations as many opportunities as we ourselves have had, if not more*. This further considers four kinds of capital stocks (opportunities) that are needed to carry on the activities of development. The four stocks are: 1) human-induced capital (houses, roads, factories, ships, equipment, technology); 2) natural capital (soil, atmosphere, forests, water, land, etc.); 3) human capital (people, their education, health and capacity levels); and 4) social capital (institutions, cultural cohesion, collective information, knowledge). These capital stocks are expected to partially complement and partially substitute. We expect that the composition of the capital stocks we leave the next generation will be different from the stocks we have today (Figure 2). Yet, we must recognize the limits of substitution, because it is impossible to conceive of any type of activity if any of the four kinds of capital is driven to zero.

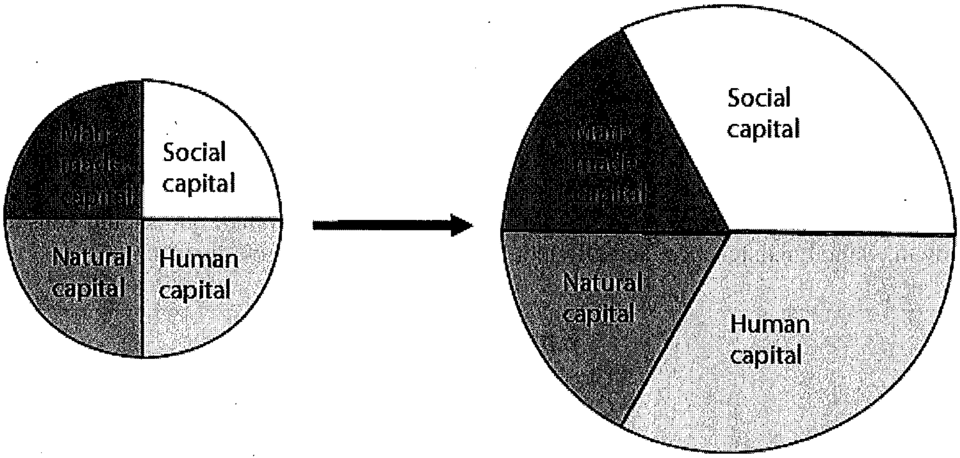

Figure 2. Possible change of capital stocks from the present status to some future time (Serageldin, 1996)

Sustainable Development of Watersheds

The concept of sustainability discussed above can also be easily applied in defining sustainable watershed development. An almost similar framework was put forward by Gottret and White (2002) in defining a methodology for impact assessment for integrated natural resource management (INRM). They based this on the framework of sustainable rural livelihoods, where sustainable rural livelihoods refer to *the capabilities, assets (including both material and social resources), and activities required for a means of living. A livelihood is sustainable when it can cope with and recover from stresses and shocks, and maintain or enhance its capabilities and assets, while not undermining the natural resource base* (Scoones, 1998).

This definition can be divided into two sub-components that reflect sustainable watershed development. The first focuses on well-being or livelihoods and includes aspects of employment and income, poverty reduction, enhancement of human capacity, and improvement of the social well-being. The second is the sustainability dimension, which includes the adaptation and resilience of livelihoods and the natural resource base on which they depend (Figure 3).

The framework considers five livelihood resources or capitals from which different production processes are derived. These are:

1. Economic/financial capital: Economic/financial capital is the capital assets (such as credit, credit/debt, savings) that are essential for the pursuit of any livelihood strategy.
2. Physical capital: Physical capital includes the household assets and farm infrastructure, including production equipment, technologies, and plantations.
3. Natural capital: Natural capital is the stock of natural resources (soil, forests, water, sequestration, etc.) from which both resource flows and useful services for livelihoods are derived.
4. Human capital: Human capital is the capacities, skills, knowledge, ability to work, good health, and physical capability important for the successful pursuit of different livelihood strategies. Human capital can be developed consciously through formal education and training and subconsciously through experience.
5. Social capital: Social capital is the social resources (networks, social relations, affiliations, associations, norms, trust, and disposition to work for the common good) upon which people draw when pursuing different livelihood strategies requiring coordinated and collective action.

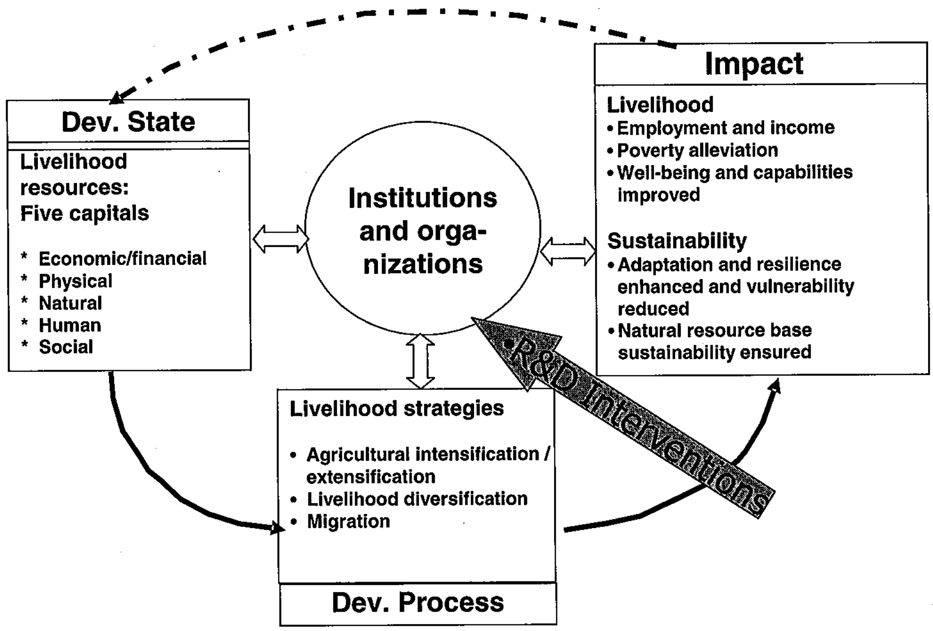

Figure 3. Analytical framework for INRM impact assessment on sustainable rural livelihoods (Scoones, 1998).

Similar to the four capital stocks that were described earlier, these five capitals identified for the production process need to be adequately balanced to attain sustainable rural livelihoods. Using the baseline information on these capitals will help identify the livelihood strategies that need to be introduced. Institutions and organizations are central to identifying restrictions/barriers and opportunities with regard to sustainable rural livelihoods.

The Core Issue: Development while Maintaining Environmental Integrity

The above discussions lead us to the core issue that has to be addressed to attain the sustainable development of watersheds, that is, enhancing social and economic development for people in the watersheds while maintaining environmental integrity. A better understanding of the connections between economic changes and the environment will create more favorable environmental outcomes and permit rational assessment of the remaining trade-offs between growth and environmentally sound objectives. However, the links between economic growth and the environment are complex.

In relating development and the environment, Serageldin (1996) indicated that rising incomes increase willingness and ability to invest in environmental protection. The same argument was put forward by Craswell and Maglinao (2001) who described the relationship between income and environmental degradation as shown in Figure 4. At very low incomes (e.g. with shifting cultivators at low population pressures) the degree of degradation is low. However, as population increases and/or demand for higher incomes increase, the need to exploit the resource base increases degradation. This reaches a point where income is high enough that the conservation ethic and the political will grow, leading to reduced rates of environmental degradation. They also indicated that the focal point for intervention is the steep part of the curves where exploitation to increase incomes rapidly degrades the resource base.

Also referring to Figure 4, Penning de Vries *et al.* (2002) argued that if a lack of "green" concerns is prevalent in a society, people are less willing to invest in environmental concerns. And if equity within society is not achieved, many people remain at a low income level even though the national average rises. If land and water resources are exploited beyond their threshold resilience, due to high population density or ecological fragility, the system fails rather suddenly. When this happens, in a short period, land is lost for agriculture, water is no longer productive, national food security is reduced, and the option for income generation through agriculture disappears. It is now recognized that food security implies security of the natural resource base as well as the food and agriculture sector, including forestry and fisheries (Koohafkhan, 2001).

Some of the more specific issues that need to be addressed to sustain the development of watersheds are presented by Tennyson (2002). These can be grouped into issues related to technical, social, and institutional aspects. They can also be related to the capital stocks described above.

Technical Issues

- Inadequate understanding of the pathways of water, sediment, and nutrient movement in response to land management.
- Lack of process-based concepts and models across many spatial scales.
- Integrating biophysical and socio-economic issues across scales.
- Appropriate sustainable natural resource management options.
- Dynamics of natural resource use intensification.
- Inability to replicate successes (lack of real understanding why some major catchment development programs are working well, while others do not).
- Defining more effectively ecosystem services of catchments and damage to on- and off-site environment from the viewpoints of farmers and of society.

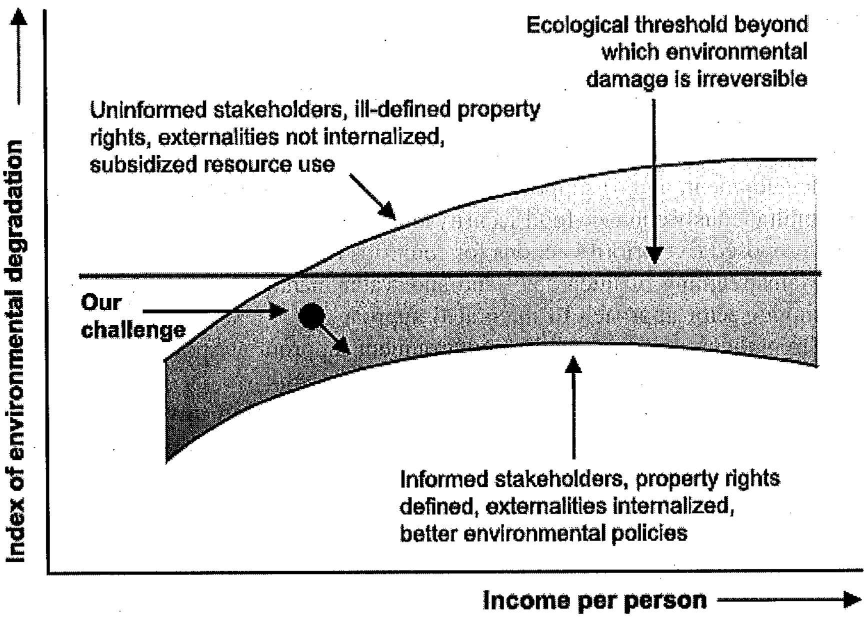

Figure 4. Relationship between income and environmental degradation (IBSRAM, 1999).

Socio-economic Concerns

- Creating options for development in catchments in which all stakeholders gain (including downstream-upstream transfers).
- Dealing with tradeoffs and conflict analysis.
- Reconciling the needs of resource-based planning with "people first" objectives.
- Training and capacity building at all levels.
- The role of youth in watershed management.

Institutional Aspects

- Multi-institutional approaches to acting together in watershed management projects.
- Linkage among central and local governments and civil organizations, together with a more coordinated and effective international aid effort.
- Political will to allocate appropriate staff.
- Lack of appropriate governance (local vs. central, upstream users vs. downstream users, community organization, mechanisms for water allocation and property rights).
- Lack of a sustainable financial and institutional mechanism.
- Lack of central and/or local government/community commitment.
- Weakness of the national research systems in developing countries.
- Finding the right way to address the policy framework and the sets of incentives that affect natural resources in watersheds.

Strategies to Address the Issues and Problems

The aforesaid issues can be addressed through efficient, effective, and relevant research and development (R&D) programs (see Figure 3). R&D here is defined as any activity that addresses the following: 1) improvement of the knowledge base, 2) finding solutions to constraints, 3) capacity development, and 4) supporting policies and institutional arrangements.

To simultaneously enhance food security and environmental quality, Penning de Vries *et al.* (2002) proposed five priority actions for countries to consider. These are:

- Mainstreaming of integrated land and water management approaches (shift from single-sector approach to integrated approaches).
- Strengthening of the enabling environment (appropriate policies, regulations, and institutional arrangements).
- Wider adoption of good management practices and environmentally sound technologies (development, dissemination, and adoption of good management practices and technologies).
- Expansion and acceleration of capacity development activities (skilled human resources to plan and implement programs).
- Strengthening of partnerships to implement priority programs (at the local, national, and international levels to provide a mechanism for a coordinated response to the issue of food and environmental security).

While most of the issues on watershed management are becoming clearer with time, most research and development efforts are now considering the most effective mechanism of how to do it more effectively and efficiently, with the ultimate goal of sustainable watershed development. The literature mentions participation and coordination, integrated and holistic approaches, etc. One should take note, however, that this is easier said than done. One has to also have a good grasp of the situation where the research is conducted. While the principles of participation are generic, applying it is another matter.

IWMI Programs Related to Watershed Management

The International Water Management Institute (IWMI) is now very much concerned with programs that are related to watershed management. This is reflected in its mission of *improving water and land resources management for food, livelihoods and nature.* The following section briefly describes three such programs.

The Management of Soil Erosion Consortium (MSEC)

MSEC is one of the four consortia established through the soil, water, and nutrient management initiative of the Consultative Group on International Agricultural Research (CGIAR). IBSRAM and PCARRD facilitated its establishment through consultations with the NARES, IARCs, ARIs, NGOs in and outside Asia. MSEC uses an integrated, interdisciplinary, participatory, and community-based approach to research that involves all land users and stakeholders on a catchment scale. It focuses on the on- and off-site impacts of soil erosion, emphasizes community involvement, and provides scientific data for rational decision-making at all levels. MSEC draws on the comparative advantages offered by the NARES, IARCs, and ARIs which conduct research at different levels, ranging from the individual plot and farm to the catchment, regional, and national scales, to develop principles of global relevance (Figure 5). It is linked to the ecoregional program for humid and sub-humid tropical Asia, led by the International Rice Research Institute (IRRI) based in the Philippines.

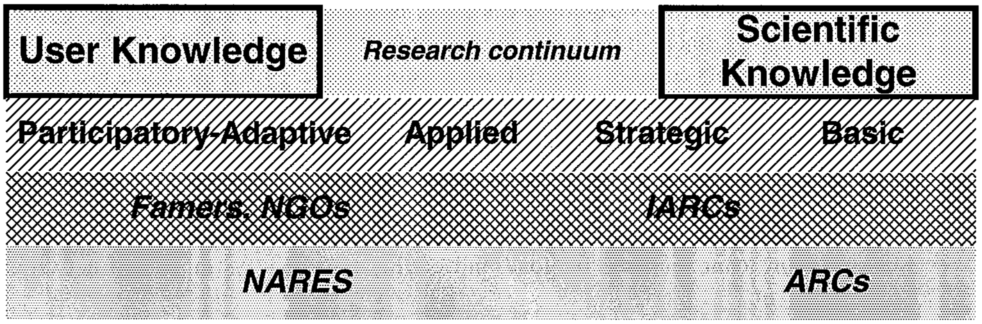

Figure 5. The primary stakeholder domains across the research continuum of an SWNM consortium (Craswell and Maglinao, 1999).

The objectives of the program are:

- to develop sustainable and acceptable community-based land management systems that are suitable for the entire catchment;
- to quantify and evaluate the biophysical, environmental, and socio-economic effects of soil erosion, both on- and off-site;
- to generate reliable information and prepare scientifically-based guidelines for improvement of catchment management policies; and
- to enhance NARES capacity in research on integrated catchment management and soil erosion control
- The program focuses 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 the enhanced adoption of land management technologies and for more accessible information as the concrete basis for decision-making.

Progress and Accomplishments

Research

- Established an active network of institutions and projects working together to address the problem of soil erosion. The network has facilitated exchange of information and expertise on catchment research.
- Adequately instrumented the benchmark catchments in six countries for long-term monitoring and scientific studies. This network of catchments provides a valuable

tool to evaluate the impact of land use practices and changes on runoff production and sediment yield in a variety of biophysical and socio-economic conditions.

- Data analysis has shown that soil losses as high as 54 t ha^{-1} annually have been recorded at the Philippine study site. This rate of erosion is way above the tolerable soil loss of 2 t ha^{-1} $year^{-1}$. Replacing the amount of nutrients lost by soil erosion with external fertilizer inputs would cost as much as US$68 ha^{-1} $year^{-1}$. With the very low income of the farmers in the study sites (only US$296 per annum in Laos), purchase of external inputs could be difficult. As erosion continues and no inputs are added, the yield will surely decline. Consequently, the decline in income will follow.
- Land management practices greatly influence hydrological behavior and soil erosion, with the proportion of the area cultivated to annual crops presenting the best predictor of sediment yield. Soil loss decreases with increasing catchment size but this can often be overridden by the effect of land use. Suspended sediments appear to be more significant than the bedload and could significantly impact on activities downstream.
- The model developed to simulate and predict soil erosion showed a four-fold increase in soil erosion with an increase of the proportion of the cultivated area from 9 to 60 percent. The model also supports the observation that land use greatly affects soil erosion, more than the effect of climate. The use of this model will greatly help planners in deciding development options for better catchment management.
- Through dialogue with the farmers, the best bet land management options were identified and introduced for evaluation. These are essentially variants of the hedgerow cropping technology combined with other options considered to more quickly generate additional income. These options have already been proven to reduce soil erosion and with the farmers' participation in the process of selection, it is expected that they will continue practicing the system which in the long run will provide better income and reduce resource degradation. Further validation of the introduced land management options is still needed to evaluate their acceptability and sustainability, and define the strategies for wider promotion and uptake at the community level to produce greater impact.
- Tools, guidelines, and methodologies for carrying out the project have been developed. These include guidelines for the site selection of benchmark catchments, biophysical and socio-economic site characterization, procedures for rainfall simulation studies, methodology for financial and economic assessment of soil erosion, a framework for impact assessment, and a soil erosion and hydrology model. These guidelines, procedures, and tools have helped the researchers in data collection and analysis. Moreover, the model is expected to provide support to planners and decision-makers in evaluating development options under different scenarios. For example, the MSEC-1 dynamic soil erosion and hydrology model is able to simulate and predict soil erosion under different land uses. It provides the planners with information on various options as a basis for decision-making.

Capacity building

- A network of 34 catchments and sub-catchments for hydrology and soil erosion management research has been established. With the adequate instrumentation put in place, the network provides a valuable asset 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.

- Fourteen training events on various topics have been conducted benefiting more than 80 NARES scientists from 18 institutions. Thirteen graduate students have also been provided assistance in the conduct and analysis of their research. This has enhanced the capacity of the national institutions in the planning and implementation of soil erosion management research at the catchment scale.

Information dissemination

- The project has published four proceedings and six articles in other journals/ proceedings. Sixteen technical papers have been prepared and presented at scientific conferences. The project also participated in international conferences and meetings to share information. The MSEC web page has been incorporated in the IWMI web site and can be viewed at www.iwmi.org/msec. The preparation of the technical papers and the participation of IWMI and its partners have provided a good opportunity for more interaction with other scientists and have broadened project and institutional linkages and collaboration.
- The project has been submitted to the ISC of the CGIAR as a case study for INRM.

Others

- Submitted a follow-up proposal for funding by ADB, latest revision submitted in August 2002.
- Submitted a proposal to the CA program of IWMI, shortlisted but not accommodated in the first four.
- Submitted a proposal for the RE-source award in Switzerland; decision to be known early in 2003.
- Linking with CP for possible funding support.

Constraints

- The nature of the work needs longer term investigation and therefore continued support is needed. At present, the financial support is provided primarily by IWMI and ADB. The support from ADB lasts until the end of December 2002.
- Although most of the members have shown keen interest in the project, some members cannot sustain their commitment.

Challenges/opportunities

- Long-term monitoring will refine the models for prediction and assist in policy-making.
- Farmers' involvement in the project will provide a feeling of ownership in the project and empower them to make more knowledgeable decisions.

- Further evaluating the best options to better manage soil erosion in catchments will provide support to sustainable upland development.
- Country initiatives could further be enhanced with more reliable information becoming available.
- There are new projects that MSEC could very well link, collaborate, and complement with.

The Comprehensive Assessment Program

The Comprehensive Assessment of Water in Agriculture (CA) is an international program supporting research, capacity building, and knowledge sharing; it is focused on providing solutions that will reduce poverty in developing countries. Through its five-year program (2002-2006), the Assessment will generate a wealth of useful data, practical knowledge, and a synthesis of experiences, and a number of water management and planning tools. These products are designed to help water users, development organizations, governments and research organizations make the best possible investments in water for rural agricultural development. The overall goal is to help countries manage water better to improve the livelihoods of the rural poor while sustaining the environment.

The priority research areas that need to be addressed are:

- Benefits, costs, and impacts of irrigated agricultural development and what conditions these impacts.
- Extent and significance of use of low quality water in agriculture (saline and wastewater), and what the options are for its use.
- Options for better management of rainwater to support rural livelihoods and land rehabilitation in water-scarce areas.
- Options and their consequences for improving water productivity in agriculture.
- Management to sustain and enhance fisheries and aquaculture systems.
- Options for integrated water resource management in basins and catchments.
- Consequences of land and water degradation on multiple users of water in catchments.

The last two areas are the most relevant to watershed management. Each usage of water in a basin potentially affects other users and uses within, calling for more integrated water resource management. Key to this is good governance, including policies and institutions. Improving water productivity is constrained by land management practices, and sustaining levels of productivity is threatened by severe levels of land and water degradation. Research should therefore focus on water productivity and food security, and search for promising practices to reverse the trends of degradation. For more information about the program, visit www.iwmi.org/assessment

The Global Challenge Program

The Global Challenge Program is a new initiative of the CG system. At present, IWMI leads the development of the Challenge Program on Water and Food. The objective of the program is to catalyze effective and efficient improvements of water productivity in food production in a way that favors the poor and is gender-equitable and environmentally sustainable. At the basin level, water productivity needs to be understood in the widest possible sense – including crop, livestock, and fishery yields, wider ecosystem services and social impacts such as health, together with the systems of resource governance that ensure equitable distribution of these benefits.

In view of the scale of issues to be addressed, the program is structured according to a number of interacting modules. At present five themes are envisaged:

- Improving the efficiency of water use in agriculture, via increased crop water productivity.
- Management of upland watersheds for multiple functions.
- Management of aquatic ecosystems and wetlands.
- Policy and institutional aspects.
- Interaction among the four themes.

The second theme bears greatest relevance to watershed management. Upper catchments present a diffuse spectrum of challenges to improving the management and use of water. The complexity of the challenge can be summarized in three phrases that represent different facets of the problem, namely, water and livelihoods, catchment hydrology, and social organization. The major focus of the research will be on: 1) water and poverty in upland watersheds, 2) identifying the hydrologic basis for improvement, 3) realizing the increased hydrologic potential in upland watersheds, and 4) extrapolation and generalization. For more detailed information, visit www.cgiar.org/iwmi/challenge-program

Summary and Conclusion

1. The Asia and Pacific region occupies a large portion of the world's land surface, nearly 60 percent of which is dominated by mountains and high plateaus. It has the most serious problem of land degradation and achieving food security.
2. Watershed management has broadened its scope from the initial concept of technical management for water resources to an integrated discipline, which includes the participation of all the relevant key actors in planning and implementation.
3. This change in thinking has not yet resulted in a corresponding progress in sustainable development of watersheds in Asia and the Pacific. The problem of land degradation, most especially that caused by soil erosion by water, continues to be a major constraint in sustaining upland development in the region.
6. The core issue of enhancing social and economic development for the people in the watersheds while maintaining environmental integrity should be addressed to sustain upland development.
7. IWMI is now completing the first four years of the implementation of the MSEC project, which looks forward to strengthening the integration of land and water management.
8. Two other programs that address land and water management at the level of catchments and river basins have started recently and are expected to contribute to improving food security and livelihoods, in harmony with nature.

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

A.R. Maglinao[1], C. Valentin[2] and F. Penning de Vries[3]

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.

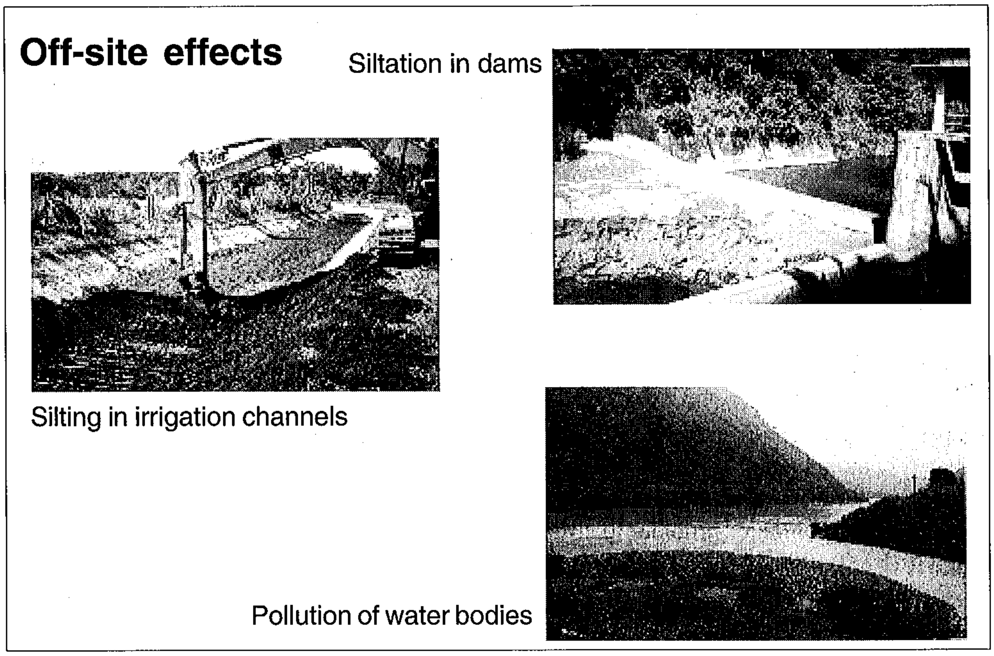

Figure 2. Downstream, soil erosion can cause siltation in irrigation canals and dams, and pollution of rivers.

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.

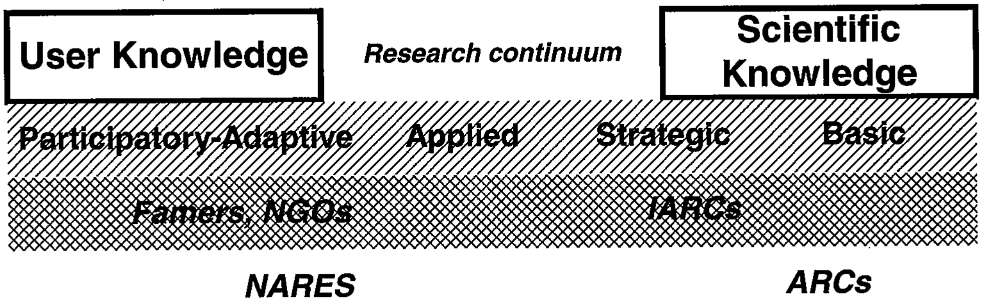

Figure 3. The research continuum showing the role of different groups in the irrplementation of MSEC research (Craswell and Maglinao, 2001)

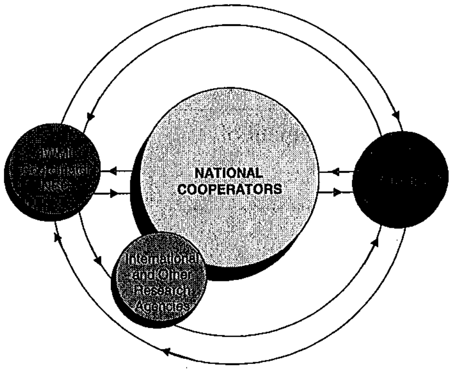

Figure 4. Schematic organization of a network/consortium

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).

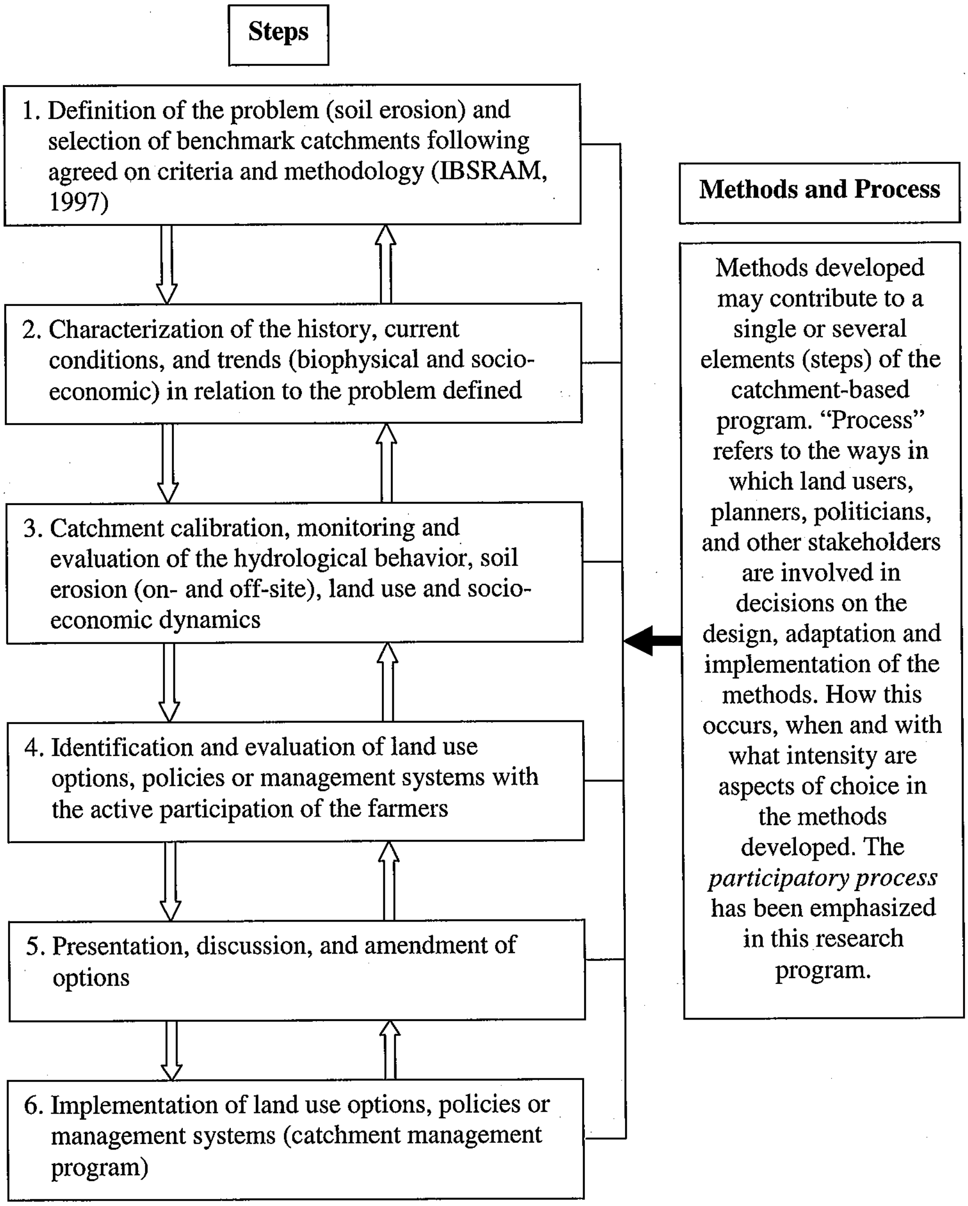

Figure 5. Steps followed in the catchment-based approach to managing soil erosion research

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 Permanent flow	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	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

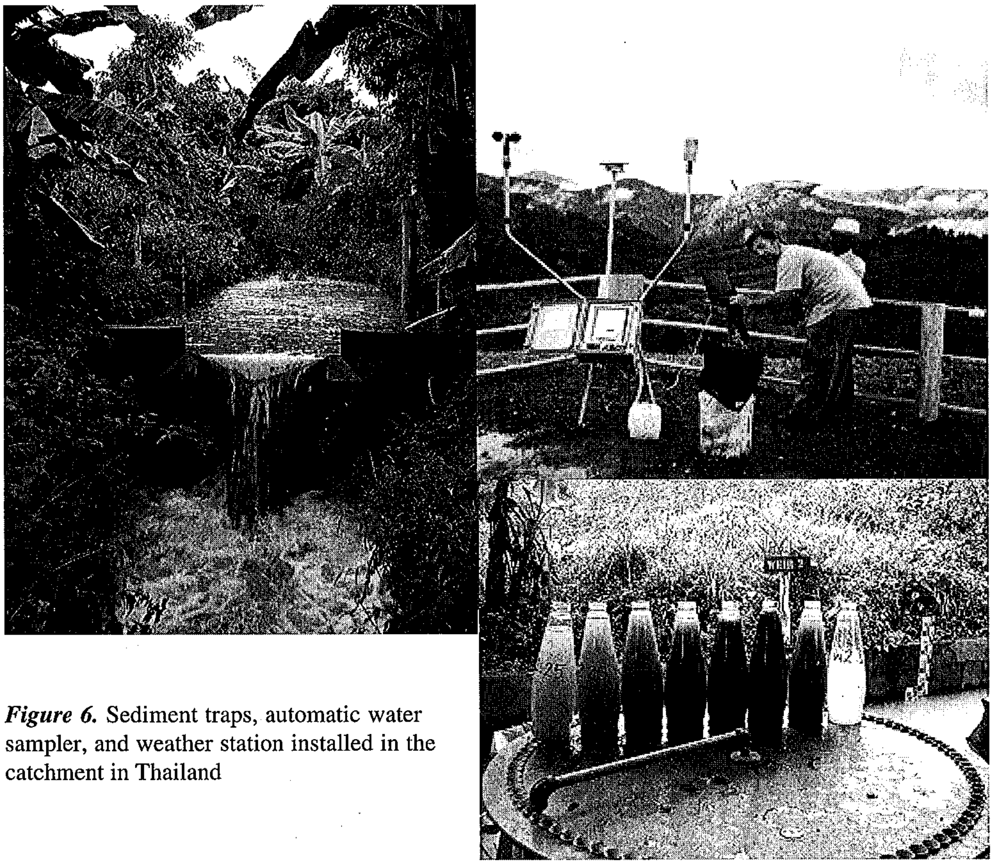

Figure 6. Sediment traps, automatic water sampler, and weather station installed in the catchment in Thailand

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

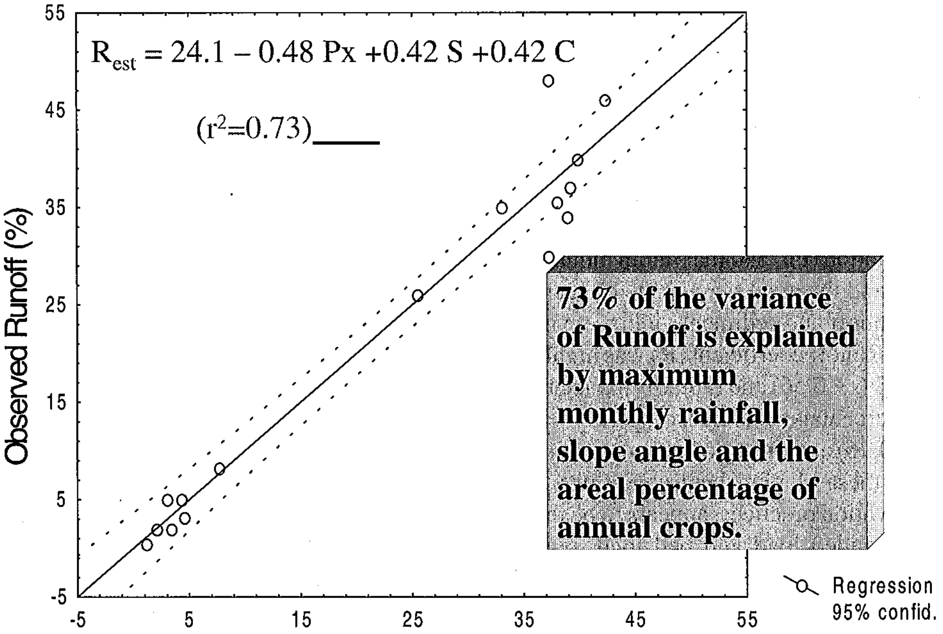

Figure 7. Observed mean annual runoff as a function of predicted runoff or a data set of 16 catchments in Southeast Asia (modified from Chaplot *et al.*, 2002)

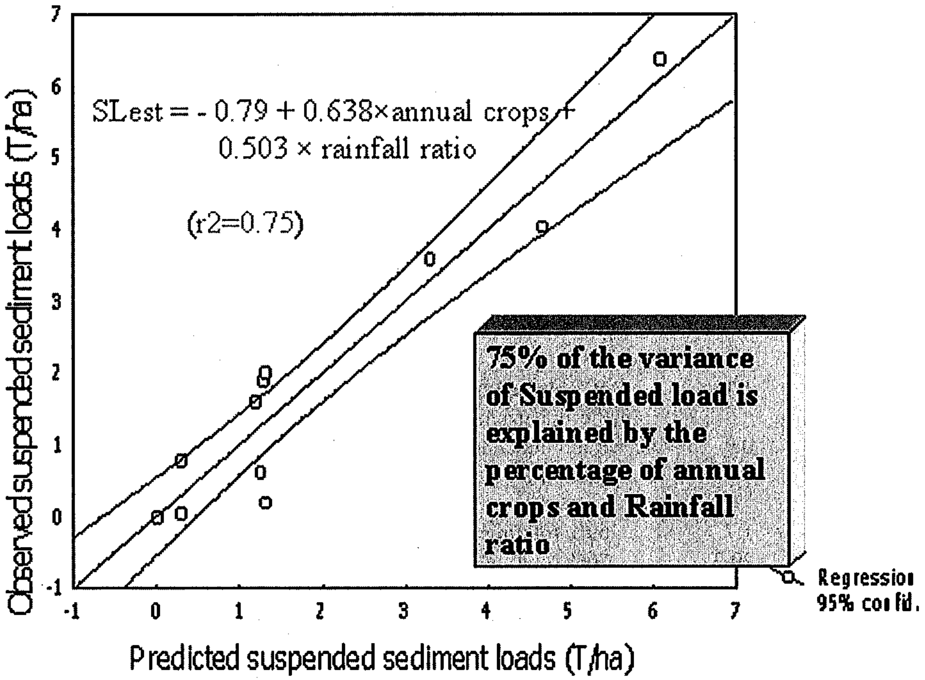

Figure 8. Observed mean annual suspended sediment load as a function of predicted suspended sediment load for a data set of 11 catchments in Southeast Asia (modified from Chaplot *et al.*, 2002)

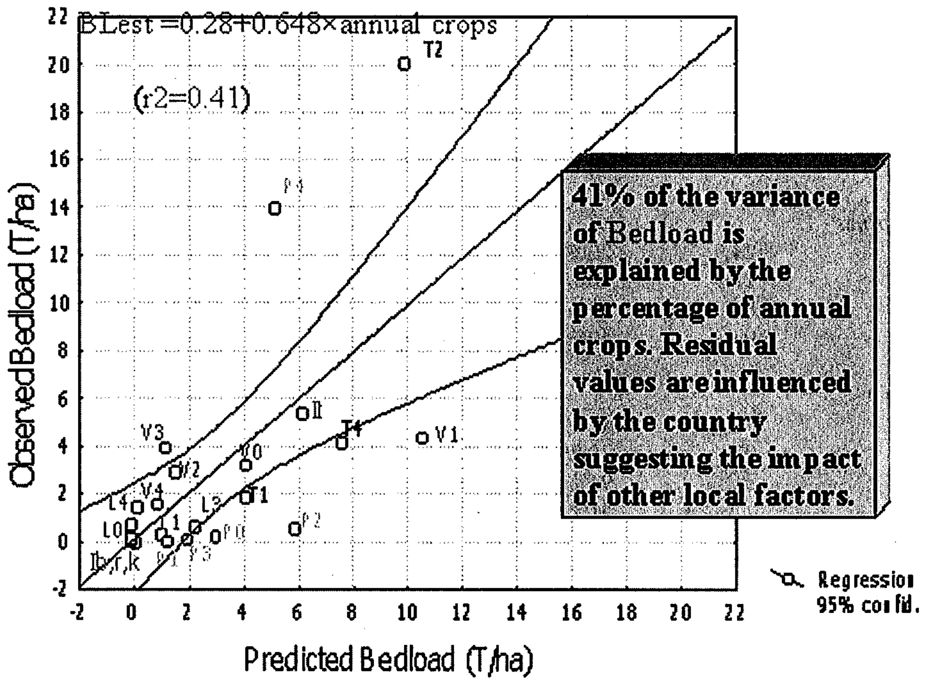

Figure 9. Observed mean annual bedload as a function of predicted bedload for a data set of 21 catchments in Southeast Asia (modified from Chaplot *et al.*,2002)

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.

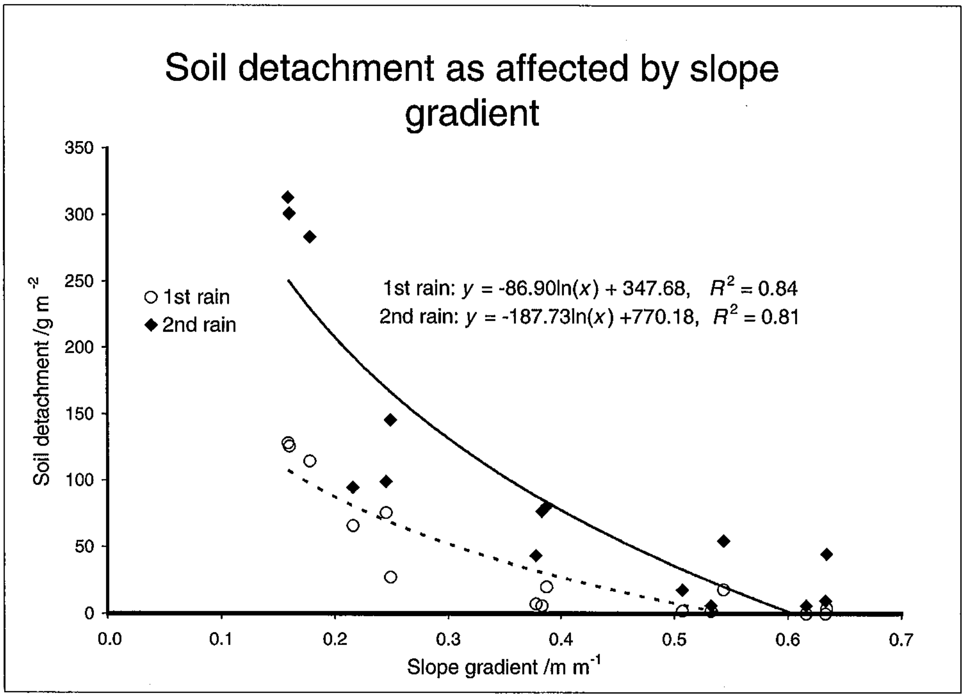

Figure 10. Soil detachment as affected by slope (Janeau *et al* 2003)

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.

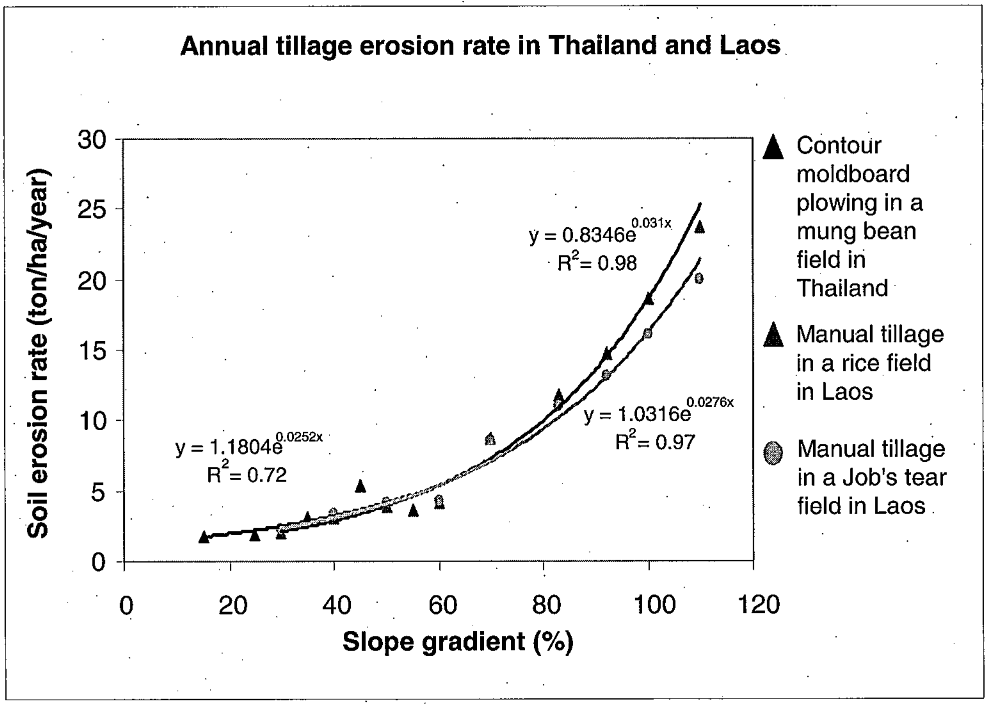

Figure 11. Tillage erosion as affected by slope

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})	1.45	50	51.2	26.4
catchment scale (t ha^{-1} yr^{-1})	17,585	605,000	620,000	321,860
Water storage volume Lost (m^3 yr^{-1})	13,400	432,142	442,857	229,900
Expected life span (yr)	>100	72	70	>100

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

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.

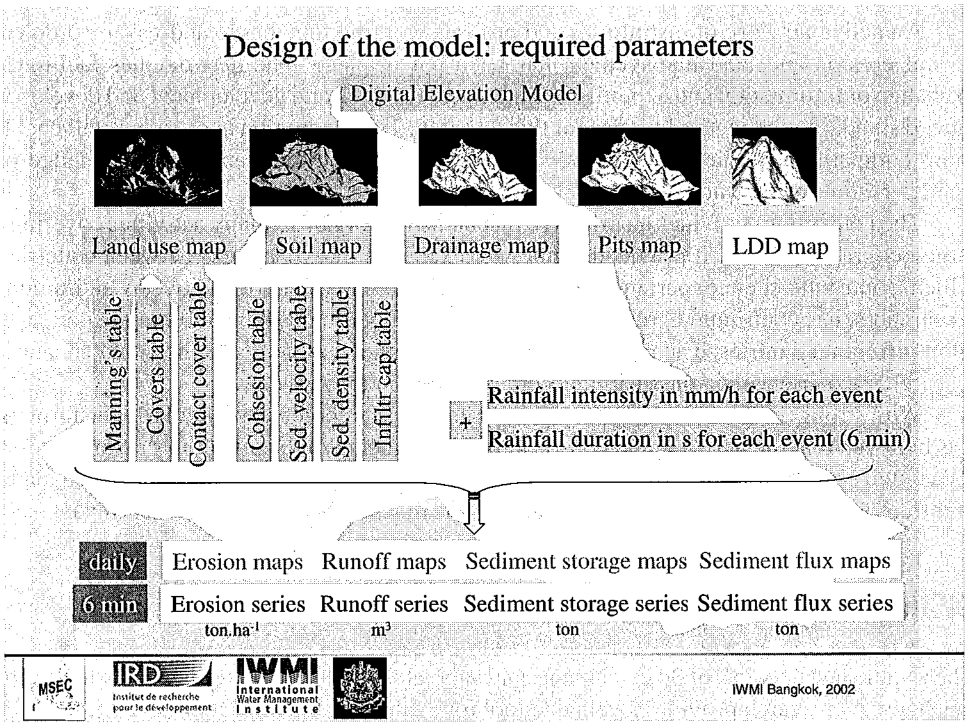

Figure 13. Flowchart of PLER (Predict and Localize Erosion and Runoff) model (Bricquet *et al.*, 2002)

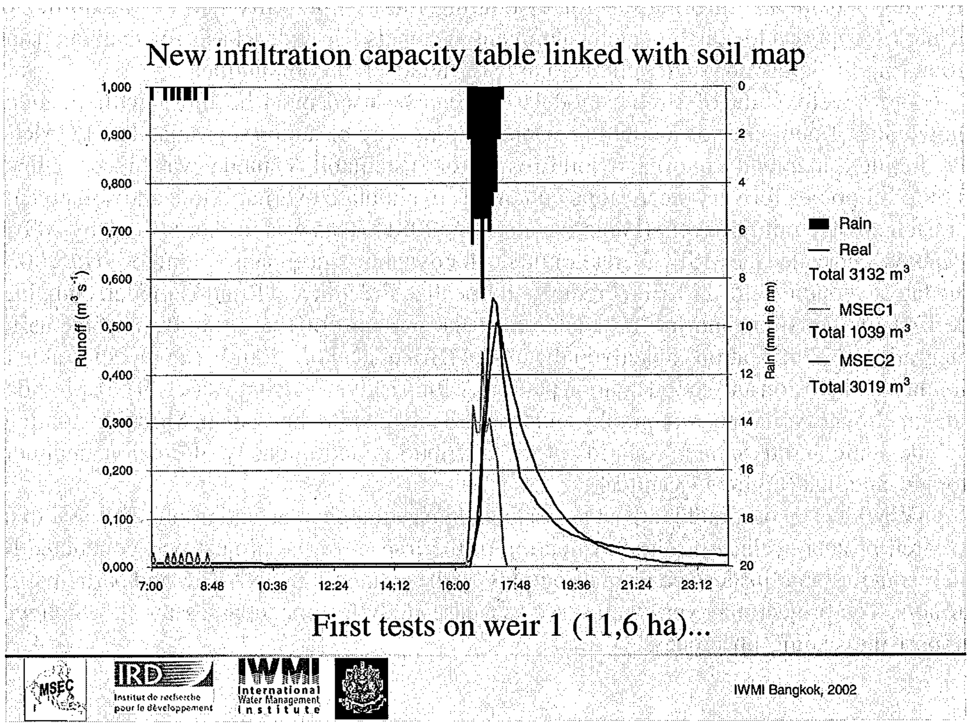

Figure 14. Comparison between observed and predicted runoff in one sub-catchment in Thailand

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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The ASIALAND Network on Sloping Land Management: Evolution from Plot-scale Experiments to a Community-based Development Program

A.B. Armada and T.Q. Correa Jr.[1]

Abstract

In addressing soil erosion and its adverse effects, the ASIALAND sloping land network has implemented research and development activities in seven Asian countries since 1988. Starting with plot-scale experiments to generate and validate soil conservation practices, the network progressed to conducting research at the farmers' field level and eventually moved on to technology promotion in targeted upland farming communities. The network's step-wise approach in finding solutions to land degradation produced promising conservation practices and valuable lessons in transferring these technologies for adoption by farmers.

Among the technologies validated, the alley cropping system showed great potential in preventing soil erosion and providing farmers with economic benefits. Lessons learned from the on-farm research of the network identified issues and constraints of farmers in adopting technologies and proposed a number of strategies to enhance farmers' awareness and participation. The network has also developed and advocated the Conservation Farming Village (CFV) approach to disseminating practices and technologies on sustainable land management.

Hinged on its research outputs, the network widens its coverage in promoting conservation practices and technologies by scaling up activities in sloping land communities through the establishment of linkages with government agencies and non-government organizations and conducting joint on-farm trials with farmers. The ASIALAND network has likewise embarked on upgrading its methodology of assessing soil erosion by shifting its research paradigm from plot-scale to catchment-based studies. This innovative approach to sloping land management will definitely complement the network's thrust of moving upland farming communities towards sustainable agriculture.

The ASIALAND Network

The Management of Sloping Lands for Sustainable Agriculture in Asia Network, or the ASIALAND sloping land network, as it is commonly known, was the pioneering network of the International Board for Soil Research and Management (IBSRAM). It was established in late 1988 with the aim of conserving soil resources in the region through the research and

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application of appropriate land management technologies to achieve sustainable agriculture on sloping lands. The network is now under the auspices of the International Water Management Institute (IWMI) and its Southeast Asia Regional Office in Bangkok, Thailand.

To fulfill its objective, the ASIALAND network established plot-scale experiments on soil conservation technologies in partnership with national agencies in seven Asian countries, namely China, Indonesia, Lao PDR, Malaysia, the Philippines, Thailand, and Vietnam. The network has gone through four major phases – technology validation, revalidation, on–farm research, and technology promotion. During the initial years of Phase I, funding support for the network was provided by the Asian Development Bank (ADB), the International Development Research Center (IDRC), and the Swiss Agency for Development Cooperation (SDC). From then until the present phase, SDC has continued to support the operations of the network. The governments of network member-countries have also provided local counterpart resources for the project.

While different levels and nature of accomplishment characterize each of the four phases of the network, the general sentiment of the participating countries is that the project's impact could be more visibly and substantially felt if efforts and activities are scaled up to reach not only individual farmers but also entire upland farming communities. The fifth and current phase of the network has thus been implemented. This paper presents a general outlook on the results of the first four phases and relates them to the network's current development thrust. The network, incidentally, is working out an arrangement to interface with another IWMI network, the Management of Soil Erosion Consortium (MSEC). MSEC focuses on soil erosion management at the catchment scale. Lessons learned from both networks could provide the needed catalyst to effect this collaboration.

Overview of Network Phases

Phase I: Technology Validation

Phase I of the network was implemented from 1988 to 1991 with the aim of identifying appropriate technologies for sloping land agriculture. Different soil conservation technologies were tested against the farmers' practice, which is characterized by up-and-down the slope tillage and no conservation measures (Table 1). Comparison of these technologies with the farmers' practice, in terms of soil and nutrient loss and crop yield, was carried out in plot experiments with varying slopes and plot sizes (Figure 1).

Phase II. Technology Revalidation

In Phase II, the network moved on to revalidating the promising results of Phase I. Two main activities were included in this phase – the continuation of the research activities of Phase I (long-term research) and the establishment of development research sites. The development research sites were essentially larger scales of the experimental plots designed for technology demonstration and training (Figure 2). Activities for this phase were carried out from 1992 to 1994.

Table 1. Different soil conservation technologies validated by network-member-countries

China	Alley cropping using *Tephrosia candida* and *Coronilla varia* hedgerows; hHillside ditches and aAgroforestry using *Eucalyptus*
Indonesia	Alley cropping using *Flemingia congesta* hedgerows; cCover cropping using *Mucuna munaneae*; and cCrop residue management
Lao PDR	Agroforestry using teak; sStrip cropping with upland rice and soybean; aAlley cropping using vetiver and mango as hedgerows; and hHillside ditches
Malaysia	Legume cover; rRubber intercropped with annual and perennial crops
Philippines	Alley cropping using *Gliricidia*, napier, banana, sapodilla, cashew as hedgerow crops
Thailand	Alley cropping using pigeon pea, *Leucaena*, congo grass, Bahia grass, and coffee as hedgerow species; hHillside ditches; and aAgroforestry with coffee and mango
Vietnam	Alley cropping using *Tephrosia candida*, aAcacia and pineapples as hedgerows

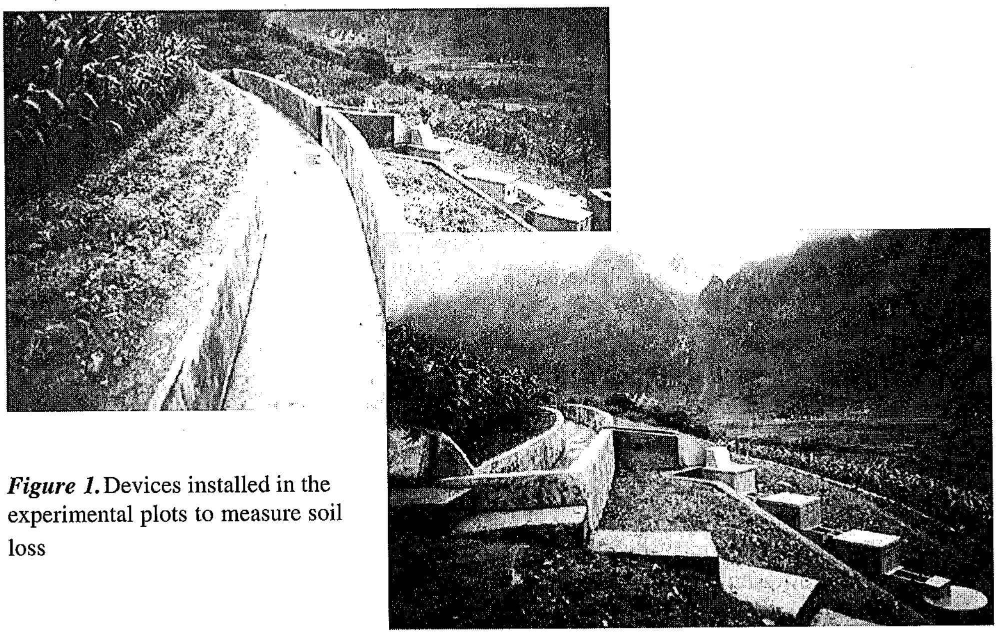

Figure 1. Devices installed in the experimental plots to measure soil loss

Phase III: On-farm Research

Phase III, which was implemented from 1995 to 1997, focused on on-farm research. This served as a transition stage from research to extension or from technology validation to technology promotion. Validated technologies in the two earlier phases, which showed sustainability and economic potential, were introduced and tested in the farmers' fields. However, instead of researchers doing the experiments, they acted as facilitators while farmers conducted the research. In the on-farm research, socio-economic information took precedence over biophysical data so that farmers' attitudes, perceptions, and feedback were used to assess reasons for the adoption or non-adoption of technologies. Long-term research sites were discontinued in some countries, while others continued them for sustainability studies.

Figure 2. Development research site in the Philippines which serves as a venue for training and demonstration

The on-farm research was conducted with the following general guidelines:

1. Principles and procedures for farming-systems research were followed, focusing on land management practices for sustainable land use.
2. Implementation was carried out at new sites following the network's guidelines for site selection.
3. Each member-country had at least 10 farmer-cooperators per site. Each farmer-cooperator tested a set of technologies according to his choice with a plot size of at least 1,000 m^2. Farms of non-cooperating farmers served as control plots.
4. The research team included extension personnel and social scientists or farming systems research specialists.

Phase IV. Technology Promotion

In its fourth phase (1998-2001), the ASIALAND network shifted to technology dissemination from its purely research activities. While notable observations and important lessons were obtained from the on-farm research phase, the adoption of soil conservation technologies among farmers still remained low, with the number of adopters being limited to the farmer-cooperators.

Phase IV therefore was implemented with three objectives: (1) to develop appropriate approaches for technology promotion, (2) to ensure technical soundness of the technologies in line with farmers' needs and preferences, and (3) to make sure that necessary support and policies from governments were instituted.

Results and Lessons Learned

Research Findings from Phases I and II

In general, the results of the experimental plots showed that the soil conservation technologies were advantageous over the farmers' practices (IBSRAM, 1993, 1995, 1995a). Soil and nutrient losses decreased with the application of conservation measures, while crop yields were enhanced through soil conservation, crop residue management, and soil fertility management. Simple cost and return analysis likewise proved the viability and productivity of soil conservation technologies.

Although, soil loss is affected by slope, rainfall, soil type, vegetation, and human activities, plot experiments show that soil conservation practices (i.e. alley cropping, hillside ditches, and grass barriers) reduced the amount of soil loss significantly when compared with the farmers' practices. Cumulative soil loss under farmers' practices reached amounts up to as much as 536.7 t ha^{-1}. Soil loss in plots with conservation measures was reduced to as low as 0.3 t ha^{-1}. As a direct consequence, nutrient losses were also higher under farmers' practices.

Crop yields in soil conservation technology plots were comparable, if not higher than those obtained from farmers' practice plots, particularly when nutritional deficiency and soil acidity were corrected. Yields in farmers' practice plots are expected to decline over time as the organic-rich surface soil is continuously eroded.

Simple cost and return analysis showed that farmers can gain favorable economic returns if soil conservation technologies are practiced. This is especially true if alley cropping is used. Fruit-bearing plants like banana as part of the hedgerow system give very high economic returns and are a source of steady and regular income for farmers.

Based on the results of six years of testing and verification, soil conservation technologies validated by the network member-countries appear to be ready for dissemination. Technology-wise, however, there is a need to look into the sustainability of these technologies from the agronomic, environmental, and economic standpoints. Another ingredient that is missing is the farmers' input. If these technologies are to be extensively promoted, farmers' responses should be taken well into consideration.

Lessons Learned from Phases III and IV

During Phase III, farmers tested soil conservation technologies that were validated in the two earlier phases. Highlights of the on-farm research include:

- More farmers have become aware of soil erosion problems and have become quite receptive towards soil conservation technologies.
- Alley cropping received more attention from farmers, compared to other technologies, in all network member-countries, mainly because of the high economic returns and steady income obtained from fruit tree components of the system.
- Distance between hedgerows has become quite an issue for farmers since hedgerows take up considerable space for planting. Widening the alleyway was considered, depending on the slope of the farm.
- In some member-countries, farmers have formed cooperatives to address marketing problems.

- Subsidies for farmers, in terms of the provision of planting materials, were seen as important and necessary in technology transfer activities, especially when working with resource-poor farmers. However, subsidies should be properly managed to avoid farmers' dependency.
- In long-term research sites, under the alley cropping system, the slope strength of experimental plots has been weakened due to the formation of terraces. Economic analysis also continued to show the advantage of soil conservation technologies over the farmers' practices.

In Phase IV, with the encouraging results of Phase III, the network commenced a full-blown extension program, focusing on appropriate approaches, technologies, and support services. The following highlights relate to the outputs *vis à vis* the identified objectives.

The primary approach that was used to enhance the adoption of sustainable land management (SLM) technologies was the establishment and development of conservation farming villages (CFVs) or upland farming communities. In most member-countries, the on-farm research sites were continued and farmer-cooperators were mobilized through the conduct of various training events, field days, and cross-farm visits. Embedded in the CFV approach was the setting up of information centers and training shelters at the village level. Information packages on sloping land technologies were made available to various users, but particularly to farmers in these information centers. At the same time, formal workshops and seminars on the participatory approach, communication skills, and related topics were held to build up the capacity of extension workers and researchers.

The CFV, as a modality for technology promotion, has increased farmers' awareness and appreciation of SLM technologies. This approach has produced a sense of belonging among farmers, which in turn has given farmers a high level of confidence and trust in their own capabilities to manage their natural resources. Likewise at the village level, the CFV has given more prominent roles to local government units in handling issues related to SLM.

In addressing the second objective, the network wanted to know how to make the technologies more attractive to the farmers with due consideration to local situations and conditions. Informal meetings with farmers and farmer groups were conducted to obtain responses and feedback. A socio-economic survey was also employed to evaluate the key constraints and opportunities of farmers. The decision support system for sustainable land management (DSS-SLM) of IBSRAM was likewise used to assess the technologies using sustainable agricultural indicators. In some countries, short-term, collaborative studies were carried out to identify other knowledge and technology gaps. When necessary, changes or modifications to the technologies were made.

The results of these activities showed that farmers recognized soil erosion as a factor that negatively affects crop production and sustainability. However, they were more concerned with the other pressing needs of their households. In some countries, there was a predicament where younger members of farming families were no longer interested in farming because they were more attracted to off-farm opportunities. Farmers with smaller farms and who lack security of land tenure were less likely to invest in soil conservation. Addressing the immediate needs of farmers through the introduction of short-term cash crops was a plus factor in adoption. Farmers' crop preferences varied depending on the needs and availability of marketing infrastructures. Sustainability-wise, technology adopters were better off than non-adopters.

The third objective focused on harnessing the support of government agencies, planning organizations, and policy-makers to actively support soil conservation. It was shown that in all countries, senior and mid-level policy-makers were adequately informed, which resulted in various concrete actions. Policy recommendations related to SLM have been proposed and collaborative projects with various national programs have been initiated. The support of local government units and related institutions has been formalized.

Overall, hundreds of people in member-countries have been reached and they have become actively involved in promoting SLM on sloping lands. In most countries, there has been a strong and successful emphasis on farmers but the impact of the SLM technologies on the community as a whole is still undetermined. The integration of livelihood and natural resources conservation may well be the link to produce a tangible impact at the community level.

Cross-country Studies

Several studies on various topics related to the research activities of the network were conducted using data obtained from the plot-scale experiments. Results of these studies were valuable in focusing and redirecting the network's research activities. Major findings were also used as a basis for technology adjustments and support for technology dissemination (Francisco, 1998; IBSRAM, 1999; Penning de Vries, 2002). Some of the results are given below:

- In a study on the economics of soil conservation in selected network countries, data showed that the adoption of soil conservation measures effectively reduced soil loss. However, there were differences in effectiveness among soil conservation measures in reducing soil loss. The study also showed that profitability of the validated technologies depended on the kinds of hedgerows and labor cost requirements. The on-site cost of soil erosion is the negative impact on crop productivity, while off-site cost constitutes high estimates in repairing damages due to sedimentation.
- In investment analysis, findings confirmed that alley cropping is beneficial for farmers because of the returns from alley and hedgerow crops and the reduction of nutrient losses due to erosion. Investment in establishing alley cropping has also been found to be financially viable in most network countries.
- The erosion model, GUEST, or Griffith University Erosion System Template, which was used to predict soil loss showed that soil erodibility in selected sites decreased over time. This indicates the positive effects of conservation practices on soil conditions.
- Results of the analysis on residue management, as a component of the alley cropping system, point to its positive effect on soil conservation by enhancing and maintaining soil organic matter content. Crop residue management is highly recommended as soils are heavily depleted of organic matter through soil erosion.

Impact of the Network

One of the objectives of the ASIALAND network is to strengthen the capability and competence of the National Agricultural Research and Extension System (NARES) in member-countries with regard to their ability to conduct adaptive research. This was accomplished mainly via training events, workshops, and national and international meetings. Network annual meetings provided participants with venues for information exchange on research results and country situations. Network partners have likewise received training on various topics such as socio-economic survey, information services and dissemination, modelling and GIS, and economic valuation, among others.

The network's impact on its partner organizations and countries is most evident in the way these partners have reoriented their research priorities and funding allocation towards SLM. Most member-countries have also integrated SLM in national policies and guidelines. The network has given its partners more opportunities to participate in regional and global research (Maglinao, 1998).

Through the outputs of the network, other international centers have adopted the Framework for the Evaluation of Sustainable Land Management (FESLM) and the soil, water, and nutrient management (SWNM) concepts through a participatory research paradigm and network and consortium approaches. Donor awareness and support for SLM has likewise increased.

The adoption of SLM technologies among farmers has also increased. Benefits from the technologies, in turn, have given farmers greater incentives to sustain their adoption.

Through the networking arrangement, a closer partnership among developing countries has been established. The development of concepts and tools provides a wider application of SLM technologies. The network has enabled the NARES not only to tackle major soil constraints to food production but also to undertake and strengthen their own research, utilizing operating funds from donors.

Reaching More Upland Farming Communities

Recommendations of the External Panel

During the latter part of Phase IV, SDC commissioned a panel of evaluators to review the accomplishments of the network and make recommendations for the implementation of Phase V. The panel gave the following recommendations:

- Strengthen the existing research-extension cooperation to include partners from non-government organizations.
- Move towards training of trainers rather than direct training of extension workers.
- Conduct a complete policy research and socio-economic study on the use of incentives.
- Assist the NARES in analyzing scientific results including their publication in view of individual scientific papers.

Goal, Objectives, and Strategies of Phase V

The goal of Phase V is to promote the widespread adoption of SLM technologies and practices in sloping areas in participating countries. With the lessons gained from Phases I to IV, the network intends to target communities in sloping lands, thereby reaching more farmers. The network-members have agreed to accomplish this through: (1) enhancing collaboration with other national agencies with emphasis on research and extension linkages, (2) strengthening the role of local government units and forging partnership with non-government organizations, (3) increasing farmers' involvement through joint on-farm experimentation, and (4) strengthening the NARES capacity in undertaking participatory research and information dissemination.

In the current phase, the network highlights the following:

- Emphasis on modalities and approaches to technology dissemination.
- Adoption of multi-sectoral and multi-disciplinary methodologies in research, development, and extension.
- Focusing on integrated farming systems rather than on soil conservation alone.
- Addressing the economic constraints of farmers through entrepreneurship and livelihoods.

Initial Results (January to October 2002)

Since the start of Phase V at the beginning of 2002, the network members have already learned a number of valuable lessons (NSC, 2002). These include:

- Site selection of pilot sites in establishing CFVs for the introduction of improved sloping/upland conservation and management technologies is very important. The pilot CFV has to represent the farming systems, physio-biological, and socio-economic conditions in the local areas. It could serve as a core or nucleus village for learning and disseminating identified and verified technologies to the surrounding villages.
- The target group of farmers in the pilot CFV is also very important. To better promote the widespread adoption of sloping/upland conservation measures by the farmers, they should form an integral part of their farming systems. This is achieved using participatory and community-based approaches. Farmers' groups or farmers' organizations, not individual farmers as in the previous phases, are addressed. The volunteer farmers should represent diversified farmers in the village to enhance wide acceptance.
- If the introduced sloping/upland conservation practices fit the farmers' circumstances and conditions, resulting in farmers' acceptance of these technologies, then the pilot CFV should be sustained as a learning base in the long run.
- There appear to be two types of farmers being targeted by the network – the subsistence farmer and the agribusiness or commercial farmer. In dealing with the first group, the aim is to increase crop yields and income for food security. In the second group, the activities are directed towards income generation and land improvement.
- The ASIALAND project is in line with the national agricultural development plans and local government programs in partner countries. Nevertheless, the research-extension linkages' system at the national level is considered to be too complicated to make national networking possible at the moment. At present, the linkage system is progressing well at the local level (province, district, and village). Formalization of linkages through agreements and protocols is encouraged for them to become operational and functional.
- Though farmers mentioned economic returns to be a motivating factor for greater acceptance of SLM technologies, it was also concurred that there should be research on what factors affect the farmers' adoption and non-adoption of the introduced sloping/upland conservation practices in partner countries. Both qualitative research and quantitative research are required. Process documentation should be emphasized. This will be useful in conducting impact assessment.
- People's empowerment is recognized as a prerequisite to sustainable development. Therefore, networking among farmers is encouraged for joint learning and sharing

(knowledge, ideas, experiences, and materials); this allows them to become more self-reliant and have mutual assistance for increased agricultural production and sustainable development.

- The active involvement of community leaders, local government units, non-government and government organizations in the planning, implementation, and evaluation process is very important in accomplishing the objectives of the project.
- Capacity building must be sustained to enhance the technical and management skills of various stakeholders.
- Micro-credit has been identified as a possible intervention in addressing the financial constraints of farmers but this should be coupled with responsibility and accountability.
- Feedback is crucial in soliciting responses between and among stakeholders. Regular meetings and dialogues should be conducted for this purpose.

Paradigm Shift in Sustainable Land Management

Catchment-scale Research

The inadequacies of earlier research on soil erosion led the former IBSRAM to adopt a new research paradigm, which resulted in the establishment of the Management of Soil Erosion Consortium or MSEC. This new paradigm provides an organizational arrangement that engages scientists and research institutions to tackle a common goal through a participatory, interdisciplinary, community- and catchment-based framework (Maglinao, 2001).

Research on soil erosion conducted on a catchment scale is a new innovation in managing the on- and off-site effects of soil erosion. This is done by quantifying and evaluating the effects of soil erosion in the biophysical, environmental, and socio-economic standpoints in one setting. All stakeholder groups in the catchment area affected by soil erosion, including farmers and policy-makers, will benefit from the knowledge generated. By recognizing the scope and severity of the problem, stakeholders are enabled to make appropriate decisions about investments and land use policy in the sloping land areas.

MSEC-ASIALAND Linkage

MSEC and the ASIALAND network share a common goal and IWMI has encouraged closer linkage and complementation between the two projects. At the moment, both projects employ people's participation and community-based approaches as key elements of natural resource management. While they differ in methodology, focus, and location, the projects target the same goal – the sustainable management of sloping lands and watershed areas.

A proposed linkage between MSEC and ASIALAND is presented in Figure 3. The technologies that have been developed and recommended by the ASIALAND network are valuable inputs to MSEC in terms of identifying the options that can be presented to the farmers at the catchment site. These technologies are expected to be technically feasible after many years of evaluation. The CFV approach or other modalities of technology promotion will also be useful for MSEC in designing the development aspect of its work.

On the other hand, MSEC can contribute its experiences in conducting catchment research, which has become relevant in the community-based approach of ASIALAND in further promoting its developed technologies. It can also complement the on-site focus of the ASIALAND project with the off-site considerations of MSEC.

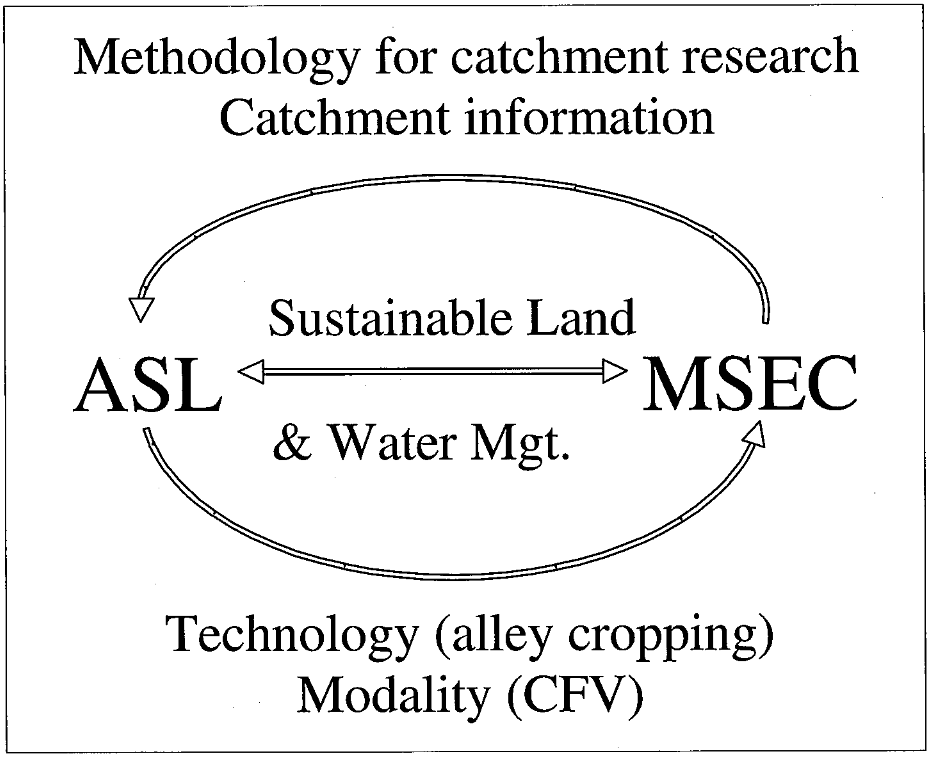

Figure 3. Proposed MSEC-ASIALAND linkage

Summary

The step-wise approach of the ASIALAND network in accomplishing its goal of assisting national agencies from its member-countries in conserving soil resources has covered activities from technology validation to on-farm research and extension. The network has progressed from plot-scale experiments to trials in farmers' fields and now development work in entire communities. Banking on the solid base of research findings and lessons gained in working with farmers, the network pursues a more dynamic and proactive approach to extending conservation farming technologies for sustainable land management. While the strength of the ASIALAND network is in its experience of more than 10 years of research, MSEC's approach opens a new dimension in soil erosion research; charting new ground for community-level development work on sloping lands.

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The Integrated Upland Agriculture Research Project (IUARP): An Alternative Approach to Poverty Reduction and Environmental Stabilization in the Uplands of Lao PDR

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Abstract

Given the diversity and complexity of the communities and their livelihood systems in the uplands of Laos, NAFRI has proposed a new approach to form the basis of its upland research program. The Integrated Upland Agriculture Research Project (IUARP) serves as a case study that employs a focal area approach, more community participation, the involvement of multidisciplinary specialists, and participatory on-farm research. First and foremost is that IUARP is functioning effectively. The process of developing and implementing the project has been difficult, but the first two years of its implementation have yielded lessons that can provide the proper direction towards sustainable upland development. Promising technologies and approaches to research are beginning to emerge that could have a positive impact on the livelihoods of upland communities. Most researchers are now familiar with the concepts of participatory research and have started to use some of the methods. Farmers have become interested and are keen to be involved in testing improved/ alternative production systems. Strong local leadership and involvement of local NAFRC researchers and PAFO and DAFO staff have been key to the success of the IUARP.

Introduction

The upland areas of Lao PDR cover about 80 to 85 percent of the country's land area. It is estimated that 280,000 households or some 30 percent of the country's 4.5 million people[2] currently live in these areas. With an annual population growth of 2.5 percent, the pressure on upland resources has been increasing. The forest tree cover has declined to less than 30 percent of the land cover from an estimated 47 percent in 1994 (MAF, 1999).

Traditional shifting cultivation predominates in the uplands with an estimated 2.3 million ha (just under 10 percent of the country) currently being used for bush fallow or cultivation (Schiller *et al.*, 1999). Rice is the single most important crop component of Lao upland farming systems although it is rarely monocropped. A range of other grain and vegetable crops is interplanted with rice. In 2000, the uplands accounted for 21.1 percent (152,110 ha) of the area planted to rice and 11.8 percent (258,750 t) of production. The northern agricultural region produced 71 percent of Laos' upland rice.

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[1] National Agriculture and Forestry Research Institute (NAFRI), Vientiane, Lao PDR
[2] National Human Development Report (1998) State Planning Committee, Lao PDR.
Lao PDR Development Co-operation (1998) UNDP

The length of the succeeding fallow is crucial to the stability of the system. The average fallow length has been reduced from over 30 years to five years (Roder *et al.* 1995). In provinces with relatively high population densities (i.e. Luang Prabang, Xiengnguen District) the fallow length may be as low as three years followed by two years of cropping (Farney, 1999). In many upland areas, increasing population pressure, lack of alternative land uses, limited land availability, fertility decline, and cumulative soil erosion, combine to make the farming systems unsustainable.

Given the diversity and complexity of upland communities and their livelihood systems, the government favors an "area-based livelihood systems" or "focal area" approach to decentralized rural development[3]. In support of this, NAFRI has proposed a new approach to form the basis of its upland research program. This paper presents the progress and lessons learned from the implementation of the Integrated Upland Agriculture Research Project (IUARP) which serves as a case study that employs a focal area approach, more community participation, the involvement of multidisciplinary specialists, and participatory on-farm research.

Project Objectives and Expected Outcomes

The Integrated Upland Agriculture Research Project (IUARP) was conceptually initiated in 1999, but implementation did not start until late 2000 when village level problem diagnosis was conducted. It is a multidisciplinary integrated research project that is aimed at participatory development and the application of applied and appropriate agriculture-based livelihood packages for upland communities. The IUARP has identified the following four major objectives:

1. To develop, test, and refine the methodology for integrated upland agricultural research;
2. To develop sustainable livelihood systems as alternatives to slash and burn;
3. To ensure current staff capacity in integrated upland agricultural research within NAFRI and relevant PAFO and DAFO is enhanced and sustained; and
4. To enhance community development, decision-making, and leadership capacity within the target communities.

Once these target objectives are addressed, it is expected that the outcomes will support the Lao government's agricultural policy to improve food security, alleviate poverty (especially reducing the disparity between rural and urban incomes), and stabilize the environment.

Implementing the Research Project

Site Selection

The IUARP employs an area-based approach to research for development and research capacity building. It is not meant to be a development project for the target villages but should quickly expand to the village cluster and watershed levels. The village cluster approach will ensure that a number of villages are included so that some of the application limits of the

[3] Dr. Phouang Parisak Pravongviengkham (1998).

component technologies and systems are defined. It ensures that the selected area is reasonably representative of the complex issues and diversity experienced within much of the uplands. This also ensures that it includes common property areas and open access resources such that the improved management options introduced play a vital role in communal food security and survival.

Project Initiation

Although it is useful to start certain activities as soon as possible this should not happen at the expense of a careful and well-informed initiation process. As such, project initiation included the following activities.

Training and familiarization of key stakeholders

The objectives, approach, participatory processes, and mode of operation of the IUARP must be clear to the local team (the staff of NAFRI, NAFRC, PAFO, DAFO), the villagers, and international component researchers. Meetings and associated training with all key stakeholders are required. Achievement of a common understanding is essential to the project's success.

Baseline studies

Biophysical (including land classification and soil characterization) and socio-economic surveys were conducted in Ban Hatsua (SSLCC, 1999). Following the decision to expand to a village cluster, a rapid socio-economic survey was conducted in each of the eight villages within the target area (Douangsavang, 2000). This foundation needs to be supplemented with more detailed participatory and biophysical surveys.

Little information on nutrient problems in the IUARP target area or Lao uplands in general exists. Baseline soil and nutrient surveys are needed before extensive work on cropping systems can commence. The results of the survey (along with annual updates based on monitoring and evaluation) are collated and published by the NAFRC in collaboration with NAFRI and distributed to all collaborating institutions.

Participatory problem diagnosis

A Participatory Problem Diagnosis (PD) is conducted in the village cluster to understand the constraints being experienced by farmers and the opportunities that they envisage for overcoming these constraints. During the PD, researchers first work with the community to gain a greater understanding of their agricultural and livelihood systems. They then work with the primary common-interest groups (e.g. farmers with only upland fields, farmers with livestock, farmers with paddy fields, etc) to get a more detailed understanding of:

- the problems that are of most concern within their agricultural and livelihood systems;
- the causal links between these problems;
- what actions the farmers have taken in the past to minimize each problem;
- which of the problems is the highest priority for solution; and
- what actions they would like to take to solve these problems in the future.

The PD identifies the priority concerns of farmers, allowing NAFRI and the other partner organizations to suggest a range of technology options which may contribute to solving these problems.

Following the PD, farmers' expectations of the IUARP have been raised and it is important to have quick follow-up to inform the farmers of the range of technology options that could be offered. During these follow-up meetings it is important to explain that no one can be sure if these technology options will provide the solutions the farmers need, but that the IUARP and the farmers are starting a process where they work together to test, adapt, and improve the options.

Research Implementation

Identification of research areas

Both component and systems research are conducted. Component research projects are generally characterized by participatory, on-farm, applied research and have outcomes that directly feed into the development of livelihood systems. Selection of component studies is based partly on an assessment by the steering committee of the critical work required to support livelihood system development and expansion, and partly on the interest and enthusiasm of potential agencies involved that contribute resources. Three areas identified during the IUARP planning workshop on April 7-8, 1999 in Luang Prabang for component studies were: 1) Rice Based Cropping Systems, 2) Crop Diversification, and 3) Livestock (Table 1). These areas require both short- and long-term strategies.

Systems research occurs where viable options exist to deal with the major problems or as component research identifies viable technologies which need to be integrated into improved farming systems. Considerable work by various institutions has been done within the region and elsewhere leading to the development of promising or proven technologies for upland environments. Promising technologies need to be matched with identified problems and needs. If no technologies exist for a certain area or group of individuals, component research may be required. Improved farming systems integrate both production and resource-protection practices.

Selection of Cooperators

Cooperator selection is needed for both component and systems research studies. Selection of cooperators takes into account community diversity. Hence income, education, gender, age, ethnic diversity, social groupings, and livelihoods are considered. Obviously other issues (e.g. resource availability, enthusiasm, and cooperation) also affect the decision.

Consideration is given to the selection of cooperator groups as well as individuals. The choice to use a group, rather than an individual, depends on the importance of the issue to the community and the nature of available interventions. For instance if poor rice varieties are a major problem to most of the farmers, and some promising alternatives are available, then a "rice productivity group" could form the basis of trial planning, design, implementation, management, and evaluation. Groups frequently achieve more, come up with more innovative solutions, and initiate more widespread interest in adoption than individual cooperators. The researcher guides the group through the process and facilitates group interaction. Groups are less useful when the issue of concern is of interest to a small number of people, available options need more extensive testing, or specific sites are necessary.

Table 1. Priority areas for IUARP component studies

Component Studies	Key Players	Short-Term Priorities	Medium-Term Priorities
Rice-Based Cropping Systems			
Rice variety improvement	NAFRC,ARC, URRC, Lao-IRRI	Incorporation of promising varieties in	Screening and selection of improved varieties, system integration.
Vegetative contours	NAFRC, TKARS ICRAF, IBSRAM	Species evaluation, demonstrations	Management and system integration
Weed management	NAFRC, URRC, Lao-IRRI	Weed ingress monitoring (seeding and cycles), crop cover, mulching, herbicides	Integrated weed management studies, herbicide evaluation.
Nutrient management	SSLCC, NAFRC, URRC, Lao-IRRI	Benchmarking soil fertility, nutrient responses	Nutrient monitoring; nutrient budgets.
Rodent control	ACIAR	Ecology studies	Management studies
Fallow management	NAFRC, TKARS, Lao-IRRI, ICRAF, IBSRAM, FLSP	Species evaluation, training.	Demonstration and system integration.
Diversification			
Perennial crops training,	NAFRC, VHRC,	Species evaluation,	Improved germplasm,
(fruit and agro-forestry)	TKARS, ICRAF, ACIAR	propagation	marketing studies
Forestry	FRC, TKARS, ICRAF	Forest land survey and identification.	Forest management
Annual crops marketing,	NAFRC, VHRC	Identify and assess	Species evaluation,
		economic options for late season.	demonstrations and system integration.
Livestock			
Forage evaluation	LRC, FLSP	Pasture and feed evaluation.	Improved forages, system integration.
Husbandry and management vaccination.	LRC, LAREC, FLSP	Introduction of improved small breed livestock and chicken	Ruminants, fish, marketing, system integration.

Field Implementation

Given the limited human resources at the local level, coordination of activities is crucial. To help coordinate and integrate field activities at the village level, the Implementing Team (IT) was set up. The IT is led by the site coordinator and is made up of local researchers and extension workers (from NAFRC, AFRS, TRS, PAFO, and DAFO). All activities are directed through the IT as this is the interface between researchers and the community. The IT meets once a month to discuss progress and future plans. An IUARP Update is sent out regularly to keep all partners informed of what is going on in the field.

In the field, research is a joint effort between farmers, DAFO staff, and researchers. Strong DAFO involvement is critical for project success as the staff are in a much better position to provide regular follow up and monitoring. The DAFO provided six staff members to work in the IUARP in 2001. Furthermore, the district governor has been involved in a few key activities, resulting in rapid acceptance of the IUARP in the villages. Involvement of the DAFO in this applied research supports the MAF policy to develop generalists at the district level for extension.

Research Cycle

Research within the IUARP target area is an ongoing process that continues for more than one season (not just a one-time injection of technologies) and involves a regular process of involvement and consultation with villagers as technologies are improved to suit the local conditions. In this cycle, following the PD, villagers **select** which technology options they would like to test and adapt during the coming year and **plan** with the project staff how this will be done. This is followed by **action** in the field and a village meeting during the dry season to **evaluate** progress and make plans for the coming year.

Development of Methodology and Livelihood Systems

Development of a research methodology which NAFRI can use to address agricultural problems in the uplands is one of the objectives of the project. It is recognized that while a lot of research has been conducted in the uplands, very little of it has actually had much impact and been adopted broadly. One of the reasons for this is that the uplands are highly diverse in ethnic groups, market access, and availability or knowledge of lowland rice or livestock. Therefore, technologies have limited domains where they can be recommended. Given this challenge, a different approach to research is required. Research needs to be more applied, adaptive, and participatory. The idea is to introduce new technologies but to work with farmers to adapt these technologies to their environment.

The methodology for integrated upland agricultural research is developed through the use of a combination of systems and component research, employing multidisciplinary, participatory, and community-focused methodologies. It emphasizes the critical role of on-farm and farmers' assessment of technologies. It likewise integrates the efforts of various national and international partners.

The livelihood systems that are developed focus on alternatives to slash and burn. These systems are expected to enhance the productivity, stability, and viability of the current livelihood systems in both the short and long term and ensure that negative environmental impacts are minimized or eliminated. Proven technologies from other programs and institutions, both from within and outside Laos are evaluated for introduction in the site. This is done with the active participation of the farmers and community groups to ensure social and cultural acceptability and to enhance adoption. Research should ascertain that these systems apply to other "livelihoods" in Laos.

Capacity Building and Community Development

Institutional capacity building ensures the enhancement and sustenance of the current staff capacity in integrated upland agricultural research. This is done through the use of current government structures at the national, regional, provincial, and district level; strengthening of the implementation of the National Program for Stabilization of Shifting Cultivation; training for staff and technicians involved in the implementation of IUARP activities.

Community development focuses on decision-making and leadership capacity building within the target communities. This is enhanced by involvement of the farmers and the community in the identification, testing, and evaluation of improved livelihood systems or components; training individuals, groups, and village organizations in new practices and resource management.

Participatory Component and Systems Research is most effective when combined with community mobilization activities. A program that assists the community to undertake planning and initiate group-based activities must complement the on-farm component and systems research. Attention must be paid to farmers' group development, locally led planning processes, group learning, and communal action. Efforts should occur at the village level to upgrade organizational management, improve skills through group training, undertake leadership training, and most importantly initiate and coordinate communal action.

Project Organization and Management

The overall project management is with the NAFRI executive committee, chaired by the director-general of NAFRI (Figure 1). The steering committee, which is composed of selected members from NAFRI and from some international organizations, advises the director-general on project strategies and direction. The technical management committee, which is chaired by the NAFRI project leader and is composed of the directors of NAFRI centers, members of the IT, and international partners, develops work plans and provides technical input. The directors of the NAFRI research centers are responsible for coordinating the activities in their sections. International organizations involved in the project work through and in collaboration with one of the NAFRI research centers. Among the international institutions collaborating in 2002 were:

1. International Rice Research Institute (Lao-IRRI)
2. International Center for Research in Agroforestry (ICRAF)
3. International Center for Tropical Agriculture (CIAT and CIAT FLSP)
4. International Water Management Institute (IWMI)
5. Australian Center for International Agricultural Research (ACIAR)

IWMI, through its MSEC and ASIALAND network projects, have played a major role in the implementation of the IUARP. While both projects highlight soil erosion and erosion management in upland areas, they consider an integrated approach to catchment management. IWMI has also contributed financially to the operation of the IUARP.

Project Monitoring and Evaluation

A project participatory monitoring and evaluation (PM&E) framework was formulated to evaluate the impact of the project (Figure 2). This was developed in a workshop in May 2002 and is expected to be finalized in November 2003 in a PM&E workshop in Luang Prabang. A component of the M&E is a baseline study conducted in the seven IUARP villages during July 2002.

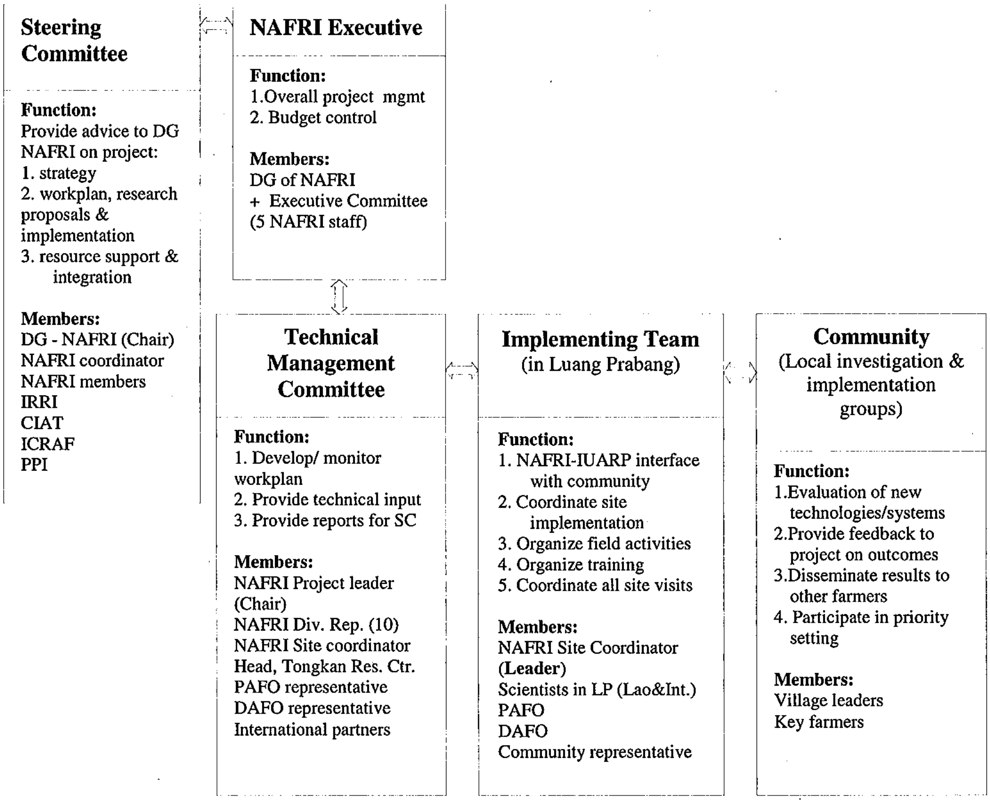

Figure 1. Organization of the Integrated Upland Agricultural Research Project

Initial Results

Site Selection

A cluster of villages within Pak Ou District (Luang Prabang Province) approximately 50 km north of the city of Luang Prabang was chosen (Figure 3). Criteria used in the selection process included:

- *Limited development*: The area should not be the focus of current or previous development projects.
- *Accessibility*: At least some of the communities within the area should be reasonably accessible thus easing logistical difficulties for this new study.
- *Community commitment*: The communities should be committed and enthusiastic to be involved. The community is expected to provide logistical and "in-kind" support to project activities as their commitment to community development.

The area encompasses eight villages with a total of 528 households and village sizes ranging from 32 to 142 households (Douangsavang, 2000). Elevation ranges from 300 to 900 m above sea level and includes communities close to major roads as well as more remote settlements. There is considerable heterogeneity represented within the village cluster, for

Figure 2. Draft participatory monitoring and evaluation (PM&E) framework for the project

IUARP objective	Key questions	Indicators	Information required	Methods/tools	Responsible party
1. The development of a participatory and integrated **methodology** for the uplands	Has the project structure and research methodology been effective in integrating the component activities?	• Activities are becoming better integrated and multidisciplinary	• Examples of sharing and cooperation (i.e. field updates)	• Content analysis of available reports	Phouthone
	How are stakeholders (research/extension/farmer) participating in R&D?	• Number of village level focal groups • The diversity of stakeholders attending workshops/meetings and engaging in further collaboration	• Examples of collaborative activities in the field	• Meeting records • Stakeholder consultation	IT/Phouthone
	Is the on-farm research addressing priorities of the local communities?	• The extent to which PD priorities are being addressed by IUARP activities • There is an increased spread of the technologies	• Priorities that are being/not being/cannot be addressed • Degree of spread of technology	• Compare work plan with PD • Impact study (see other objectives) • Village mapping	Phouthone/SEU/IT
2. The **delivery and acceptance** of sustainable livelihood systems for the focal area	What component technologies are being adopted/adapted by farmers into integrated livelihood systems?	• Number of farmers who adopt/reject new component technologies. Why? • Kind of technologies being tested maintained and adopted. Why? • Nature of adaptation by farmers (by ethnic group/IK) • Integration of components at household level • Spontaneous spread of technologies	• Tracking farmer responses to various technologies • Information for non-participating farmers as to limitations to adoption • Information from other stakeholders	• Matrix/preference analysis to participating households • Simple questionnaire for adoption/adaption • Focus group discussions • Debriefing after field days/cross visits	Bounthanh responsible for coordinating/collating
	What are the impacts on livelihood and NRM (income employment, slash and burn, gender roles etc)?	• Level of income • Level of employment • Conditions/changes in upland land use • Food self-sufficiency • Change in NRM practices • Stability of livelihood systems **(Well being/ethnic/ gender categories for above)**		• Case studies with the following elements: ➢ Benchmark survey ➢ Livelihood analysis ➢ Farm map/plan ➢ Seasonal calendars ➢ Other??? (above on 6-7 hh/village)	SEU/IT

3. The ability of the project to **enhance the capability** of NAFRI, PAFO, and DAFO staff to implement integrated research programs	Does involvement in the IUARP contribute to improved capacities of personnel and is this capacity being effectively utilized to undertake integrated and participatory research?	• Number and types of training organized within the IUARP • Training provided matches the responsibilities of trainees • Evidence of utilization of newly acquired skills/ knowledge • Training highlights the participatory dimensions • The neglected and underemphasized subject areas	• Training offered • Responsibilities of person • Use of skills learned	• Training database (includes training, person, responsibilities/ roles) • Training needs' assessment • Structured feedback from trainees	Bounthanh
	Have the principles/ strategies and technologies espoused by the IUARP been a source of influence to other stakeholders involved in upland R&D?	• Those involved in IUARP have used the principles/ lessons of IUARP to benefit their other related activities • Number and type of visitors to the IUARP • Number and type of workshops/ conferences where IUARP experiences have been shared		• Informal discussions • Village level records • Database/trip reports • Follow-up with selected visitors	IT/village head
4. The impact of the project on **community mobilization**, group activities and participation	What strategies/activities are effective for community participatory research for upland development and what factors have contributed to this success?	• Number of households involved in participatory research and development • Relative effectiveness of strategies used • Factors of success identified (factors affecting farmer group performance identified)		• Work plan • Inventory of strategies used and farmers' assessment • Self-assessment of group performance	IT with farmers
	What are the outcomes/ impacts of participation and what have farmers learned?	• Farmers' knowledge base enhanced/improved • Farmers are able and willing to articulate lessons learned from working with the IUARP • Group cohesiveness and active participation of all members in group decision		• Self-assessment of group performance • Results from case studies • Cross-visits for purposes of peerreview	IT with farmers

example: different ethnic groups, differences in the relative importance of livestock and lowland rice, and differences in market accessibility.

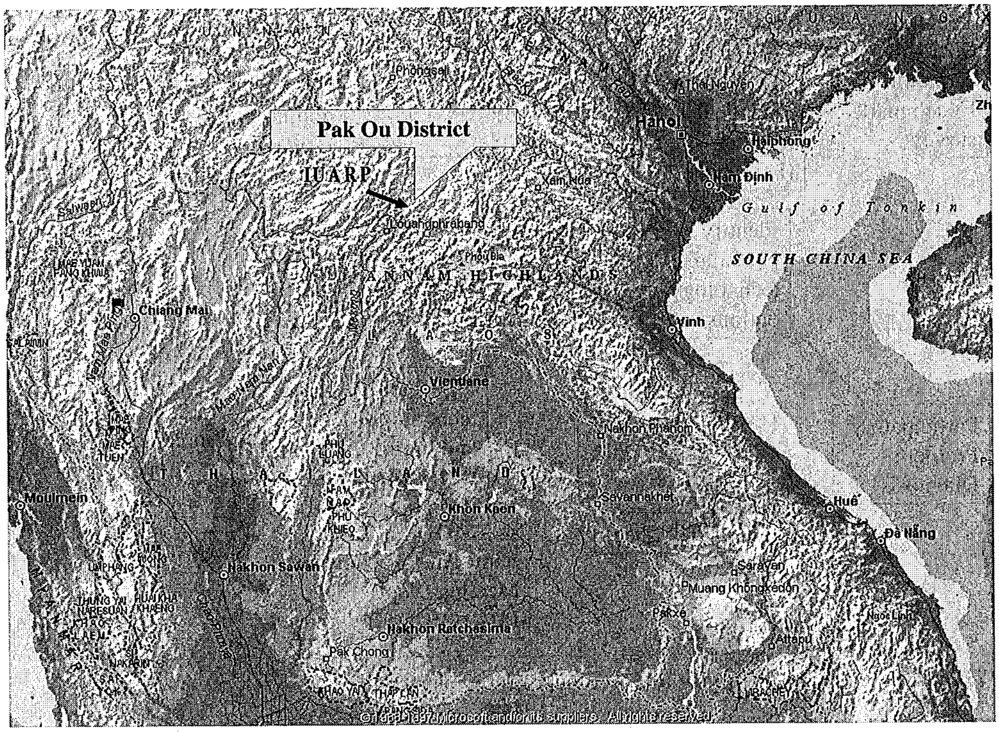

Figure 3. Physical location of the project in Pak Ou District

Research

Research began in 2001 in four villages with 50 farmers' households. Research activities were based on the problems identified by farmers during meetings conducted in each village. The number of villages increased to seven in 2002, with 230 participating farmers. During the first two years, there has been considerable research aimed at training researchers to conduct and use participatory research approaches. This has led to some important lessons and an activity cycle which is used within the IUARP.

During the first two years, the IUARP adopted and modified the research cycle to assist in the coordination and implementation of field activities (Figure 4). This approach has allowed researchers and farmers opportunities to develop research activities together, educate farmers in new methods, and learn from farmers' experiences. It is a cyclical approach that requires that lessons learned in one year are applied to the next. This approach is ideal for developing technologies that are suitable for farmers. As technologies develop to the point where they can be more broadly applied or scaled up, alternative approaches may need to be considered.

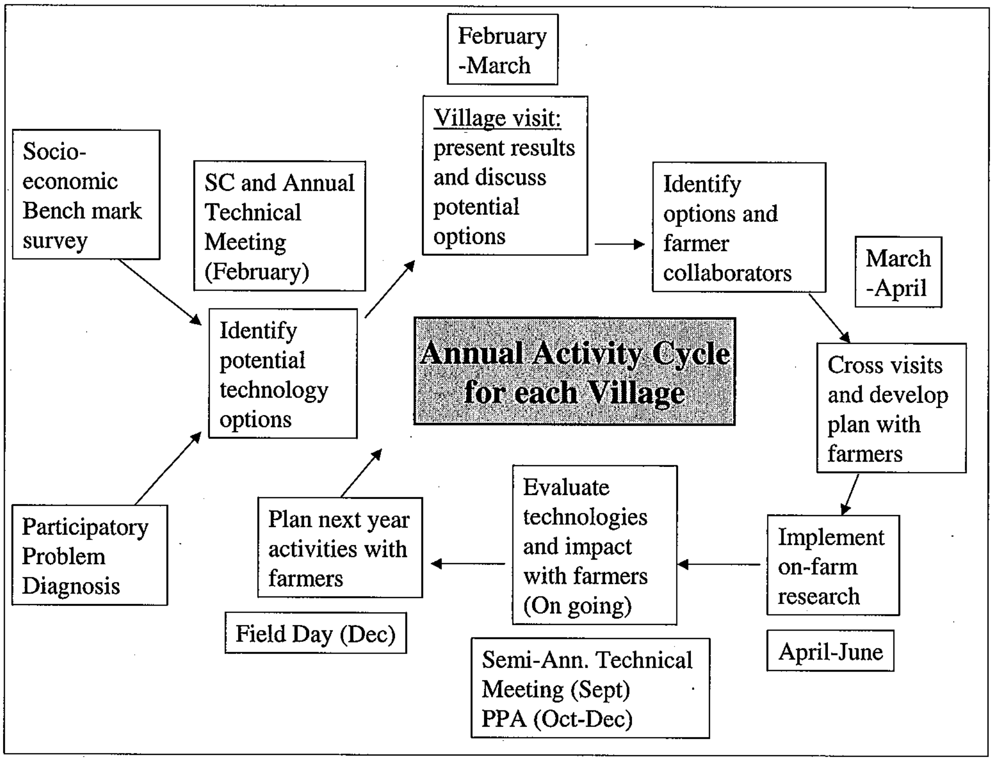

Figure 4. Annual research cycle followed in project implementation

Development of research methodology

During the first two years, there has been considerable research aimed at training researchers to conduct and use participatory research approaches. Most of these courses have been directly linked with ongoing field activities so that researchers are able to see a direct application of the training and use it. As such, most of the staff working in the IUARP are now familiar with participatory approaches and are getting better at using them. This has led to some important lessons and an activity cycle which is used within the IUARP.

Some of the lessons which have been learned in this process are:

- Training in participatory research approaches requires a lot of time and effort in the first couple of years.
- Constant follow up and training is necessary to ensure that these methods are being used appropriately.
- The most effective training events are those that are linked directly to field work, providing immediate hands-on experience related to the researchers' fields of interest.
- The efforts put into such training are valuable and promote:
  - increased trust of the farmers;
  - farmers wishing to collaborate.

Participatory research methodologies have increased farmers' trust in researchers and extensionists, which has made it much easier to work with farmers in the community. Involving farmers in the research process has further developed trust and the spread of technologies within the community.

Development of Sustainable Livelihood Systems

The conduct of research activities is expected to support the development of sustainable livelihood systems for the upland farmers. Based on the problems identified, a number of research activities is now being conducted (Table 2). These activities address the four main problems which have been identified by farmers.

Table 2. Research activities conducted to address the problems identified by farmers

Problem addressed	Research aActivity	Partners (Implementing partner in bold)
Food shortage	Fallow improvement	**KTU, NAFRC**, IRRI, FRC, ICRAF, CIAT
	Upland rice variety evaluation	**NAFRC**, IRRI
	Upland rice seed priming	**NAFRC**, IRRI
	Rodent management	**ARC, NAFRC**, ACIAR
	Variety evaluation for gall midge resistance and yield	**NAFRC**, IRRI
	Improving new paddy productivity	**NAFRC**, IRRI
	Assist in dry season expansion	**NAFRC**, IRRI
	Sloping land management	**SSLCC, NAFRC**, IWMI
Livestock and fisheries	Forage evaluation	**PAFO,** CIAT-FLSP, LRC
	Cage fish evaluation	**LARReC**, NAFRC
	Pond fish evaluation	**LARReC**, NAFRC
	Earth pond frog raising	**LARReC**, NAFRC
Low income	Fruit trees evaluation	**NAFRC, HVRC**, ICRAF
	Integrated fruit tree systems	**AFRS**, FRC, ICRAF
	Teak plantation management	**TRS**, FRC, ICRAF
	Fruit tree nurseries	**AFRS, HVRC, NAFRC**, FRC, ICRAF
Deforested forest areas	Rattan evaluation	**AFRS**, FRC, ICRAF

Technologies that are most preferred by farmers are those with short-term economic benefits. Such technologies provide good entry points to working with farmers and developing farmers' trust.

Before farmers can integrate many new technologies into an integrated farming system, they need to become familiar with the new technologies. This requires some time as they test the technology. However, once they become familiar with a technology, farmers begin to integrate these components into their farming systems. How farmers integrate varies with farmers and the resources they have. As researchers we need to provide technical options and expertise initially and then monitor and document how farmers are adapting and integrating these components.

There are some technologies that have developed to the stage where farmers are confident and would like to expand into larger areas. This provides an opportunity for the project to monitor the adaptation and adoption of these technologies or systems. Of interest to the

IUARP is whether these systems will be expanded without heavy project inputs – providing a good test for how applicable a technology is. Careful planning will be required to ensure the process is done well and that there is adequate monitoring, evaluation, and documentation of the process.

Institutional Capacity Building

The IUARP is implemented by and through the Lao government agencies. This ensures significant transfer of skills and experience to the Lao counterparts. The steering committee coordinates and plans joint training at its annual meetings.

As the IUARP brings together national and international research and development agencies, it provides an opportunity for significant training for local staff and communities. Training and institutional capacity building are major commitments requested from agencies cooperating in either the systems or component research. Many topics for training modules exist.

In the first two years much effort has been directed towards developing staff capacities in the area of participatory research. Using these methods has been successful, but constant follow up, support, and training continue to be required.

One of the most effective means of training is to provide training on a needs' basis. As researchers need to do an activity in the field, training should be applied immediately before doing it. This allows the trainees to easily remember what has been taught and gives the training an immediate application.

Community Development

A number of activities has been initiated to strengthen and support community development. Through the participatory research framework, various training events have been offered to farmers. These relate to technical aspects such as management of fruit trees and frogs as well as having the opportunity to visit other areas to see what other farmers are doing.

One of the most popular activities has been related to fruit tree orchards and the development of intensive home gardens. While the project has initially provided fruit trees for farmers to evaluate this system, if farmers want to expand on their own there needs to be a mechanism which allows them to do so. Farmers have indicated that the main constraint to developing such gardens is availability of reasonably priced fruit tree seedlings. In 2001, six farmers were trained in nursery management. Since then they have grown paper mulberry seedlings for sale and have started to grow fruit trees.

During 2002, there were many visitors to the IUARP. Some of these visitors simply came to witness the progress. More and more visitors are coming to learn from the farmers and the process that is being used in the IUARP. This gives IUARP farmers the opportunity to share their experiences and has resulted in greater confidence.

Constraints and Challenges

Some constraints have been identified during the first couple of years of the project. These need to be addressed to ensure that the project continues to run smoothly. These constraints are:

1. Not all activities direct their research through the IT, making coordination of activities difficult.
2. When conducting research, the research objective and questions are not always clear. Without this type of information it is not possible to know what data to collect or how to follow up on the research activities.
3. When conducting research and particularly participatory research, it is important to listen and respond to farmers. This may mean changing the protocol and direction of research. If we do not respond to farmers' knowledge and suggestions they will be reluctant to work with the project. Furthermore, the participatory aspect of the research is often not reported on.
4. There are limited human resources at NAFRI, PAFO, and DAFO to carry out research and many of these staff are poorly trained.
5. Many of the NAFRI researchers and technicians are excellent technically, however, there is a general lack of some basic scientific skills. This includes methodology, analysis, and reporting on results. Training in these areas and interpreting data into useful information that is ready for use by farmers and extension workers are key important issues as the IUARP looks for ways to scale up.
6. Another general area where skills are limited is in the area of socio-economic and simple economic analysis of technologies. Simple partial budgets can be done before research even begins. Farmers do not adopt technologies that are economically not feasible.
7. There are a number of emerging opportunities for technologies to be scaled up. Approaches used will be different for different technologies; however, careful thought should be given to how this is done so that it can be monitored and documented.

Summary and Conclusion

Since activities first began two years ago a lot of progress has been made in the IUARP. This is summarized as follows:

The IUARP is functioning effectively. However, the process of developing and implementing a program has been difficult; over the past two years some of the accomplishments are: a draft PM&E framework for the project has been developed; a clear management and financial structure has been developed; the local implementing team has been strengthened (through increased training and responsibilities); meetings at national, local, and community (such as planning meetings and field days) levels are held regularly; the research process has been clarified and strengthened; field updates are provided regularly to keep all partners informed of progress at the field level.

Promising technologies and approaches to research are beginning to emerge that could have a positive impact on the livelihoods of upland communities. Participatory research has been mainstreamed. This has involved much training (formal and on the job) in participatory research. Most researchers are now familiar with the concepts of participatory research and have started to use some of the methods. Further training, on an "as needed" basis, will continue to be required.

Farmers are interested and are keen to be involved in testing improved/alternative production systems. This year, researchers are involved with over 15 activities and working with over 230 households. Farmers are starting to integrate various components into improved farming systems and expand these activities on their own. Much of this success can be attributed to working within a participatory framework.

Strong local leadership and involvement (local NAFRC researchers and PAFO and DAFO staff) have been the key for the success of the IUARP. This has allowed for decisions to be made rapidly and activities to be implemented in a timely manner. Furthermore, it ensures adequate follow up throughout the year.

Greater links can be established between IUARP and extension or development organizations. The IUARP is a good venue for visits by other farmers as many activities can be seen in a relatively small area.

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Statistical Analysis of Long-term Series Rainfall Data: A Regional Study in Southeast Asia

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Abstract

The occurrence of many extreme events in hydrology cannot be forecast on the basis of deterministic information without sufficient skill and lead time. In such cases, a probability approach is required in order to incorporate the effects of such phenomena into decisions.

A short statistical study was conducted on a long-term series of data on daily rainfall from three weather stations in Vietnam (Hoa Binh), Laos (Luang Prabang), and Thailand (Phrae). These stations are relatively close to the MSEC study sites. The recorded period ranges from 28 to 50 years. The analysis was made on annual and maximum daily rainfall. Statistical adjustments gave the values for decennial and centennial return periods. Annual rainfall followed a normal distribution while maximum daily rainfall followed a Pearson 3 distribution.

All stations had reached annual values close to the millennium frequency (frequency 0.99) for the maximum values recorded and close to the centennial frequency (0.01) for the minimum values. All stations have reached the maximum daily values equal or higher than the centennial value. The highest observed value for Hoa Binh station (416.4 mm) is probably a millennium occurrence. There was a small tendency of the rainfall values to decrease in 1997 which was a strong El Niño year in the region. From this study, we may adjust rainfall data inputs for the erosion model developed by MSEC and extend the study to a larger area.

Introduction

The occurrence of many extreme events in hydrology cannot be forecast on the basis of deterministic information without sufficient skill and lead time. In such cases, a probability approach is required to incorporate the effects of such phenomena into decisions. If the occurrence can be assumed to be independent of time, then frequency analysis can be used to describe the likelihood of any one or combination of events over the time horizon of a decision (WMO, 1983).

Interpretation of precipitation has two major purposes. One purpose is to evaluate the observations that sample a precipitation event or series of events. The evaluation of the observed sample includes consideration of extraneous influences, such as deficient or changing

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gauge exposure, and interpretation of the effects of physical environment, such as physiography. The other purpose is to describe the event in a form appropriate for display, subsequent analysis, or other applications.

Little is known about trends in rainfall in the Southeast Asia region. A study conducted by Manton *et al.* (2001) showed a gap in the Indochinese Peninsula. Via the Management of Soil Erosion Consortium (MSEC) led by the International Water Management Institute (IWMI), it has been possible to gain access to three recorded series in this region. This paper provides a statistical analysis of long-term rainfall data in the region.

Location of the Study

The analysis was made using the data from three weather stations relatively close to the MSEC project sites. These stations are Hoa Binh in Vietnam (20° 49' N, 105° 20' E), Luang Prabang in Lao PDR (19° 53' N, 102° 08' E), and Phrae in northern Thailand (18° 08'N, 100° 10'E) (Figure 1). The period of record is 41 years for Hoa Binh, 51 years for Luang Prabang, and 28 years for Phrae. Daily rainfall data are available in all stations.

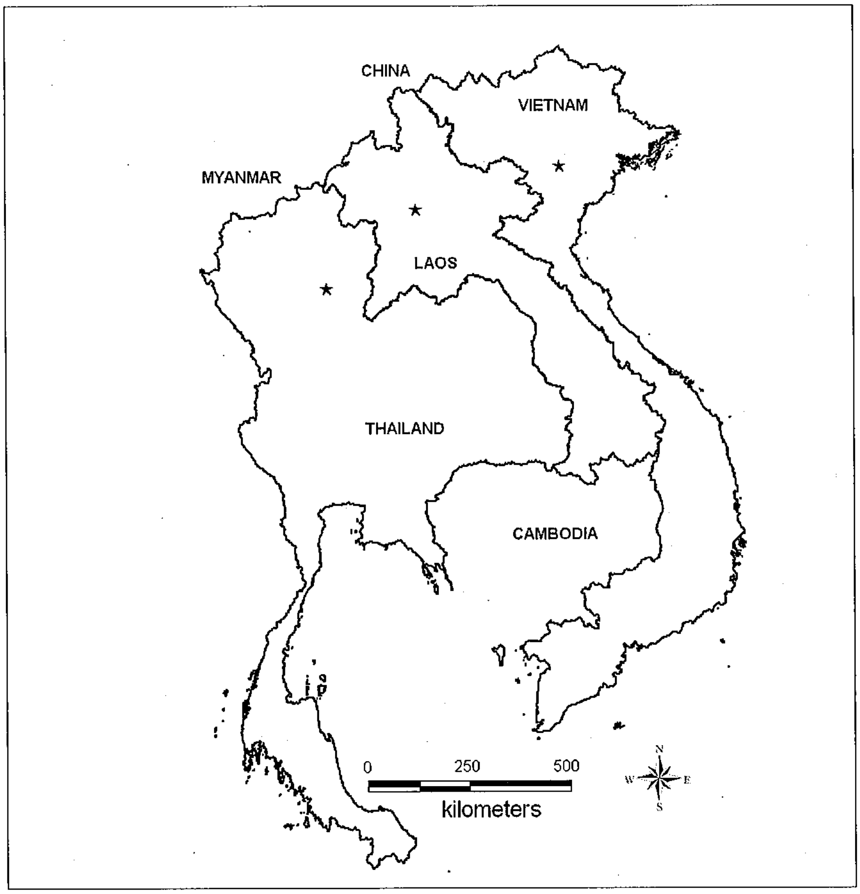

Figure 1. Location of the three stations

Results

Homogeneity of the Data

The homogeneity of hydrological or meteorological data is a requirement for valid statistical application. The most commonly used information about non-climatic influences comes from records of station movement, changes in instrumentation, problems with instrumentation, sensor calibration, changes in surrounding environmental characteristics, observation practices, and other similar occurrences (Guttman, 1998). The double-mass curve analysis introduced by Kohler (1949) is a graphical method of identifying and adjusting inconsistencies in a station record by comparing its time trend with those of other stations. Changes in slope of the double-mass curve may be caused by changes in exposure or location of gauge, change in procedure in collecting and processing data, etc (WMO, 1994). The data collected from all the sites within the region should be highly correlated, have similar variability, and differ only by scaling factors and random sampling variability.

As shown in Figure 2, there is no change in the slope of the curve for both the Hoa Binh and Phrae stations. So, we can consider all series as homogenous. With the very close correlation coefficient, it is also possible to extend the series of Hoa Binh and Phrae but only for annual or monthly values.

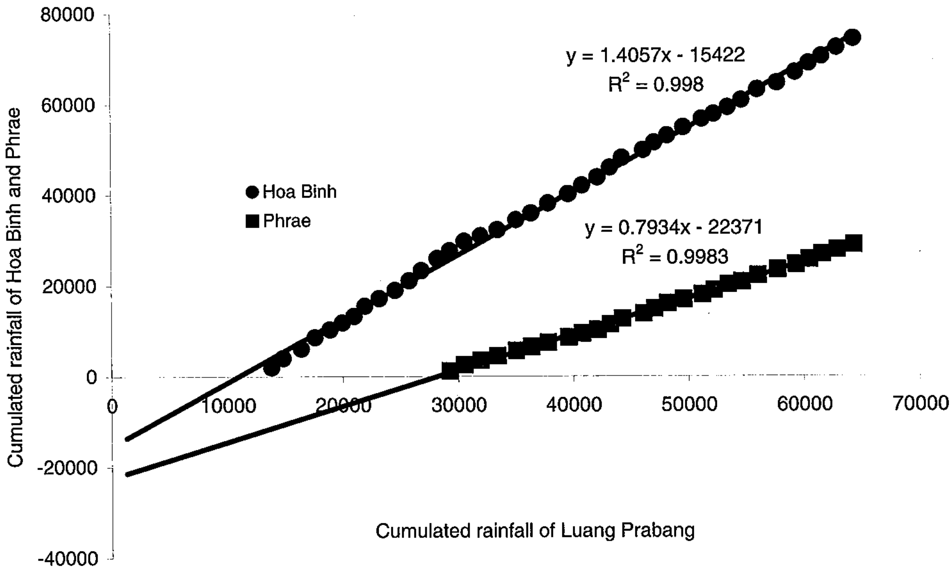

Figure 2. Double-mass curve for Hoa Binh and Phrae stations

Annual Rainfall Analysis

"Climatic Normal" is defined by the World Meteorological Organization (1983) as "period averages of a climatic element such as temperature or precipitation computed for a uniform and relatively long period comprising at least three consecutive ten-year periods". Manton *et* *al.* (2001) assumed that the annual total rainfall had generally decreased between 1961 and 1998. And the number of rainy days (with at least 2 mm of rain) has decreased significantly in Southeast Asia. Looking at the variations of the annual total rainfall (Figure 3) of the three stations, it is difficult to detect a trend of an increase or decrease in the annual amount of rain. Possibly a small decrease can be detected but not quantified now.

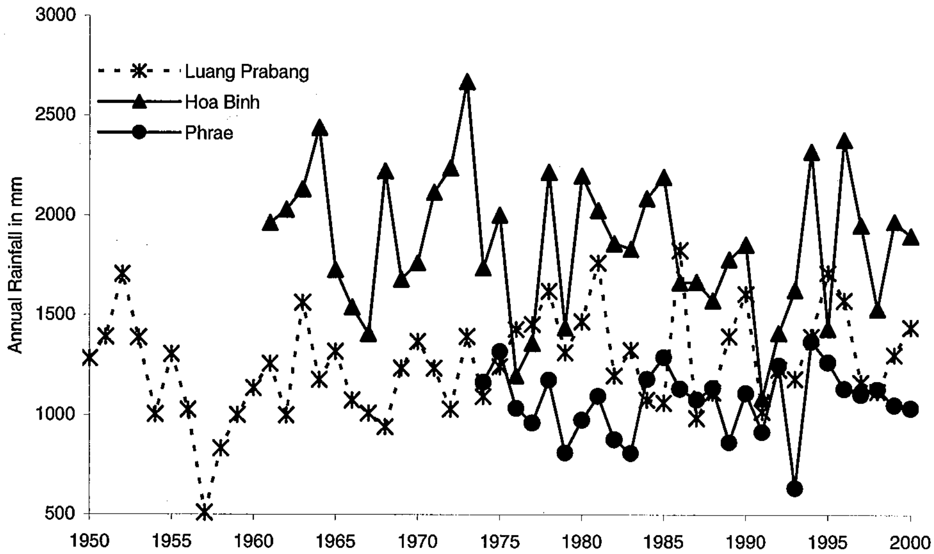

Figure 3. Variation of the annual rainfall at the three stations

The 1957 value of Luang Prabang looks very low. Checking the record, we cannot reject this very small amount of rain (511.1 mm). We can assume the same comment for the 1993 value for Phrae (635.9 mm). Standard statistical results are presented in Table 1.

Table 1. Summary statistics of the annual rainfall of the three stations

	Average	Variance	Std. deviation	Min.	Max.	Std. kurtosis
Hoa Binh	1,856.7	127, 290	356.8	1,085.2	2,671.7	-0.473
Luang Pranbang	1,261.2	65, 058	255.1	511.1	1,827.5	0.817
Phrae	1,084.6	34, 107	184.7	635.9	1,461.3	0.273

Annual rainfall usually follows a Gauss statistical distribution (Figure 4a, 4b). Figure 4a shows the statistical adjustment, while Figure 4b presents the frequency distribution. Accordingly, we calculated the different return period values with the Normal law. Results are presented in Table 2.

According to the calculations, we can see that all stations had already reached annual values close to the millennium frequency (frequency 0.99) for the maximum values recorded. For the minimum values, all stations have already reached centennial frequency (0.01).

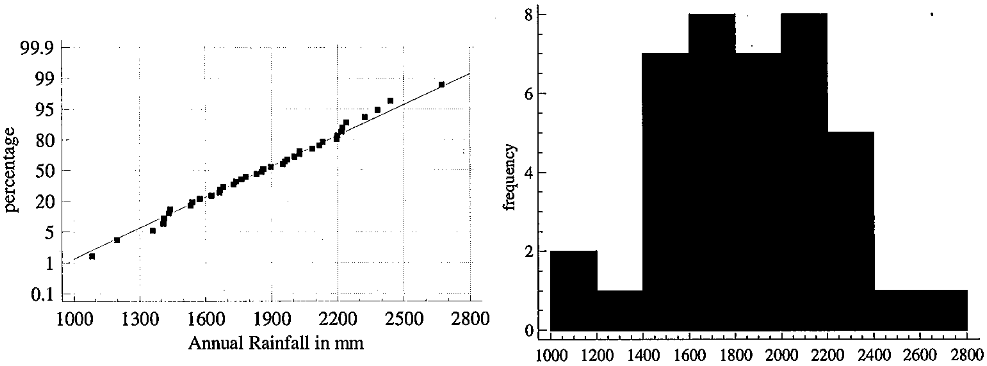

Figure 4. Annual rainfall at Hoa Binh station: statistical adjustment (left), frequency distribution (right)

Table 2. Frequency analysis of the annual rainfall of the three stations

	0.01	0.1	0.5	0.9	0.99
Hoa Binh	1,064.2	1,420.8	1,856.7	2,292.7	2,649.3
Luang Pranbang	710.7	958.4	1,261.2	1,563.9	1,811.6
Phrae	654.9	848.3	1,084.6	1,321.0	1,514.3

Maximum Daily Rainfall

Figure 5 presents the distribution of the maximum daily rainfall for the three stations. For this type of data, we have no Gauss distribution and the data can be adjusted with a Log Normal distribution (Figure 6). Standard statistics are given in Table 3.

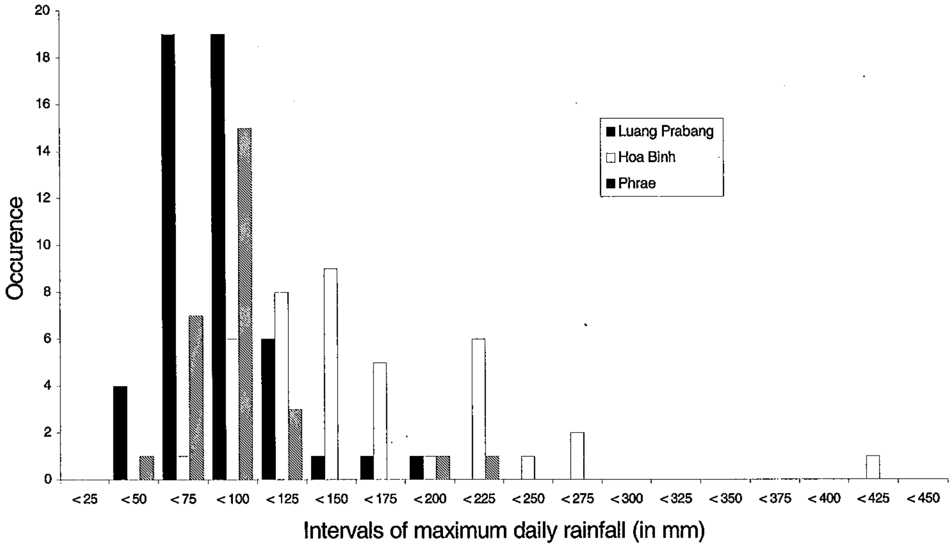

Figure 5. Frequency histogram of maximum daily rainfall at the three stations

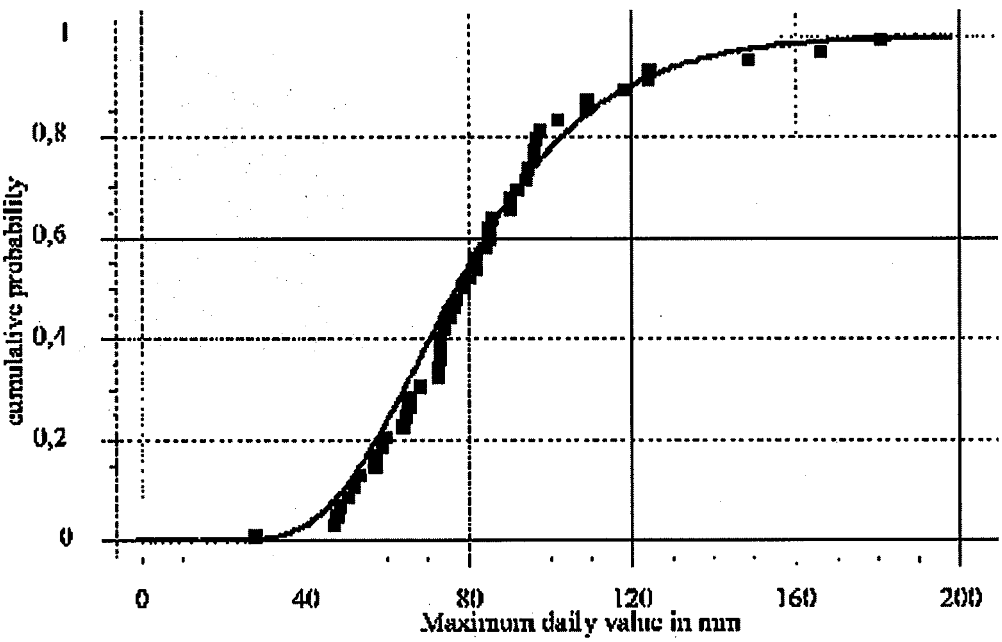

Figure 6. Adjustment of maximum daily rainfall at Luang Prabang station

Table 3. Summary statistics of the maximum daily rainfall of the three stations

	Average	Variance	Std. dDeviation	Min.	Max.	Std. kurtosis
Hoa Binh	156.1	4, 293.2	65.5	58.3	416.4	6.620
Luang Pranbang	83.2	852.8	29.2	27.7	180.7	3.615
Phrae	90.2	1, 278.8	35.7	43.3	218.2	7.062

The calculations of return period values are done following the Pearson 3 law. Results are given in Table 4. Pearson 3 law is one of the statistical laws used in hydro-meteorological studies especially for unique events.

Table 4. Frequency analysis of the maximum daily rainfall of the three stations

	0.01	0.1	0.5	0.9	0.99
Hoa Binh	64.4	90.2	142.6	238.6	378.9
Luang Pranbang	34.7	50.7	79.2	121.0	168.1
Phrae	48.4	58.0	81.3	132.4	222.7

The highest observed value for Hoa Binh station (416.4 mm) is probably a millennium occurrence. We can also notice that all stations have reached maximum daily values equal to or higher than the centennial calculation. The same comment can be made for the lower values. We could see here an increase in heavy precipitation events as have occurred in the United States (Karl and Knight, 1998).

Conclusion

This study is just a starting point for a deeper investigation of the climate in the region. As we can detect a decrease in the annual total rainfall for the three stations, we should continue this study with more stations in the region, including South China. A limitation of such a study is the low spatial density of stations with homogenous data

Acknowledgement

This study is a contribution to the Management of Soil Erosion Consortium led by the International Water Management Institute and funded by the Asian Development Bank (RETA 5803). Special thanks go to the National Departments of Meteorology of the different countries which provided the data.

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Analysis of Rainfall–Runoff Relationship on Sloping Uplands

W. Soda[1]

Abstract

The long-term data accumulated by the ASIALAND Management of Sloping Uplands Network were used to study the relationship between rainfall and runoff. An attempt was made to determine any relationship between these parameters and soil infiltration capacity. Data for seven years from Vietnam were used. In general, higher rainfall produced higher runoff. It was also shown that the runoff from the different soil conservation treatment plots (which could represent different land use) varied. The bare plot (T5) produced the highest runoff, followed by the farmer's practice (T1). The alley crops of corn + black bean with tea as the hedgerow (T2) and corn + black bean with Tephrosia candida *and tea as the hedgerow (T3) were equally effective in reducing runoff. Alley crops of corn + black beans with* Tephrosia candida *as the hedgerow (T4) produced the lowest runoff. This analysis supports the findings of the network which showed varying soil loss from different plots under different rainfall conditions. Relating the critical rainfall (rainfall at which runoff starts to occur) further showed that higher runoff occurred in treatments with lower values of critical rainfall. Further relating this to soil infiltration capacity, shows that T2, T3, and T4 are more efficient in promoting infiltration compared to bare soil and the traditional farming system. In terms of relationship between the infiltration and runoff coefficient, there was a trend of higher infiltration with lower runoff coefficient as shown in T1, T2, and T5. This trend was not observed in T3 and T4. This may need consideration of other parameters like rainfall intensity and duration and antecedent soil moisture content in the analysis.*

Introduction

Rainfall, runoff, and infiltration are three related parameters (Figure 1). When the rain falls on the ground, the water moves into the soil primarily through the forces of capillary action and gravity. As rainfall continues, water continues to infiltrate into the soil until the rainfall intensity exceeds infiltration capacity and runoff is generated. Rainfall at this point is called "critical rainfall" when runoff starts to occur. As shown in Figure 1, it is the rainfall at point 4. The surface runoff will be generated first before the soil has become fully saturated (Horton, 1933 as cited in Boutorabi, 2001). The generation of runoff will continue as long as the rainfall intensity exceeds the actual infiltration capacity of the soil. It will stop when the rate of rainfall becomes lower than the actual infiltration rate. Dune and Black (1975) as cited by Boutorabi (2001) present a second mechanism of runoff development brought by the volume of water exceeding the storage capacity of the soil. It occurs particularly in soils where the groundwater is close to the surface and rainfall of low intensity and volume can still saturate the soil.

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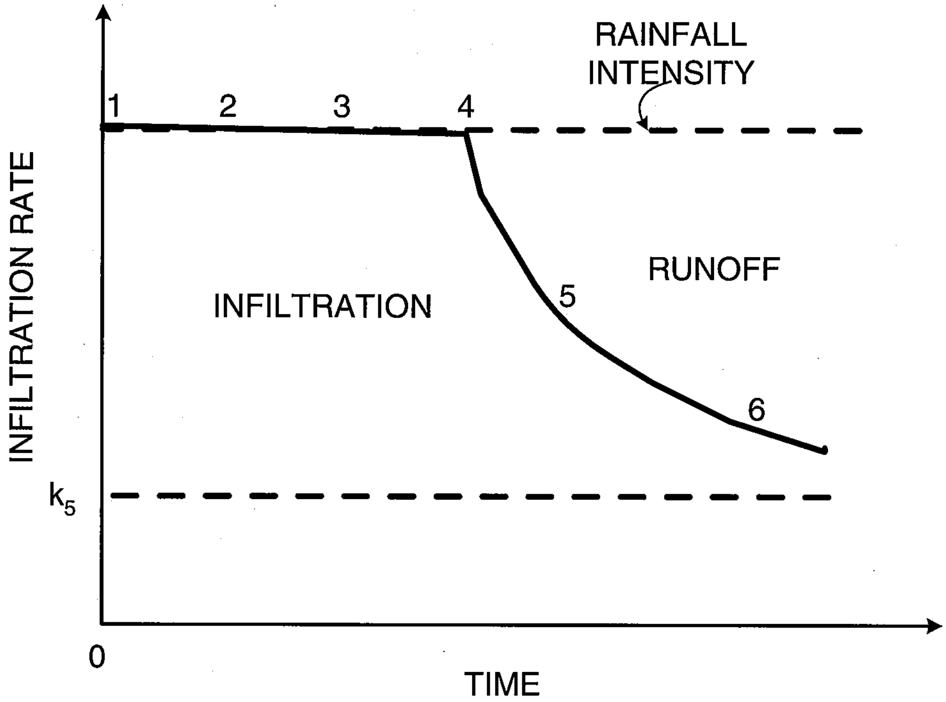

Figure 1. Infiltration rate as a function of time (after Mein and Larson, 1971a as cited in Singh, 1989)

Infiltration is the process of entry of water into the soil through the soil surface (Singh, 1989). The infiltration rate is the rate at which water enters into the soil surface. It is expressed as volume per unit area per unit time and has the dimension of length per unit of time. The infiltration capacity of the soil depends on many factors such as soil characteristics, surface characteristics, precipitation characteristics, antecedent condition, and fluid characteristics (Boutorabi, 2001; Paige, 2000; Critchley, 1991; Singh, 1989)

While there are many factors that may have a direct bearing on the occurrence and amount of runoff (Dijk, 2002; Byer, 2002; Boutorabi, 2001; Paige, 2000; Gatot *et al.*, 1999; Critchley, 1991; Singh, 1989; Sharma, 1986), there is a dearth of knowledge on the infiltration capacity measurements on steep slopes. This paper presents an analysis of the relationships between rainfall and runoff and evaluates derived values of soil infiltration capacity. Further evaluation of these parameters could then be related to soil loss and erosion.

Methodology

The analysis made use of the long-term data of the ASIALAND Management of Sloping Uplands network collected for seven years from the Vietnam site. The network has collected data from five other countries: China, Laos, Malaysia, Philippines, and Thailand. The data have been entered in a database termed “SALAD”.

Data of rainfall and runoff collected from 1993 to 1999 were used. A simple histogram was created for the annual rainfall and runoff from the daily data. Linear regression analysis was done to relate rainfall and runoff using the equation, $Y = aX + b$, where Y is runoff (mm), X is rainfall (mm), and a and b are linear regression coefficients.

Using the same equation, the critical rainfall was determined by obtaining the value of X at $Y = 0$. The runoff coefficient was calculated by getting the ratio of the total runoff and the total rainfall. The difference between rainfall and runoff was considered as the infiltration. Regression analysis was also done to determine the relationship between runoff coefficient and infiltration.

Further analysis of the relationships was done considering the different treatment plots of the experiment. The site in Vietnam had five different treatment plots:

Treatment 1 (T1) =	Farmer's practice using corn and black bean, no hedgerow.
Treatment 2 (T2) =	Corn and black beans and tea as the hedgerow.
Treatment 3 (T3) =	Corn and black beans with *Tephrosia candida* and tea as the hedgerow.
Treatment 4 (T4) =	Corn and black beans with *Tephrosia candida* as the hedgerow.
Treatment 5 (T5) =	Bare plot.

Results and Discussion

Relationship between Rainfall and Runoff

Figure 2 shows the yearly rainfall and runoff values of the different treatment plots from 1993 to 1999. The general trend indicates higher runoff at higher rainfall. In all years, the bare plot (T5) always produced the highest runoff, followed by the farmer's practice (T1). The alley crops of corn and black beans with tea as the hedgerow (T2) and corn and black beans with *Tephrosia candida* and tea as the hedgerow (T3) were equally effective in reducing runoff. Alley crops of corn and black beans with *Tephrosia candida* as the hedgerow (T4) produced the lowest runoff. The results clearly show the positive effect of the hedgerow treatments in reducing runoff.

The positive relationship between rainfall and runoff is further illustrated in Figure 3. There were however different degrees of relationship, with T3 and T4 showing higher correlation values between rainfall and runoff. This result is somewhat misleading as one expects an increased soil infiltration rate in the treatment plots.

It was also observed that the runoff from T2 was almost the same in 1994 and 1995 although the rainfall in 1994 was twice the amount in 1995 (2,000 as compared to 1,000 mm). This was also observed in T5. This can possibly be explained by factors like the intensity of rainfall, which unfortunately was not measured. A rough explanation is provided by Figure 4 which shows a higher runoff on a per rainy day basis in 1995 in both treatments.

Relationship between Critical Rainfall and Runoff

Figure 5 shows the comparison between critical rainfall and runoff. Relatively higher runoff was observed at lower critical rainfall. This implies that a larger proportion of rainfall may have infiltrated into the soil which caused further delay in the occurrence of runoff. Thus the alley cropping treatments could have enhanced the infiltration capacity which could be a reason for reduced runoff. Using actual field measurements, Beloy and Paningbatan (2002) showed that land use/land cover types largely influence the infiltration rate of the soil.

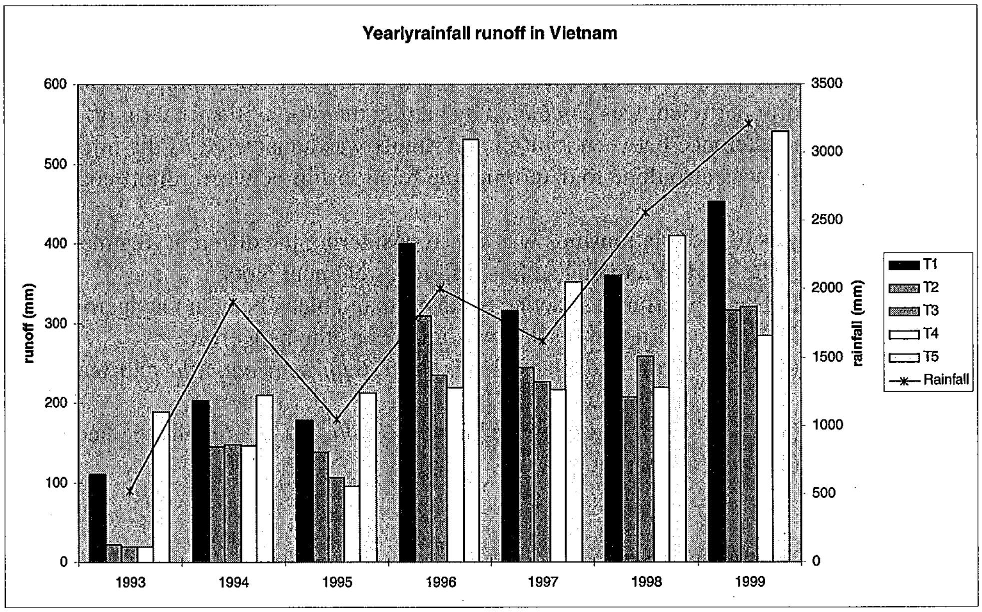

Figure 2. Yearly rainfall and runoff values of different treatments from 1993 to 1999

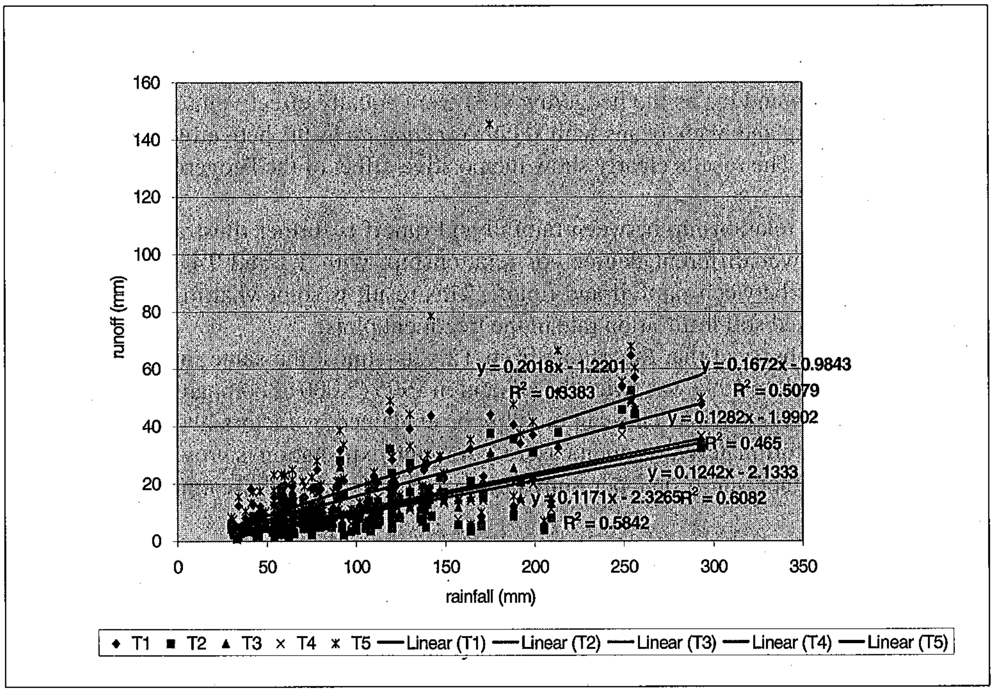

Figure 3. Relationship between rainfall and runoff under different treatments

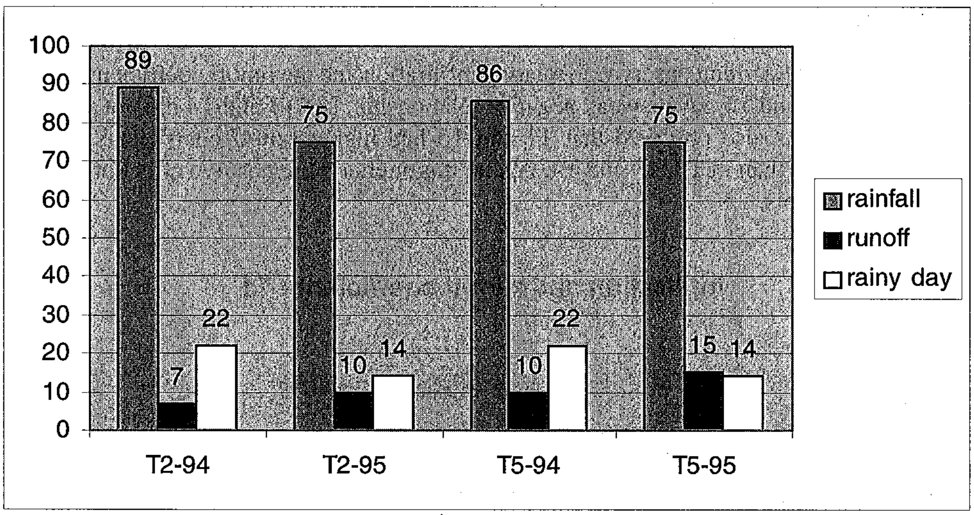

Figure 4. Rainfall and runoff per day and the number of rainy days in 1994 and1995

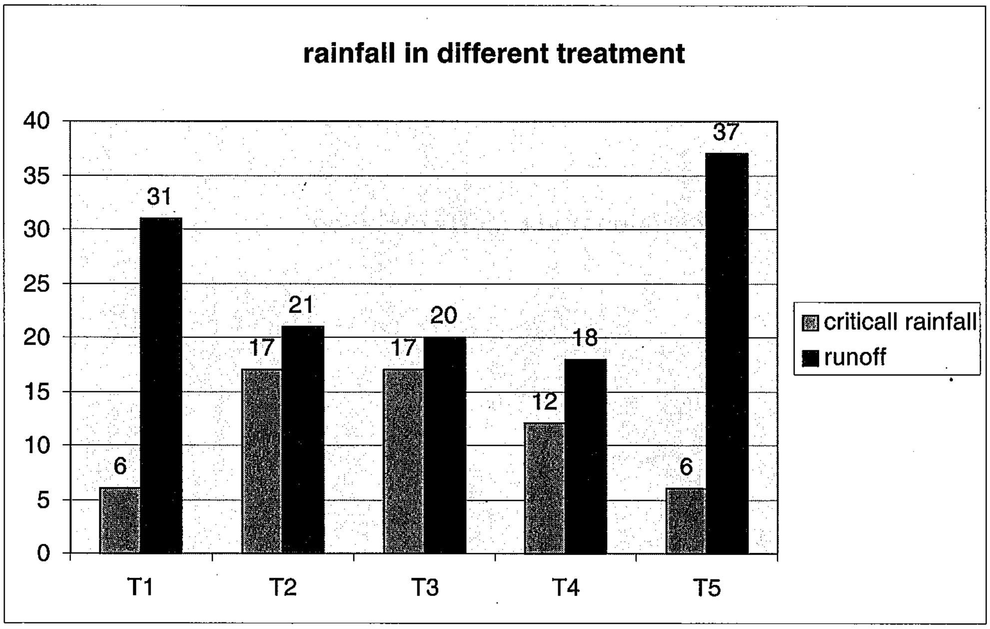

Figure 5. Relationship between critical rainfall and runoff in each treatment

Relationship between Infiltration and Runoff Coefficient

There was no general trend observed in relating infiltration and the runoff coefficient (Figures 6 to 10). T1, T2, and T5 gave a weak negative relationship, but T3 and T4 did not show any trend at all. It was also observed that T1 and T5 had higher runoff coefficients at lower infiltration values than in T2, T3 and T4. Again, this supports the positive effect of the alley cropping treatments.

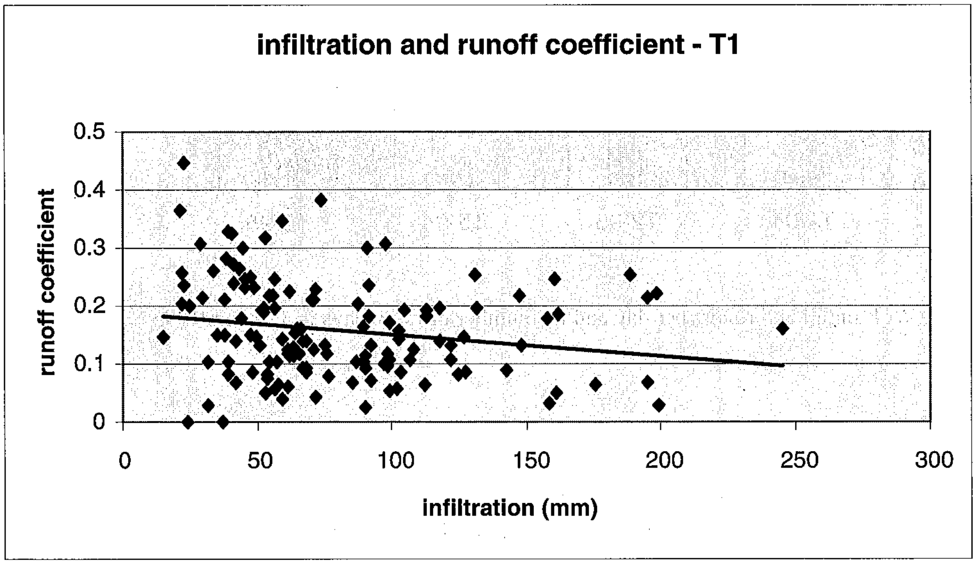

Figure 6. Relationship between infiltration and runoff coefficient in T1

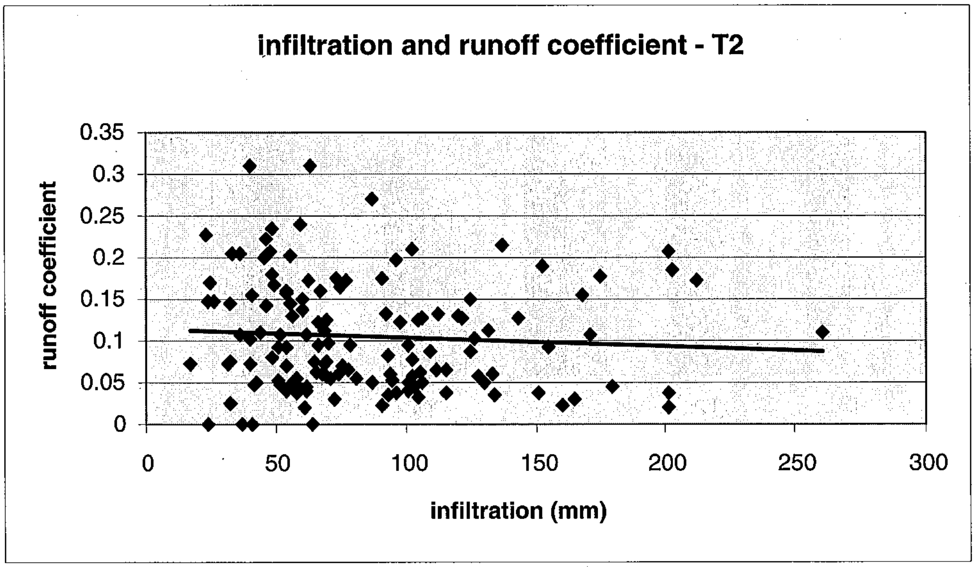

Figure 7. Relationship between infiltration and runoff coefficient in T2

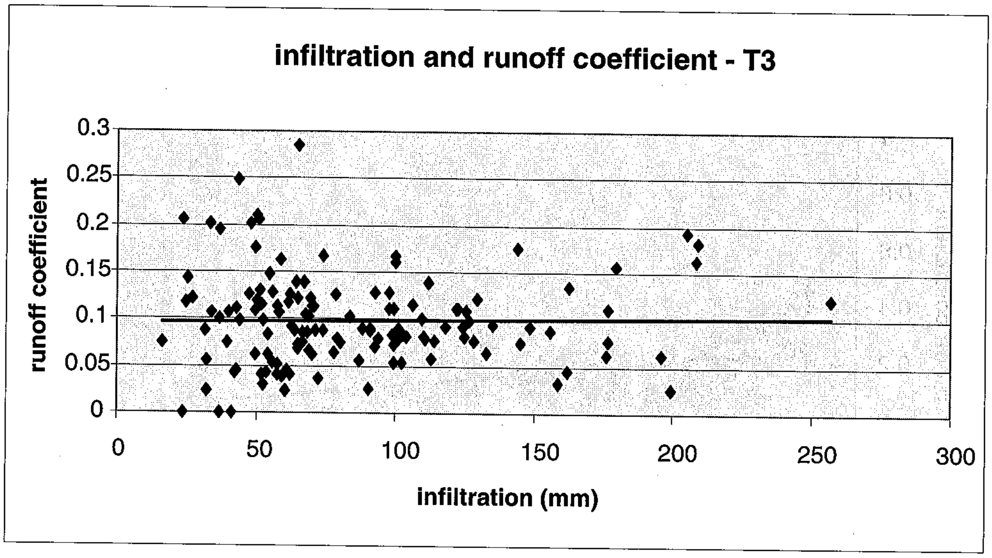

Figure 8. Relationship between infiltration volume and runoff coefficient in T3

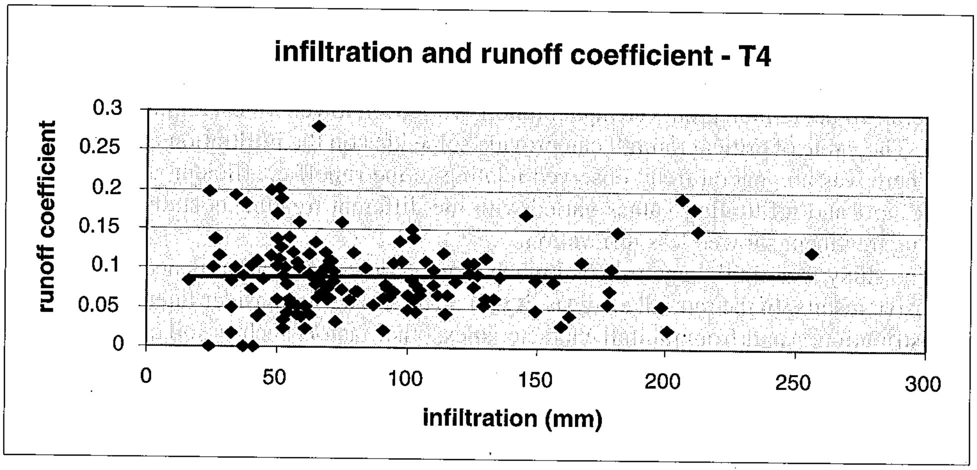

Figure 9. Relationship between infiltration volume and runoff coefficient in T4

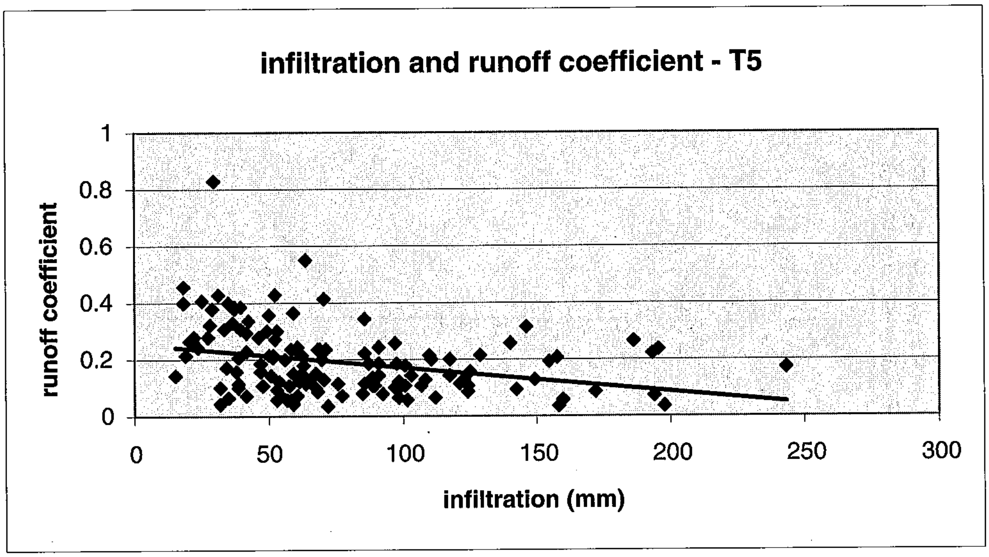

Figure10. Relationship between infiltration and runoff coefficient in T5

Summary and Conclusion

The seven year data on rainfall and runoff from the ASIALAND network site in Vietnam were used in the analysis and evaluation of the relationship between rainfall, runoff, and infiltration. In general, higher rainfall produced higher runoff. Moreover, lower critical rainfall gave higher runoff. The value of critical rainfall can provide some idea on the infiltration capacity of the soil. There was no general trend observed relating to the runoff coefficient and infiltration rate. Runoff and infiltration values varied with the different treatments studied. The alley cropping treatment showed less infiltration.

The study is an initial analysis and much more detailed evaluation is needed for more conclusive results. In the rainfall analysis, it will be necessary to consider intensity, duration and distribution. Apart from rainfall characteristics, other factors such as soil characteristics, antecedent soil moisture, and slope must be considered.

Acknowledgement

I wish to thank the Asian Development Bank (ADB), the Swiss Agency for Development Cooperation (SDC) and the International Water Management Institute for their financial support to both the MSEC and ASIALAND projects. Dr. Amado R. Maglinao, Dr. Christian Valentin, Dr. Jean-Pierre Bricquet, Mr. Jean-Louis Janeau, Dr. Robert W. Simmons, Dr. Suraphol Chandrapatya, and Mr. Rungnadhee Phonkarm are also acknowledged for their support and technical guidance. I also recognize the contribution of the country coordinators of the ASIALAND project.

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Tillage Erosion on Very Steep Slopes in Northern Laos

B. Dupin[1], K.B. Panthahvong[2], A. Chanthavongsa[3] and C. Valentin[4]

Abstract

In northern Laos, weed pressure is rapidly increasing as a consequence of the shortening of the fallow period. Due to the prevailing steep slopes, weeding operations can induce tillage erosion, which is the process of downhill soil movement caused by the force applied by agricultural tools and gravity. The objective of this study was to assess tillage erosion under on-farm conditions in northern Laos.

The experiment was conducted during the cultivation season of 2001 in the Houay Pano Catchment, located near Ban Lak Sip, in Luang Prabang District. The farmers cultivate upland rice and Job's tears after a 1-3 year fallow period with no external inputs. Tillage erosion due to land preparation was assessed on nine slope gradient classes (30-110 percent), with three replications. Tillage erosion due to weeding operations was monitored over the cultivation period on seven classes of slope in an upland rice field (30-85 percent) and in a Job's tear field (40-102 percent) located on the same Alfisol. In total, 76 measurements were performed, 27 for land preparation, 21 in the Job's tear field, and 28 in the upland rice field. For each measurement, 100 aggregates of 1-2 cm were dried, painted, and used as tracers. They were placed along a contour line marked by a string. Hoeing or weeding was then performed and the distance between each displaced aggregate and this benchmark line was measured, enabling the calculation of the soil flux caused by a tillage pass, and the annual tillage erosion rate per hectare. The results confirm the importance of tillage erosion on steep slopes (2, 4, and 18 t ha^{-1} year^{-1} on slopes with gradients of 30, 60, and 100 percent, respectively). The other factors that affect tillage erosion are weed pressure as long as it increases depth and the number of tillage operations and contact cover because this traps aggregates and so reduces soil displacement.

In northern Laos, soil transported due to tillage are of the same order as those due to runoff as measured at the plot scale under traditional farmers' practices. Alternatives that limit weed infestation and thus tillage operation need to be developed and tested in terms of soil conservation.

Introduction

In northern Lao PDR, farmers practice slash-and-burn agriculture on steep hill slopes. Due to population growth, fallow periods are decreasing, which implies serious problems for the

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restoration of soil fertility and weed infestations. Increasing weed pressure is the major constraint in upland rice production. Not only are labour inputs massive but also frequent hoeing increases the risks of soil loss. Farmers cultivate upland rice and Job's tears after a 1-3 year fallow period and must allocate an increasing number of days to weeding operations (Table 1). Due to the prevailing steep slopes, these operations can induce tillage erosion. Tillage erosion is the process of downhill soil movement caused by the force applied by agricultural tools and gravity. This process (manual tillage erosion) was studied by Turkelboom *et al.*, in 1999 in northern Thailand to estimate soil losses due to deep (15 cm) hoeing operations. Soil flux by tillage erosion has been quantified as a function of slope angle and slope length. In Laos this manual practice consists of a very shallow scraping of the soil with two types of hoe to cut the weeds. However the repetition of this operation can lead to high levels of erosion. The objective of this study was to assess tillage erosion under on-farm conditions in northern Lao PDR.

Table 1. Cultivation practices for upland rice and Job's tears (cropping seasons 2001 and 2002)

	Upland rice		Job's tear field		
	Days ha^{-1}	Labour Input (%)	Days ha^{-1}	Labour input (%)	Tools
Field preparation (March)	41	14.5	27	14.0	Machete
Burning (April)	1	0.4	1	0.5	
Land preparation (May)	26	9.2	25	13.0	Hoe
Planting (June)	43	11.0	8	4.1	Bamboo stick
1st weeding (June)	36	51.9	53	55.4	Curveding hoe
2nd weeding (July)	38		22		Curveding hoe
3rd weeding (Aug)	38		32		Curveding hoe
4thrt weeding (Aug)	35				Curveding hoe
Harvest and transport (Sept)	25	8.8	25	12.9	Curveding hoe
Total	283	100	193	100	

Materials and Methods

The experiment was conducted during the cropping season of 2001 in the Houay Pano Catchment, located near Ban Lak Sip, in Luang Prabang District. The farmers weed their fields going up the slope.

Before starting the experiment, different tillage tools and techniques were noted while farmers were weeding. In addition, cultural history and the consequences of land use change were discussed with farmers. We mainly focused on the use of tillage.

The fields of Job's tears (*Coix lacryma Jobi*; "Mak Deuay" in Laotian,), are usually weeded twice whereas the rice fields require three or four weeding operations depending on the intensity and the type of invasion.

Tillage operation due to land preparation was assessed on nine slope gradient classes (30-110 percent), with three replications in a two-year fallow slashed, burnt, and traditionally hoed by farmers. Tillage erosion due to weeding operations was monitored over the cultivation period on seven classes of slope gradient in an upland rice field (30-85 percent) and in a Job's tear field (40-102%) located on the same Alfisol. In total 76 measurements were performed, 27 for land preparation, 21 in the Job's tear field, and 28 in the upland rice field.

For each measurement, we used the tracer method, which was the most reliable, as tested by Turkelboom *et al.* (1999). For each measurement, 100 aggregates of 1-2 cm were dried, painted, and used as tracers. They were placed along a contour line marked by a string. Hoeing or weeding was then performed and the distance between each displaced aggregate and this benchmark line was measured, enabling the calculation of the soil flux caused by the tillage pass, and the annual tillage erosion rate per hectare.

The soil mass that passes a unit contour length for one tillage pass, or soil flux Qt (Turkelboom *et al.,* 1999), was calculated using Eq. (1)

$$Qt = D_m Dr \qquad (1)$$

where Qt is the soil flux caused by tillage (in kg m^{-2} tillage $pass^{-1}$); D_m the mean downslope displacement distance of the tracers (m); D the mean tillage depth (m) and r the bulk density of the soil (kg m^{-2}), as measured with the cylinder method.

Mean soil losses per hectare for one tillage pass can be derived from the soil flux Eq. (1) and from the downslope field length using Eq. (2):

$$TE = Qt\,10/L \qquad (2)$$

where TE is the tillage erosion rate (t ha^{-1} tillage $pass^{-1}$), Qt the soil flux caused by tillage (kg m^{-2} tillage $pass^{-1}$); and L the downslope field length (m). To enable comparisons, a fixed value of L (50 m) was used.

Contrary to seedbed preparation, weeding is not space continuous. This manual practice consists of a very shallow scraping of the soil with a hoe to cut the weeds.

Tillage erosion due to weeding is given by Eq. (3):

$$TE_w = S_w TE \qquad (3)$$

Where TE_w is the tillage erosion rate (t ha^{-1} tillage $pass^{-1}$) due to a weeding operation; TE the tillage erosion rate derived from Eq. (2); and S_w the area effectively tilled during the weeding operation. In practice, we used C_w as a surrogate to S_w.

Knowing the number of hoeing (n_h) and weeding (n_w) operations, the annual tillage erosion (ATE) can be calculated using Eq. (4):

$$ATE = n_h TEp + n_w TE_w \qquad (4)$$

Where ATE is the annual tillage erosion (t ha^{-1} $year^{-1}$); TE_h and TE_w (t m^{-2} tillage $pass^{-1}$) are the tillage erosion due to hoeing and weeding operations, respectively; and n_h and n_w the number of hoeing and weeding operations, respectively.

Results

Soil Losses Due to Hoeing

Due to their growing capacity, *Graminaeae* and bamboos were systematically uprooted. Nevertheless hoeing remains most often very superficial with a mean depth of 2 cm. Figure 1 shows clearly the influence of the slope gradient.

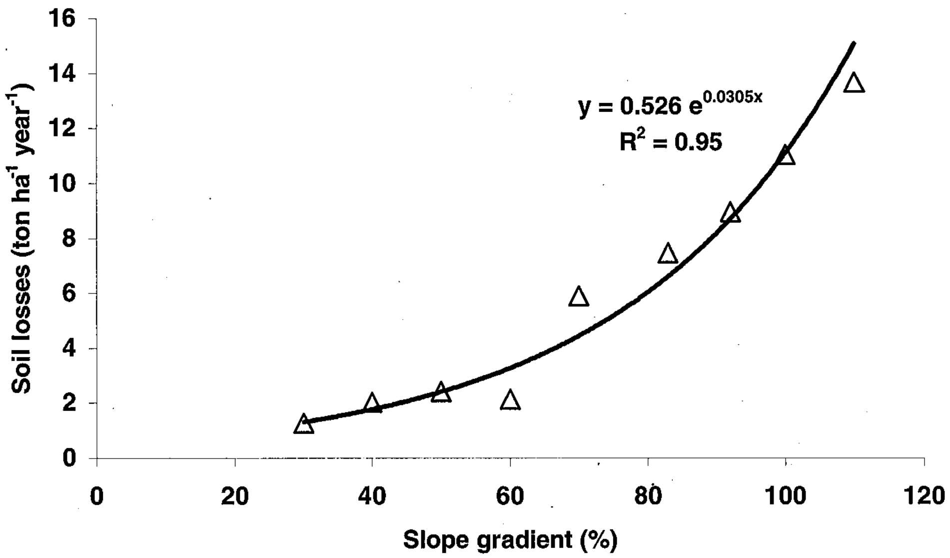

Figure 1. Tillage erosion due to hoeing as influenced by slope gradient

After burning on the short fallow, weeds infest the field and cover all the field area. Farmers are forced to hoe their fields to limit weed competition with the crop.

Tillage erosion due to this operation depends on aggregate stability, soil smoothness, and contact cover. The first operation affects stable aggregates that are reinforced by roots whereas a second hoeing displaces smaller aggregates on a smoother soil surface. As a result the second weeding generates higher tillage erosion because the soil surface is smoother and aggregates can thus roll further down. Usually, farmers practice only one hoeing but if they delay between this operation and the seeding they may need a second hoeing with higher associated tillage erosion rates.

Soil Losses Due to Weeding

The weeding operation consists of a very shallow scraping of the soil with a curved hoe. The repetition of this operation leads to important soil losses for both crops (Figures 2 and 3).

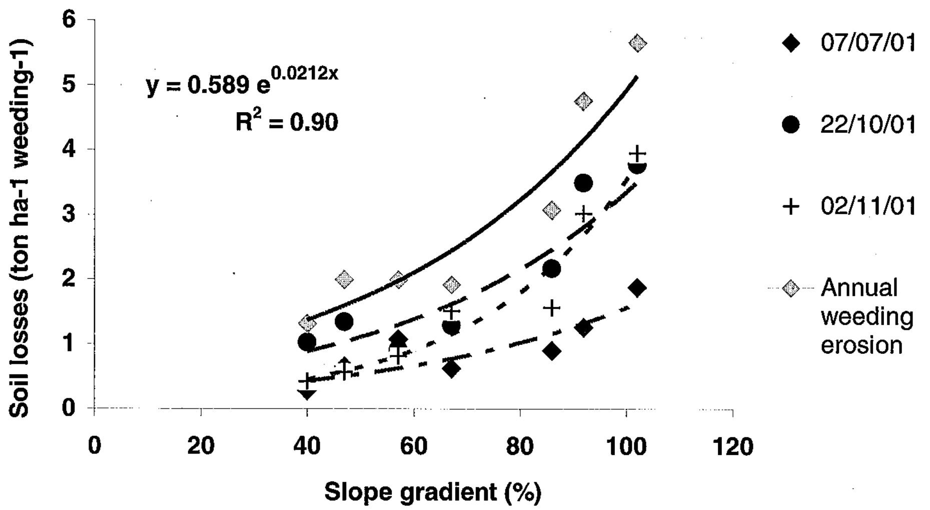

Figure 2. Tillage erosion due to weeding as influenced by slope gradient for Job's tears

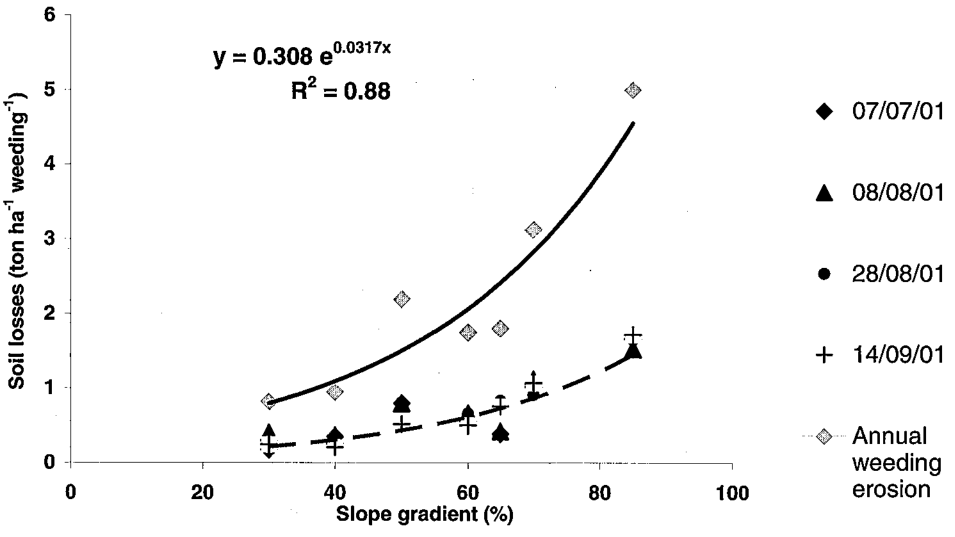

Figure 3. Tillage erosion due to weeding as influenced by slope gradient for upland rice

Weeding operations generate different rates of tillage erosion depending on several factors. These include the area effectively tilled and the contact cover that prevents the area from being displaced. This contact cover, directly in contact with the soil, is essentially composed of slashed weeds that are either left on the soil or gathered together. The basal cover of the crop is also a component of this cover since it is an obstacle to aggregate displacement. Contact cover plays a key role as it influences aggregate displacement distance and thus tillage erosion. Steeper slopes have more effect.

A multivariate regression based on the experiments shows a high significant relation (R^2 = 0.86) between the mean downslope displacement distance of the tracers (D_m), the slope gradient (S, %), and the contact cover (C_c, %), Eq. (5), Figure 4. Tillage erosion can thus be estimated replacing Qt as a function of the slope and the contact cover:

$$Qt = 44.42\ e^{(0.0265\ S\ -\ 0.0185\ Cc)}\ Dp) \qquad \text{Eq (5)}$$

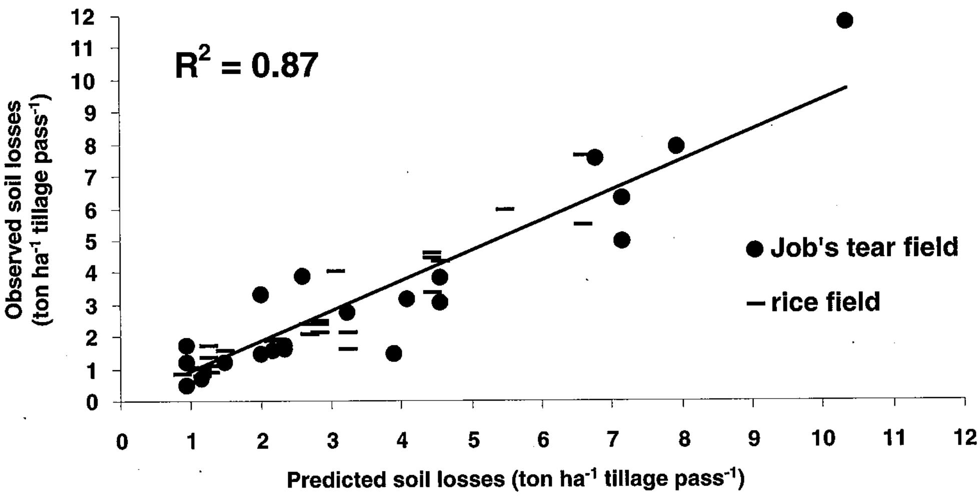

Figure 4. Relation between predicted values and observed values

Annual Tillage Erosion

Annual tillage erosion is high in both crops (Table 2). It is slightly higher for the steeper fields cultivated with upland rice than Job's tears because weeding erosion in an upland rice field is more severe than in a Job's tear field as this crop requires three weeding operations instead of two for Job's tear cultivation.

Table 2. Annual tillage erosion estimated from Eq (5) for Job's tears and upland rice

	Annual tillage erosion (t ha^{-1} yr^{-1})	
Slope gradient (%)	**Job's tears**	**Rice**
30	2.3	2.1
40	3.3	3.1
50	4.1	3.9
60	4.2	4.1
70	8.6	8.7
80	11.0	11.8
90	13.2	14.8
100	16.05	18.6
110	20.0	23.7

On a mean slope of 60 percent, soil losses due to tillage erosion are of the same order as those due to runoff as measured at the plot scale under traditional farmers' practices (5.7 t ha^{-1} $year^{-1}$; mean over five years, Phommasack *et al.*, 1998, 1999)

Discussion and Conclusion

Tillage erosion results from land preparation and from repeated weeding operations. Erosion in here is defined as the movement of soil from the higher elevation to and deposition at the lower portion of the slope. Our data confirm the importance of this erosion on very steep slopes and the exponential nature of the relationship between tillage and slope gradient.

The other factors that affect tillage erosion are weed pressure that increases depth and the number of tillage operations and contact cover that traps aggregates and thus reduces soil displacement.

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} $year^{-1}$). These soil losses affect the most fertile soil layer. Soil clods detached by tillage operations accumulate in the depressions or at the field limits.

Because of the increasing weed pressure, tillage erosion is likely to become very serious, especially on the steepest slopes, which will become more frequently cultivated. Alternative practices that limit weed infestation and thus tillage operations need to be developed. Where a short fallow period is still possible, improved fallow should be tested. This includes sowing pigeon pea (or *Crotalaria, Leucaena, Gliricidia*) in the previous crop (NAFRI, 2002). Pigeon pea grows faster and provides more nutrients to the soil than a fallow composed of natural species, and can limit weed proliferation. Two other practices can also limit tillage erosion. The first is the no till system that consists of mixing cropping cereals and the cover crop. The field is prepared without burning and without tillage operations. The cover crop reduces weed growth and the mulch provides nutrients. The second is contour planting. This limits soil movement as the soil moves downslope and accumulates in the lower portions of the alley. It induces the formation of terraces. The topsoil from the upper part of the alley moves downslope and accumulates in the lower part. Although terraces decrease tillage and water-induced erosion, they generate a dramatic change in soil physical, chemical, biological, and hydrological properties (Thapa *et al.*, 1999).

Acknowledgement

The authors wish to acknowledge the farmers of Ban Lak Sip for their collaboration during this study.

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Hydrologic Behavior and Land Use Characteristics of Some Catchments in Asia

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Abstract

Initial results from two MSEC catchments and three sub-catchments from 2000 to 2002 were analyzed to establish baseline information on the relationships of land use characteristics and hydrologic behavior. Based on one- to three-year annual hydrographs, previous stream classifications were validated. The streams of Mapawa Catchment and Rambutan sub-catchment were both reclassified as ephemeral while those of Dong Cao Catchment, and Tegalan and Kalisidi sub-catchments are perennial and intermittent, respectively, as initially classified. There were no observed consistent relationships between land use and annual runoff coefficients within each of the five catchments and sub-catchments. The variations in annual direct runoff coefficients among catchments and sub-catchments could hardly be attributed to differences in their present land use. It is surmised that such variations are more related to their differences in geology and soil classification. Analysis of storm hydrograph behavior of the Mapawa Catchment showed that there is practically no base flow even if about 95 percent of its annual rainfall of 2,400 mm has infiltrated and possibly percolated below ground surface. Percolating water does not come out in its stream but is added to the water table that flows to the Alanib River downstream. The same conditions could be true in the case of the Babon Catchment and its three sub-catchments. In spite of relatively lower porosity and a smaller fraction of rainfall infiltrating and percolating down the soil profile, a year-round base flow occurs at the Dong Cao stream. Presumably, an impermeable layer lies just below its streambed so the water table can easily rise above it. More years of field data monitoring are needed to come up with conclusive results

Introduction

Quantitative field data on the environmental impacts of different land uses are indispensable information to guide extension workers in advising farmers on conservation farming techniques and for planners and decision-makers to formulate appropriate and implementable policies for the sustainable development and management of our natural resources. Such information is also very useful for engineers for the proper design of water control structures for irrigation, flood control, and soil and water conservation, and for the validation and improvement of runoff and sediment yield prediction models.

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Inter alia, the more significant environmental impacts of land use and cover type modifications are hydrologic in nature (Figure 1). Specifically, these include variation in runoff, groundwater quantities, and sediment yields. In most of the less-developed countries, however, there is a dearth of factual data on the effects of land use on the hydrologic behavior of a catchment. Indeed, the ongoing catchment studies in six Asian countries being conducted via the Management of Soil Erosion Consortium (MSEC) program under the International Water Management Institute (IWMI) are a move towards addressing such data gaps.

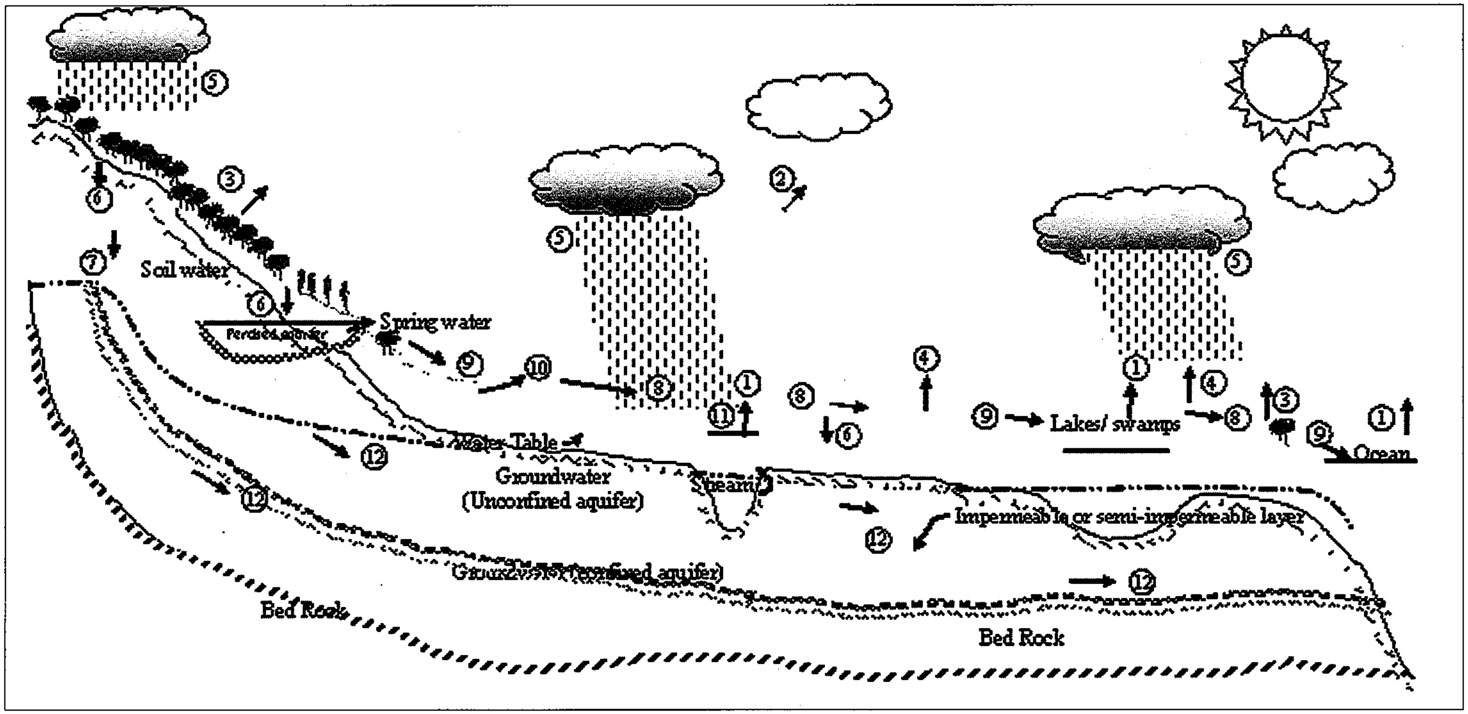
This paper attempts to analyze the initial results of the MSEC catchment studies that are relevant to the assessment of the hydrologic impacts of land use.

MSEC Methodology of Hydrologic Data Monitoring

The hydrologic data being monitored and the measuring devices used in all the six MSEC catchments are listed in Table 1. Figure 2 shows a typical instrumentation layout in a catchment area. Regular field monitoring of possible change in the land use and cover types is being done in each catchment. Specific farming activities are also noted including soil and water conservation measures being practiced or introduced by the project.

Table 1. Hydrologic data and the measuring devices used in MSEC catchment monitoring

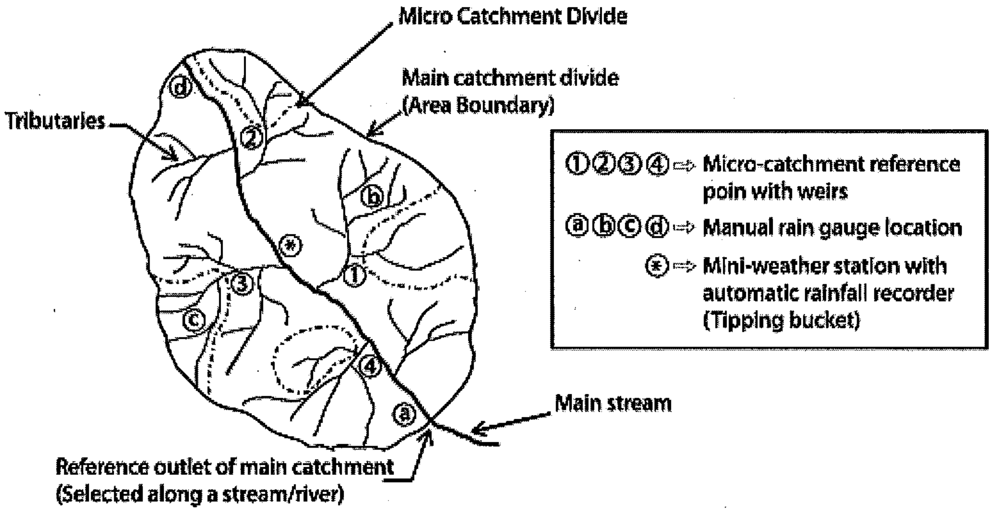
Hydrologic dData	Measuring instrument per catchment
a. Precipitation (i) total daily rainfall (ii) rainfall intensity	• 5-8 mManual rain gauges • 1 automatic meteorological station (AMS)
b. Runoff sStream flow, or water yield	• Flume or cCompound sharp-crested weir (contracted rectangular weir with V-notch). Water level is being measured by a staff gauge and an automatic water level recorder (see Figure 1) with data logger
c. Sediment load/yield (i) Bed load	• Approach channel of the weir (see Figure 1) Sserves as a bed load sediment tank or interceptor. Such trapped sediments are considered bed load. Every Aafter every sediment-producing storm rainfall, water is drained from the tank and then the bulk sediment volume is measured. A sample is taken out and oven-dried in the laboratory to get the dry mass density. This density multiplied by the bulk volume is the total sediment dry mass for the storm.
(ii) Suspended load	• Initially, no common sampler was used. Others just used manual scooping with can samplers or series of sampling cans at different levels in the weir approach channel. • ICRISAT-design automatic pumping type samplers were delivered to most catchments during the last quarter of 2001 but not all have beenwere installed.



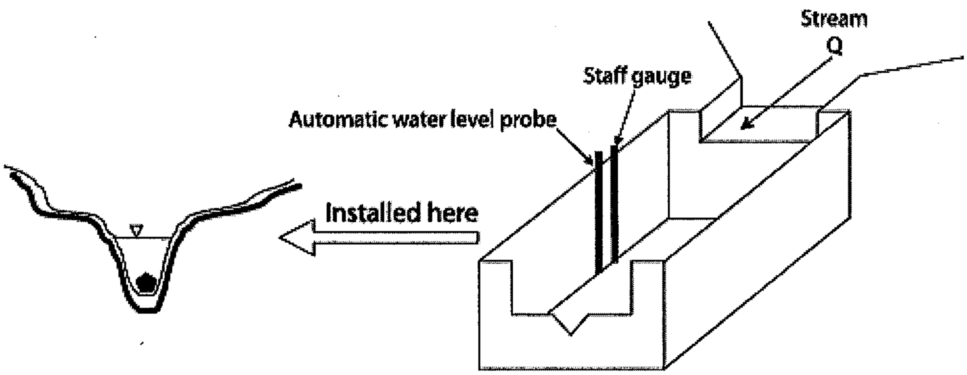
Notes:

1	= Evaporation from water surfaces (oceans, lakes, rivers, dams, canals)	7	= Percolation
2	= Raindrop evaporation	8	= Surface runoff or direct runoff
3	= Transpiration from plants	9	= Soil erosion and sediment transport
4	= Evaporation from moist soil	10	= Interflow
5	= Precipitation/rainfall	11	= Total runoff (or streamflow or water yield)
6	= Infiltration through soil surface	12	= Groundwater flow

Figure 1. The hydrologic cycle



a) Plan view of catchment showing instrumentation location.



b) Stream cross-section at reference outlet (where runoff or stream flow and sediment load / yield ar being measured)

c) Typical compound weir (sharp-crested and contracted rectangular weir with sharp-crested V-notch) for measuring streamflow and sediment load (installed at reference outlets)

Figure 2. Typical MSEC catchment hydrologic instrumentation for monitoring rainfall, streamflow and sediment load

The field data relevant to this paper were requested from the results of the different MSEC-participating countries. Additional information was extracted from the progress and cross-country reports, and technical papers presented during the 6th (2001) and 7th (2002) MSEC meetings held in Hanoi, Vietnam and in Vientiane, Laos, respectively.

Results and Discussion

Table 2 shows the locations and basic descriptions of two main catchments (Mapawa in Philippines and Dong Cao in Vietnam) and three sub-catchments (Tegalan, Rambutan, and Kalisidi in Indonesia). Their observed respective annual precipitation, runoff (or water yield), and sediment yield from 2000 to 2002 are given in Table 3.

Annual Hydrograph Behavior and Stream Classification

Based on its annual hydrograph, a stream or river of a catchment may be classified as *perennial*, *intermittent* or *ephemeral* (Wanielista, 1990; Subramanya, 1984; and Linsley *et al.* 1949). If the water table is below the streambed, the groundwater "gains" water and such a stream is referred to as an *influent stream*. If the groundwater is "losing" water to the stream, the latter is called an *effluent stream* (Figure 3). A perennial stream is one which always carries some flow throughout the year. It is either an effluent stream all year round or is continuously gaining water from perennial springs upstream. An intermittent stream is one with limited contribution from groundwater. It may be effluent during the wet season, but becomes influent during the dry season. A stream which does not have any base flow contribution is referred to as ephemeral. It becomes dry soon after the end of the storm flow.

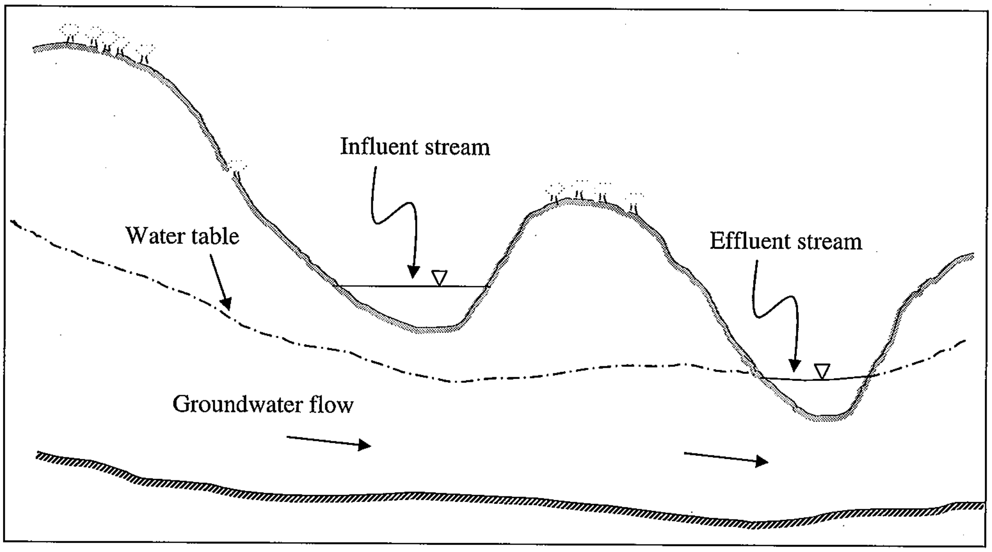


Figure 3. Influent and effluent streams

Accurately determined stream classification based on daily or weekly rainfall-runoff discharge variations at the initial stage of a study is very informative base data. It could serve as an indicator of evaluating the long-term impacts of watershed modification. Depending on the catchment's geological, soil, and topographic characteristics, its stream may shift from one type to the other if significant land use change and soil conservation measures are effected.

Measured at its main weir, the Mapawa Catchment was initially classified (Maglinao *et al.*, 2001) as intermittent. After plotting its weekly runoff in 2001 (Figure 4), however, it appeared

Table 2. Location and description of some MSEC study catchments in Asia

	Mapawa (Philippines) Main weir (MW)	Dong Cao (Vietnam) Main weir (MW)	Babon (Indonesia) Rambutan	Tegalan	Kalisidi
Province	Bukidnon	Hoa Binh	Semarang	Semarang	Semarang
Coordinates: Latitude	08?02'50" N	20?57'40" N	07 20' S	07 20' S	07 20' S
Longitude	125?56'35" E	105?29'10" E	110 E	110 E	110 E
Catchment area (ha)	84.5	45.5	0.9	1.1	13.0
Elevation (m)	1,080-1,505	125-700	390-510	391-510	392-510
Slope range (%)	15-20	40-60	22-25	45-47	22-55
Geology	Basalt, pyroclastic	Schist	Basaltic lava	Basaltic lava	Basaltic lava
Soil order/sub-group	Ultisols	Ultisol	Audic Dystropepts	Audic Dystropepts	Audic Dystropepts
Stream classification	Ephemeral b	Perennial	Ephemeral c	Intermittent d	Intermittent d

a Source: (Maglinao et al., 2001)
a Originally classified as intermittent (Maglinao et al., 2001)
c Originally described as intermittent (Agus et al., 2002)
d As reported (Agus et al., 2002)

Table 3. Annual precipitation, runoff (or water yield) and sediment yield of some MSEC catchments in Asia.

Catchment name and code	Area (ha)	Annual precipitation (mm)				Annual runoff or water yield (mm)				Annual runoff coefficient (%)				Annual sediment yield (tons/ha)			
		2000	2001	2002	Ave.	2000	2001	2002	Ave.	2000	2001	2002	Ave.	2000	2001	2002	Ave.
Mapawa, MW a	84.5	2,270	2,907	2,103	2,448	96.70	78.00	-	87.35	4.30	2.70	-	3.57	3.80	4.80	1.10	3.23
Dong Cao, MW b	45.5	1,224	2,501	1,171	1,632	647.00	1,286.00	770.00	901.00	52.80	51.40	65.80	55.21	0.64	9.14	3.46	4.41
Babon c																	
a. Rambutan	0.9	-	3,062	3,104	3,083	-	6.14	95.00	50.57	-	0.20	3.10	1.64	-	0.01	0.15	0.08
b. Tegalan	1.1	-	3,161	2,924	3,042	-	162.00	151.00	156.50	-	5.10	5.20	5.14	-	10.78	9.58	10.18
c. Kalisidi	13.0	-	3,234	3,104	3,169	-	104.00	425.00	264.50	-	3.20	13.70	8.35	-	1.92	8.00	4.96

a Source: (Ilao et al., 2002)
b Source: (Toan et al., 2002)
c Source: (Agus et al., 2002

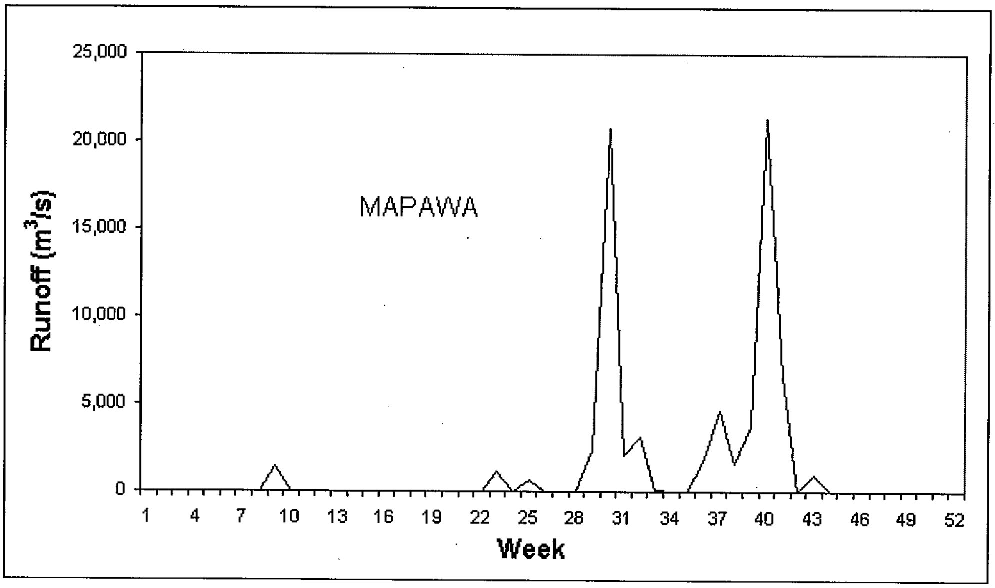


Figure 4. Annual runoff hydrograph of Mapawa main catchment for 2001

that it was more of an ephemeral type than intermittent. Monthly runoff data for the Dong Cao main weir from 2000 to 2002 (Figure 5) prove that it is indeed perennial as initially classified by Maglinao *et al.* (2001). The sub-catchments of Rambutan, Tegalan, and Kalisidi were reported by Agus *et al.* (2002) as having intermittent flow. Based on their monthly runoff discharges as shown in Figure 6, however, it appears that the Rambutan sub-catchment may be classified as ephemeral. A plot of their daily or weekly rainfall-runoff discharge relations from 2000 to 2002 may validate these observations.

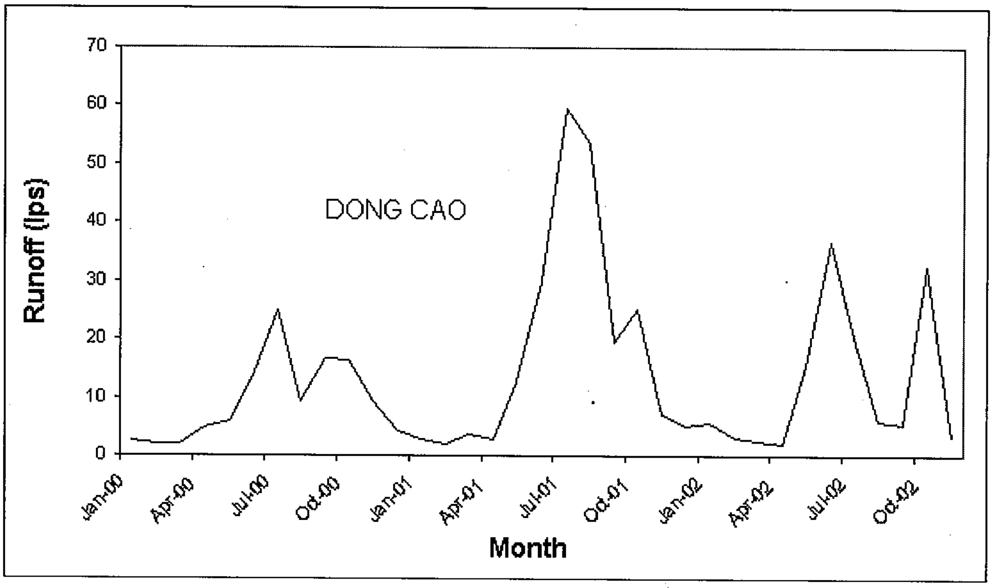


Figure 5. Annual runoff hydrograph of Dong Cao main catchment (2000 to 2002).

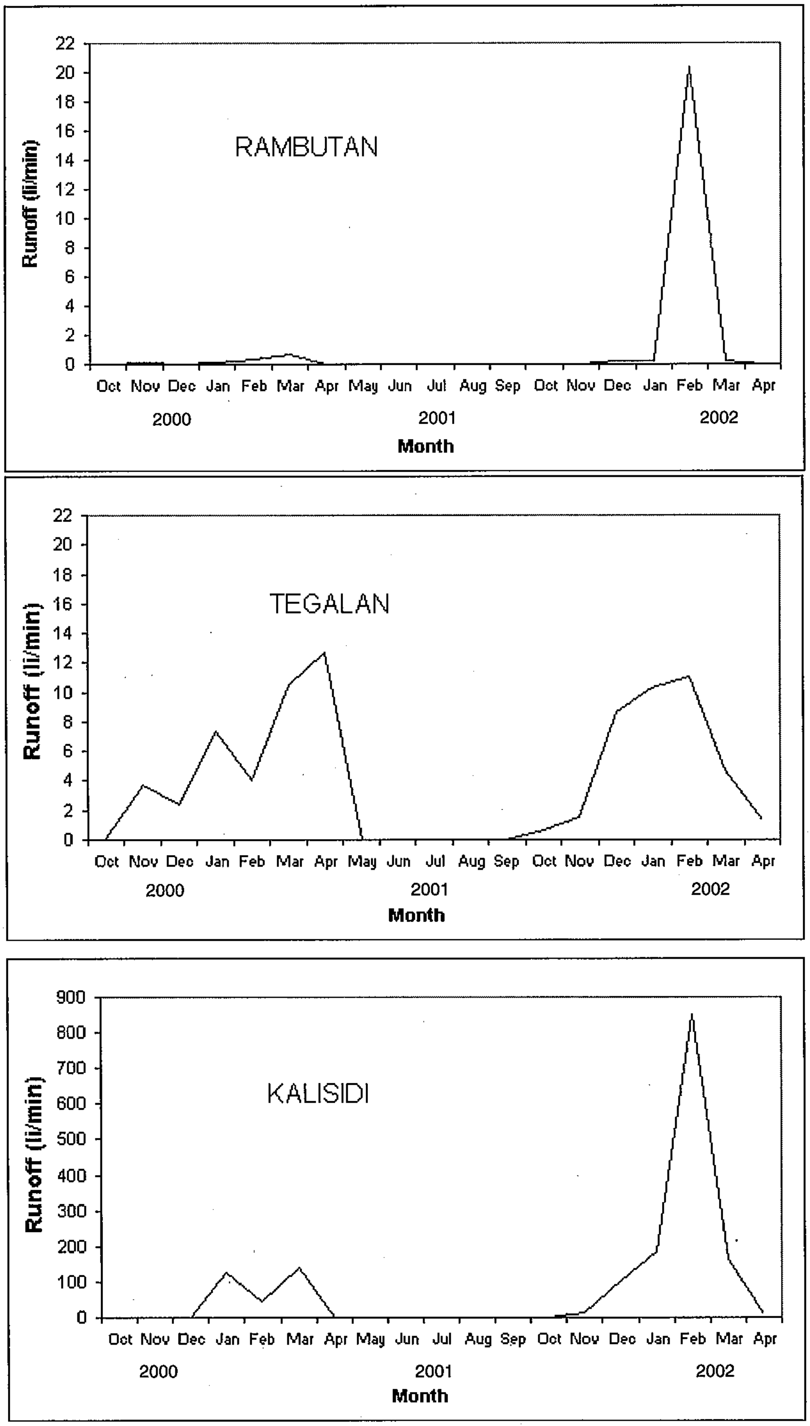


Figure 6. Annual runoff hydrographs of the Rambutan, Tegalan, and Kalisidi micro catchments (October 2000 to April 2002)

The probability of the above intermittent and ephemeral streams becoming perennial with the introduction of soil conservation measures is worth investigating. This may include further validation of the geology, soil order, and sub-group, and whether the stream is influent or effluent. Sample boring down the soil profile to determine sub-surface porosity and permeability and soil water dynamics may have to be done. MSEC-Laos has done much to this effect.

Behavior of Runoff Coefficients

Runoff, streamflow, and water yield are synonymous terms which all refer to the total water (combined surface or direct runoff and base flow as illustrated in Figure 7) passing the gauging station, such as weirs or flumes, of a given catchment or micro catchment. The ratio of the annual runoff to the annual precipitation is the annual runoff coefficient which may be expressed in decimal or in percent. It is called the direct runoff coefficient if the numerator is the surface or direct runoff. From the viewpoint of sustainable soil and water conservation in general, the smaller the direct runoff (DRO) coefficient is, the better, as this means a higher fraction of the precipitation is added to the soil water storage and eventually may recharge the groundwater or aquifers. A low DRO coefficient also implies relatively lower surface runoff, hence lower erosivity and capacity to transport eroded soil downstream.

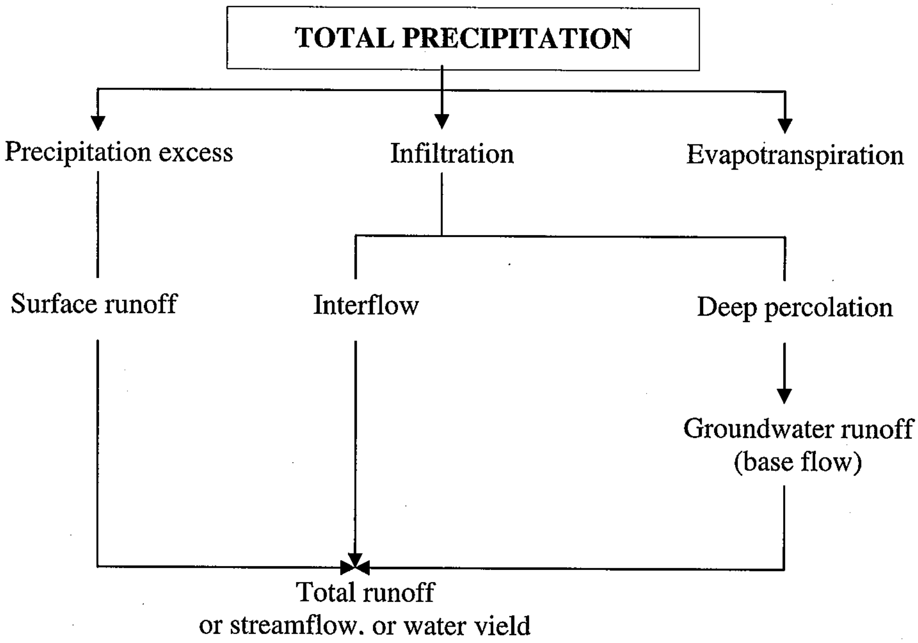


Figure 7. Disposition of total precipitation

Variations of Annual Runoff Coefficients within the Catchment

Table 3 presents the computed two- to three-year annual runoff coefficients of five MSEC catchments and sub-catchments from 2000 through 2002 and their corresponding land use descriptions are shown in Tables 4a and 4b. In general, there appears to be no consistent relationship between land use and annual runoff coefficients. In the Mapawa Catchment, for instance, the percent cropped area increased from 24 percent in 2000 to 27 percent in 2001 (Table 4b), but the annual runoff coefficients decreased from 4.30 to 2.70 percent even if the annual precipitation increased from 2,270 to 2,907 mm. On the other hand, the percentage of annually cultivated area in the Dong Cao Catchment decreased from 36 percent in 2001 to 24 percent in 2002 (Table 4b) but the runoff coefficient increased from 51 to 66 percent. The same inconsistent relationship is also observed for the three Indonesian sub-catchments. There were no significant land use changes from 2001 to 2002 (Table 4a) for the Rambutan and Kalisidi catchments but the runoff coefficients increased by at least 300 percent. While Chaplot *et al.* (2002) found no significant correlation between annual runoff coefficients and land use among initial observations in several MSEC catchment studies, there is still a need for longer years of study before a more reliable conclusion can be made.

Table 4a. Land use conditions in some MSEC catchments for 2001 and 2002[a]

Catchment name	Surface area (ha)	Slope angle S (%)	C (%)	F_a (%)	C_p (%)	O (%)	F_o (%)
			Percent surface area covered per land use[b]				
Year 2001							
1. Mapawa (MW)	84.50	14.00	23.67	44.97	16.80	0.00	15.38
2. Dong Cao (MW)	59.52	25.00	28.00	22.00	20.00	30.00	0.00
3. Babon							
a. Rambutan	2.00	12.00	0.00	0.00	0.00	100.00	0.00
b. Tegalan	3.20	14.00	50.00	0.00	0.00	50.00	0.00
c. Kalidisi	38.50	8.00	0.00	0.00	0.00	100.00	0.00
Year 2002							
1. Mapawa (MW)	84.50	25.00	24.79	40.59	7.40	11.83	15.38
2. Dong Cao (MW)	59.52	21.00	5.90	57.70	0.00	0.00	5.20
3. Babon							
a. Rambutan	2.00	12.00	0.00	0.00	0.00	100.00	0.00
b. Tegalan	3.20	14.00	60.00	0.00	40.00	0.00	0.00
c. Kalidisi	38.50	8.00	0.00	0.00	0.00	100.00	0.00

[a] Source: (Chaplot *et al.* 2002)

[b] Land uses: Annual crops (C), fallow or pasture (F_a), crops with conservation practices (C_p), orchards (O) and forest (F_o)

Variations of DRO Coefficients among Catchments

The DRO coefficient of a catchment is best determined from the hydrographs (Figure 8) of its rainfall storm events. For perennial and intermittent streams such as Dong Cao, Tegalan, and Kalisidi (see Table 2), the DRO is estimated by first separating it from the base flow as illustrated in Figure 4. In the case of ephemeral streams like those of the Mapawa and Rambutan catchments, there is practically no base flow so the observed annual flow is totally considered DRO. As such, their annual DRO coefficients are equal to their respective annual runoff coefficients listed in Table 3. Unfortunately, the DRO data for the Dong Cao, Tegalan, and Kalisidi streams are not available. Based on their annual hydrographs in Figure 5, however, a conservative estimate may indicate that the base flow at the Dong Cao main weir could be around 20 percent of the annual precipitation. Thus, for the three-year average, the annual

Table 4b. Land use conditions in some MSEC catchments from 2000 to 2002

Catchment and lLand uses	Year		
	2000	2001	2002
1. Mapawa [a]			
a. Catchment area (ha)	84.5	84.5	84.5
b. Cropped area			
- Percen (%)	24	27	27
- Crops	Corn, potato, Chines cabbage, sweet peas coffee	Corn, potato, Chines cabbage, sweet peas coffee	Corn, potato, Chinese cabbage, sweet peas coffee
c. Other vegetation			
- Percen covered (%)	76	73	73
- Vegetation	Grassland, eucalyptus, bamboo	Grassland, eucalyptus, bamboo	Grassland, eucalyptus, bamboo
2. Dong Cao [b]			
a. Catchment area (ha)	45.50	45.50	45.50
b. Annually cultivated area (ha)	35.68	35.68	24.20
- *A. mangium* intercropped with cassava			
- Cassava intercropped with taro and *A. mangium*	9.23	10.30	0.00
- Arrow root			
- Cassava monoculture	0.00	1.18	0.00
- Fallow	0.00	0.35	0.00
- Natural grasses	16.25	16.78	2.33
c. Forest area (ha)	0.00	0.00	14.80
- *A. mangium*	1020	7.07	7.07
- *Veminia Montana*	2.38	2.38	13.86
- Eucalyptus	0.00	0.00	11.48
d. Land for other purposes (ha)	0.90	0.90	0.90

DRO coefficient could be about 30 percent. Being of intermittent flow, the DRO coefficients of Tegalan and Kalisidi should be close to their annual runoff coefficients in Table 3, which are both less than 10 percent.

Summarizing the above estimates, the average DRO coefficients of Mapawa, Dong Cao, Rambutan, Tegalan, and Kalisidi are roughly 3.6, 27.0, 1.6, <5.1, and <8.4 percent, respectively. Referring to their land use conditions in Tables 4a and 4b, there appears to be no significant differences to account for the variations in their DRO coefficients. These were the initial findings of Chaplot *et al.* (2002) in their correlation study. Only land slope shows significant relations with runoff coefficients. Considering that the average land slope of the Dong Cao Catchment (Table 2) is not too high compared to that of Mapawa, Rambutan, Tegalan, and Kalisidi, there must be some other factors that could explain the big difference in the DRO coefficients of the Dong Cao Catchment compared to the others.

One probable reason could be their differences in geology. As indicated in Table 1, Dong Cao Catchment is underlain by a schist formation while the catchments of Mapawa, Rambutan, Tegalan, and Kalisidi are all under a basalt formation. As described by Karanth (1989), crystalline rocks such as granite, gneiss, schist, gabbro, and diabase are practically impervious and impermeable. The porosity of these rocks is confined to minute disconnected interstices within the mineral grains or between the granular fabric.

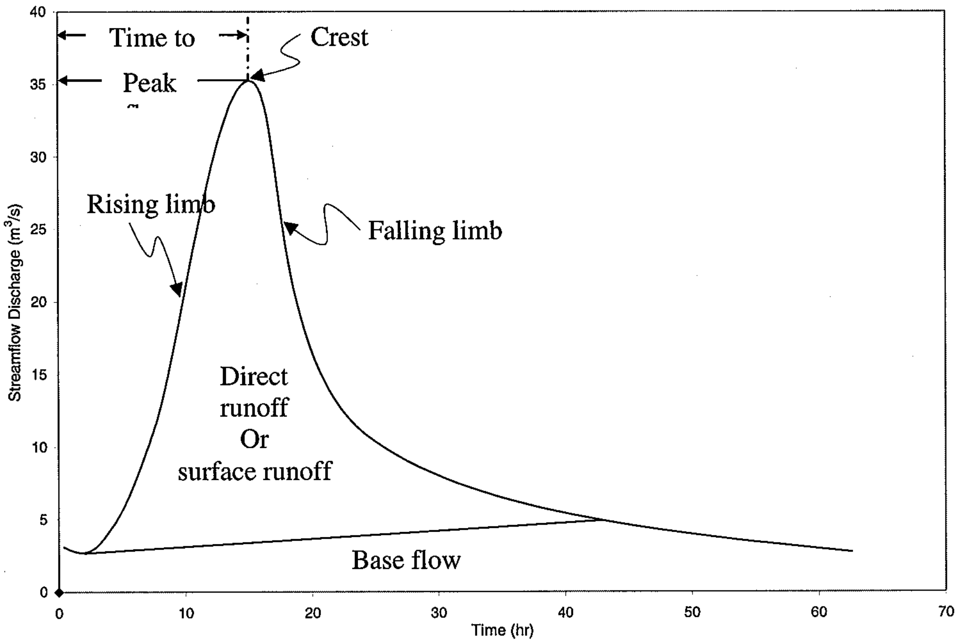


Figure 8. Components of a storm hydrograph

On the other hand, the distinctive geohydrological feature of volcanic rocks such as basalt, according to Karanth (1989), is the significant porosity in the form of interstices in vesicular varieties and pillow lavas, lava tubes, and occasional tunnels. These differences in geological properties of the different catchments may have influenced the topsoil porosity and infiltration rate, hence, the variations in their DRO coefficients which could hardly be explained by their land use alone. Within the Mapawa Catchment, a single ring infiltration test showed that the lowest rate of 35 cm hr^{-1} was observed at the top thin soil layer within a potato-cropped area and the highest rate of 129 cm hr^{-1} at the naturally vegetated surfaces. In the Indonesian catchments, Agus *et al.* (2002) surmised that the low-recorded runoff coefficients could indicate high infiltration capacity of the Inceptisols at the site.

Based on the above discussion, it appears that geological difference is the major reason why about 30 percent of Dong Cao's annual precipitation occurred as DRO while less than 10 percent of the annual precipitation was DRO in Mapawa, Rambutan, Tegalan, and Kalisidi. However, further field validation of the actual geology and soil classification of the above catchments needs to be done.

Storm Hydrograph Behavior

Another hydrologic characteristic of a catchment which could be affected by land use is the storm hydrograph behavior which could be described in terms of its components as shown in Figure 7. The more relevant components in soil and water conservation include the proportions of the direct runoff and base flow, and the peak discharge. Land use which effectively contributes to a significant decrease in direct runoff and peak discharge, and an increase in base flow would then be preferred and should be determined or developed for a given catchment or locality. While it would normally require long years of catchment studies to come up with some conclusive results, baseline data on storm hydrograph behavior in the MSEC catchment studies should be established.

Table 5 shows the estimated values of the relevant storm hydrograph components of some storms in the Mapawa Catchment in 2000 and 2001. Figure 8 shows the hydrograph of one sample storm. With the short period of the study, no significant changes in the hydrograph behavior could be observed. These data will best serve as a baseline reference from which to compare the behavior of future hydrographs in the same catchment as land use changes are effected. No storm hydrograph data were received from the other MSEC-participating countries.

Investigation of Mapawa's 2000-2001 storm hydrographs such as that shown in Figure 8 indicates practically zero base flows. When the weekly runoffs were plotted with time as shown in Figure 4, it is clear that not a fraction of the annual rainfall which infiltrated the ground surface appeared as base flow at the main weir. As such, the stream was classified earlier in this paper as ephemeral.

Table 5. Magnitudes of storm hydrograph components for sample storms in Mapawa Catchment (main weir)

Date of occurrence	Rainfall (mm)	Direct runoff		Direct runoff coefficient		Q_p (m^3/s)	t_p (min)
		m^3	mm	ratio	%		
2000							
1. September 24-25						0.55	15
2. October 5-6						0.917	125
3. November 5						0.669	10
2001							
1. September 13-14	33.90	4,127.40	4.74	0.140	14.0	0.826	35
2. September 26-27	35.60	2,997.00	3.44	0.097	9.7	0.186	105
3. October 4-5	22.00	4,563.00	5.24	0.238	23.8	1.122	20
4. October 6-7	22.20	4,806.90	5.53	0.249	24.9	0.927	30
Total/average	113.70		18.95	0.167	16.7		

Note: Q_p = peak runoff
t_p = time to peak

With no base flow appearing at Mapawa's main weir, the next question would be to account for the disposal of the almost 95 percent of the 2,450 mm average annual precipitation which infiltrated the ground surface. The most probable explanation is that being an influent stream (see Figure 3), the water table is lower than the streambed at the main weir throughout the year. Thus the fraction of precipitation at the Mapawa Catchment which infiltrated, percolated, and added to the aquifer does not occur as base flow of its stream at the main weir but possibly to the base flow of the perennial Alanib River which it intersects less than half a kilometre downstream. This relationship of the influent Mapawa stream and the effluent Alanib River may be likened to that shown in Figure 3. The same relationships maybe true for that of the Babon River and the three sub-catchments of Rambutan, Tegalan, and Kalisidi.

For the Dong Cao Catchment case, the fraction of precipitation which infiltrates and percolates down the soil profile keeps the water table always above the streambed at the main weir. A year round base flow is maintained making it a perennial stream. It is more likely that the geological formation exhibits an impermeable or semi-impermeable layer not far below the main streambed so the water table can be easily maintained by the annually infiltrating water. It is also possible that groundwater flow from higher aquifers is contributing to the base flow. Field validation through piezometers, as being conducted at the Lao PDR MSEC catchment, may have to be done to validate these assumptions.

Recommendations

The ongoing MSEC catchment studies are a great contribution towards generating information to show that appropriate land uses could sustain the use of our land and water resources and enhance the environment. However, generation of adequate and reliable information would require longer duration of field data observations.

That hydrologic field data monitoring is quite costly is not a question. The gathering of enormous but unreliable data should therefore be minimized if not totally avoided. Towards improving the reliability of field data, the specific recommendations are as follows:

a. Ascertain the functionality and accuracy of field instruments. Preparation of a field manual on the proper observation, operation, and maintenance of installed instruments could be considered. It should be simple enough to be easily understood by field observers. If necessary, it may be written in the local dialect of a concerned observer.
b. Ascertain the capability and sustainability of field data observers. More than one capable staff member may be needed to minimize data gaps when an observer gets sick or resigns.
c. Occasional checking/verification of actual field data monitoring to ensure uniformity of procedure and reliability of collected information.
d. Use of uniform technical terms and units to avoid confusion and for easy comparison of results with other publications. A glossary of terms and units may have to be agreed upon.
e. The delineation of catchment divides with respect to the actual stream flow gauging stations should be done using topographic maps and re-checked in the field. Some catchment areas being reported are not yet fixed.
f. Consider the inclusion of other indicators of groundwater recharge, specifically the spring water discharge (if some exist within the catchment area) and water table/piezometric water level variation in all catchments if possible. A common methodology and instrumentation for these indicators is necessary if they are to be monitored.
g. Measurement of gully and stream bank erosion rates and factoring them in the total sediment yield before computing the sheet and rill erosion rate.
h. More detailed characterization of the geology and soil classification of each catchment.

i. Monitoring of variations in soil water, water table, or piezometric level, which is being done at the MSEC-Lao PDR catchment, could also be followed in the other MSEC catchments.

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Evaluation of Environmental Factors and Soil Erosion in MSEC Catchments

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Abstract

Although changes in land use or management practices most commonly modify surface runoff, soil erosion, and soil fertility, such processes are still very poorly documented at the scale of catchments. The Management of Soil Erosion Consortium (MSEC) initiated a research project in six countries of Asia. MSEC provides the data collected from catchments representative of a variety of situations. This study aims to test existing regression models (Phommasack et al., *2001) for the prediction of runoff and annual erosion amounts over the study catchments. The data set for model generation consisted of annual budgets for 2001 from five catchments and 21 sub-catchments located in five countries of Southeast Asia (Indonesia, Laos, the Philippines, Thailand, and Vietnam). Runoff and erosion budgets from the 2002 rainy season for these catchments constituted the validation set.*

The runoff (R) model showed a root mean square error (RMSE) of 18 percent. An error analysis revealed that accurate estimations occurred for larger catchments. At smaller catchments, R was overestimated in Laos where high infiltration capacity and sub-surface runoff occurred, and was underestimated in Thailand where eroded soils induced high surface runoff rates. The model for bedload prediction showed a mean error (ME) of 4.5 t ha^{-1}, which is weak considering a bedload standard deviation of 5 t ha^{-1}. Accurate estimations occurred for suspended load (SL). These results confirmed the ability of prediction models to accurately estimate catchment outputs for runoff and partial sediment. These results also illustrate the real need to integrate erosion mechanisms acting at different spatial scales.

Introduction

Water availability, water quality, and sediment delivery have become crucial for food security, human health, and the environment. In particular, most concerns stem from the rapid changes in land use patterns caused by demographic, economic, political, and cultural transitions (Ingram *et al.*, 1996). Inappropriate land use has long been recognized as one of the major causes of decreasing water supply, and accelerated soil erosion and nutrient loss, particularly

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in areas of recent land cover changes such as the tropical regions. The conversion of tropical rainforests to pastures or cultivated land commonly results in a reduction of surface soil porosity. Increased erosion removes the first top cm where most organic matter and nutrients are concentrated. In addition to decreased on-site productivity, these processes lead to off-site consequences including flooding; decrease in groundwater recharge; pollution by nutrients, heavy metals, and pesticides; siltation; and eutrophication of reservoirs (IGBP, 1995).

Despite the crucial need for a sound assessment of these processes, available data remain scarce and are usually based on a single process observed at a specific scale (e.g. soil loss from erosion plots). In the sloping lands of Southeast Asia, land use changes are very rapid due to strong demographic, economic, and political drivers. In many locations, the pristine forest has been cleared for slash-and-burn cultivation or for more intensified systems based on the use of pesticides, fertilizers, and machinery. At the onset of the rainy season, the tilled soil that is left bare tends to crust and generates runoff, which concentrates and generates gully erosion. Conversely, appropriate land use can lead to soil and water conservation.

To tackle these issues, the Management of Soil Erosion Consortium (MSEC) initiated a research project in six countries of Asia with the support of the Asian Development Bank (ADB). It aims at developing, adapting, and disseminating appropriate tools and methodologies to reduce the on- and off-site effects of erosion on land and water resources (Maglinao, 2001). Each participating country has selected a catchment of about 100 ha and equipped it and at least four sub-catchments to monitor runoff and sediment yield. These catchments are representative of the prevailing biophysical and socio-economic conditions in the area. The objectives of this particular study are: (i) to assess runoff and sediment yield annual budgets from the data collected in 2001 from five catchments and 21 sub-catchments; (ii) to assess the impact of land use, climate, and topography on runoff, bedload, and suspended load annual budgets; and (iii) to predict annual runoff and sediment yield using statistical models.

Materials and Methods

Data Acquisition

Rainfall, runoff, and sediment yields and other climatic data were collected in 2001 from five catchments and 21 sub-catchments in five countries in Southeast Asia. The landscape descriptions of the study sites in Indonesia, the Philippines, Thailand, and Vietnam are presented in Figure 1 and of Laos in Figure 2. In 2002, Indonesia studied four sub-catchments; Laos, eight; the Philippines, four; Thailand, four and Vietnam, four.

In 2001, catchment delineation and topographic features of the catchments were derived from Digital Elevation Models (DEM) with a 10 m mesh. In most cases, DEMs were available at 10 m resolution generated by interpolation from digitized contours of 5 m intervals in a 1: 50,000 topographic map. Some more accurate DEMs have been established by interpolation from field spot heights using a theodolite (e.g. Laos). Topographic characteristics such as slope angle and its standard deviation for each sub-catchment were estimated from DEMs using Arc-View® software (ESRI, 1994).

Runoff and erosion data were collected at the outlet of each catchment and sub-catchment where measuring devices had been installed. Runoff data were gathered both manually using staff gauges and automatically using automatic water level recorders. Water level in the weirs

Figure 1. Landscape characteristics and land management in Indonesia (4 sub-catchments), Philippines (4 sub-catchments), Thailand (4 sub-catchments), and Vietnam (4 sub-catchments).

was automatically recorded at a time step lower than 10 minutes. In Laos, Thailand, and Indonesia, water samples were collected during the main rainfall events to assess the sediment concentration. The time interval for water sampling differed among sites. Samples were collected at time intervals from two minutes to one 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 depending on the amount accumulated. Runoff and sediment yield data were computed to obtain yearly means. Mean annual suspended sediment concentration was combined with water flux data to assess the annual suspended load, using data interpolation between the sampling periods.

Rainfall data were collected using manual rain gauges and an automatic weather station installed in each catchment site. Data from the manual rain gauges were recorded with a daily time step while six-minute data acquisition was recorded by an automatic weather station.

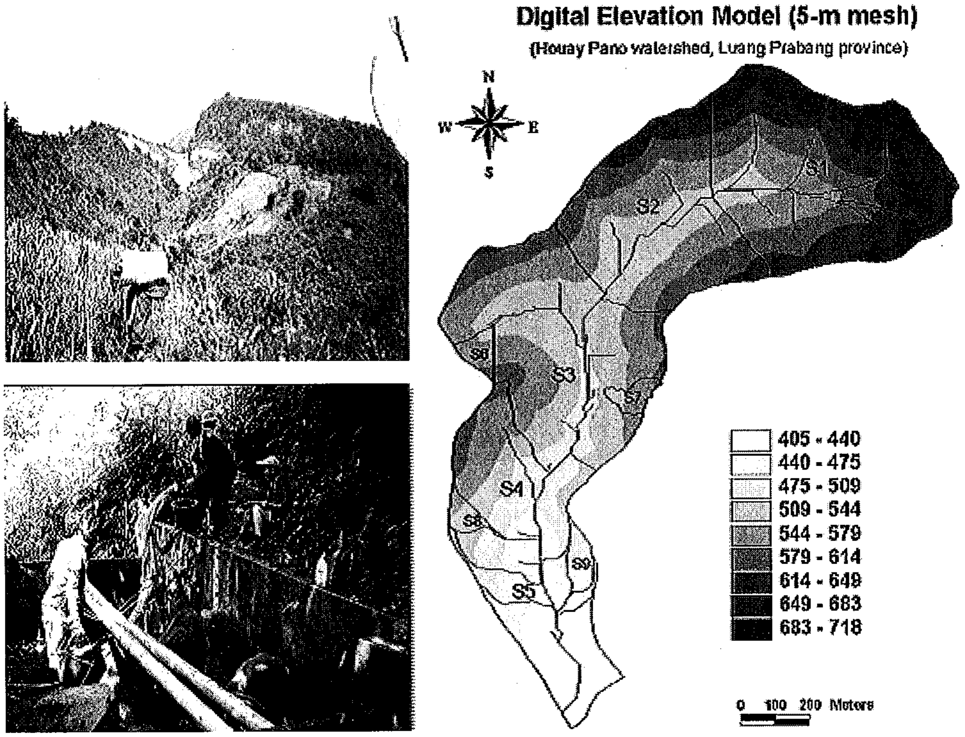

Figure 2. The Lao PDR site: landscape and land management of the main catchment and bedload collection at the outlet of one sub-catchment (pictures, left); digital elevation model with a 10-m mesh, channel network distribution, and location of the 9 sub-catchments

Land use was assessed from 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).

Statistical Analysis and Modelling

A factorial analysis was done to evaluate the effect of climate, topography, and land use on runoff and sediment yield. The relation between environmental factors and runoff amount (R), bedload (BL), and suspended load (SL) was first investigated using correlation analysis. Variance analysis was done between runoff and sediment yield as dependent variables and environmental factors as independent variables. These environmental factors included the yearly precipitation amount (P), the precipitation ratio (Pr) between the minimum monthly precipitation (Pn) and the maximum monthly precipitation (Px), the slope gradient (S), the catchment area (Surf) and the areal percentage of each land use type. Forward stepwise regression analyses (Neter *et al.*, 1989) were established using 2001 data to predict runoff and sediment yield using environmental factors as predictors. Regression analyses were performed using the Statistica® package for use on a personal computer (Statsoft, 1996). Parameters with statistical significance at the 0.01 level were considered for computing predictive equations and reporting results. The analysis considered data from 16, 21, and 11 sub-catchments for R, BL, and SL, respectively. The data in 2002 from 23, 18, and 25 catchments and sub-catchments were used to validate the generated regression models for R, SL, and BL, respectively.

Results and Discussion

Environmental Factors, Annual Runoff, and Sediment Yield

The main topographic and land use factors of the five catchments and 21 sub-catchments studied in 2001 are shown in Table 1. These same factors studied in 2002 for five catchments and 24 sub-catchments are shown in Table 2. The mean catchment area was 40.1 ha in 2001 (min. 0.9 ha, max. 290 ha) and 23 ha in 2002 (Tables 3 and 4, respectively). The decrease in the mean surface area in 2002 was due to the increase in the number of study catchments with a small surface area. This was the case in Laos with the construction of three new weirs at the outlets of S6, S7, and S8 with a surface area of 0.64, 0.60, and 0.57 ha, respectively.

Table 1. Main topographic and land use factors of the 5 catchments and 21 sub-catchments in 2001

Country	Local name	Study name	Surf (ha)	S (degree)	C (%)	Fa (%)	Cp (%)	O (%)	Fo (%)
Indonesia	Babon	Ib	290.0	10.0	0.0	0.0	0.0	100.0	0.0
	Sill	Is	150.0	8.0	10.0	0.0	90.0	0.0	0.0
	Tegalan	It	3.0	14.0	50.0	0.0	0.0	50.0	0.0
	Rambutan	Ir	2.0	12.0	0.0	0.0	0.0	100.0	0.0
	Kalisidi	Ik	38.0	8.0	0.0	0.0	0.0	100.0	0.0
Laos	S0	L0	1.0	25.0	0.0	69.0	0.0	31.0	0.0
	S1	L1	19.1	29.0	9.2	76.0	0.0	0.8	14.0
	S2	L2	32.8	27.0	1.7	19.7	0.0	7.0	11.6
	S3	L3	51.4	25.0	18.6	61.2	0.0	9.5	10.2
	S4	L4	60.2	28.0	2.3	52.7	0.0	9.9	35.1
	S5	L5	63.0	17.0	0.0	55.7	0.0	31.0	13.4
Philippines	Main	Po	84.5	14.0	23.7	44.9	16.8	0.0	15.4
	MC1	P1	24.9	14.0	10.0	60.2	12.1	0.0	16.1
	MC2	P2	17.8	14.0	47.7	39.3	5.6	0.0	11.2
	MC3	P3	7.9	14.0	15.2	75.9	12.7	0.0	12.7
	MC4	P4	0.9	25.0	42.5	31.9	0.0	0.0	21.3
Thailand	W1	T1	7.5	14.1	30.0	0.0	30.0	30.0	0.0
	W2	T2	7.8	11.6	80.0	0.0	0.0	10.0	10.0
	W3	T3	2.2	12.7	3.0	2.0	2.0	92.0	0.0
	W4	T4	7.5	14.6	60.0	0.0	15.0	15.0	10.0
	Flume	Tf	79.5	11.4	70.0	5.0	12.0	8.0	5.0
Vietnam	W 1	V0	4.6	28.0	80.0	0.0	20.0	0.0	0.0
	W 2	V1	9.4	29.0	0.0	5.0	95.0	0.0	0.0
	W 3	V2	6.2	27.0	0.0	35.0	65.0	0.0	0.0
	W 4	V3	11.7	31.0	0.0	60.0	40.0	0.0	0.0
	MW	V4	59.5	25.0	28.0	22.0	20.0	30.0	0.0

Surf (ha) is the catchment area; S, the slope angle (?); 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 forest

Table 2. Main topographic and land use factors of the 5 catchments and 24 sub-catchments in 2002

Country	Local name	Study name	Surf (ha)	S (degree)	C (%)	Fa (%)	Cp (%)	O (%)	Fo (%)
Indonesia	Babon	Ib	35.0	10.0	51.0	0.0	49.0	40.0	0.0
	Sill	Is		8.0					
	Tegalan	It	3.2	14.0	60.0	0.0	40.0	0.0	0.0
	Rambutan	Ir	2.0	12.0	0.0	0.0	100.0	100.0	0.0
	Kalisidi	Ik	38.5	8.0	0.0	0.0	100.0	100.0	0.0
Laos	S1	L1	19.6	29.0	49.5	36.0	0.0	0.7	13.8
	S2	L2	32.8	27.0	27.5	7.6	0.0	0.0	5.8
	S3	L3	51.4	25.0	8.9	15.8	0.0	4.6	3.4
	S4	L4	60.2	28.0	1.1	7.1	0.0	0.2	5.4
	S5	L5	63.0	23.8	0.1	1.6	0.0	0.0	1.5
	S6	L6	0.6	25.6	54.7	6.3	54.7	9.4	29.7
	S7	L7	0.6	28.8	76.3	0.0	0.0	0.0	19.9
	S8	L8	0.6	22.6	52.9	0.0	52.9	0.0	77.6
	S9	L9	0.7	25.5	86.7	0.0	86.7	0.0	13.8
Philippines	Main	Po	84.5	25.0	24.8	40.6	7.4	11.8	15.4
	MC1	P1	24.9	33.0	15.1	56.8	8.0	4.0	16.1
	MC2	P2	17.9	27.0	57.0	16.9	9.8	4.4	11.9
	MC3	P3	8.0	22.0	65.5	7.9	12.7	1.3	12.7
	MC4	P4	0.9	15.0	56.7	33.3	0.0	0.0	10.0
Thailand	W1	T1	11.8	15.4	46.2	7.2	0.0	35.3	11.3
	W2	T2	9.6	13.5	67.6	1.2	0.0	4.8	26.4
	W3	T3	3.2	17.8	40.9	0.0	0.0	0.2	58.9
	W4	T4	7.1	13.7	71.0	7.9	0.0	3.2	17.9
	Flume	Tf	93.2	15.1	63.4	2.8	0.0	10.4	23.4
Vietnam	W 1	V0	3.7	20.0	0.0	67.0	0.0	0.0	0.0
	W 2	V1	7.7	24.0	44.0	38.0	0.0	0.0	0.0
	W 3	V2	10.8	24.0	0.0	63.0	0.0	0.0	0.0
	W 4	V3	7.2	24.0	0.0	26.0	0.0	0.0	0.0
	MW	V4	45.5	21.0	5.9	57.7	0.0	0.0	5.2

Surf (ha) is the catchment area; S, the slope angle (?); 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 forest

Table 3. Main statistics (mean, minimum, maximum, standard deviation) for environmental factors in 2001

	Surf (ha)	P (mm)	Pm (mm)	Pr %	S (degree)	C %	Fa %	Cp %	O %	Fo %
Mean	40.15	2,019	466	16	18.8	22.4	27.5	16.8	24.0	7.2
Min	0.94	1,385	275	3	8.0	0.0	0.0	0.0	0.0	0.0
Max	290.00	3,840	672	31	31.0	80.0	76.0	95.0	100.0	35.1
SD	62.08	938	151	9	7.7	26.8	28.4	27.1	34.8	8.9

Surf (ha) is the catchment area; P, the yearly precipitation amount; Pm, the maximum monthly precipitation; Pr (%) the ratio between Pn, the minimum monthly precipitation and Pm; S, the slope angle (?); 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 forest

Table 4. Main statistics (mean, minimum, maximum, standard deviation) for environmental factors in 2002

	Surf (ha)	P (mm)	Pm (mm)	Pr %	S (degree)	C %	Fa %	Cp %	O %	Fo %
Mean	23.01	1,745	371	2	20.6	36.7	17.9	18.6	11.8	13.6
Min	0.57	1,090	145	3	8.0	0.0	0.0	0.0	0.0	0.0
Max	93.20	3136	548	14	33.0	86.7	67.0	100.0	100.0	77.6
SD	26.55	647	127	4	6.8	28.5	22.0	32.2	26.8	17.9

Surf (ha) is the catchment area; P, the yearly precipitation amount; Pm, the maximum monthly precipitation; Pr (%) the ratio between Pn, the minimum monthly precipitation and Pm; S, the slope angle (?); 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 forest

The yearly precipitation amount (P) ranged from 1,385 to 3,840 mm in 2001 and from 1,090 to 3,136 mm in 2002; the precipitation ratio (Pr) ranged from 0.03 to 0.31 in 2001 and from 0.03 to 14 in 2002 (Tables 3 and 4). The slope gradient (S) varied from 8 to 33°.

In 2002, the runoff coefficient was estimated for all sub-catchments except in the Philippines and the Sill sub-catchment in Indonesia. SL was not estimated in the Philippines, the four small sub-catchments of Vietnam, the Sill Catchment of Indonesia, and the main flume of Thailand. The BL was not estimated at the outlet of the Lao catchments (as in 2001 due to the configuration of the weir with no trapping area), the Sill, and the main catchment of Thailand.

The mean runoff coefficient (R) was 22 percent in 2001 (with a range from 0.4 to 48 percent) and 22 percent in 2002 (with a range from 0.3 to 64 percent); mean bedload (BL) was 3 t ha^{-1} (0.01-20 t ha^{-1}) in 2001 and 1.9 t ha^{-1} in 2002 (Tables 5 and 6). The mean suspended sediment load (SL) was 1.8 t ha^{-1} (0.04-6.4 t ha^{-1}) in 2001 and 1.9 t ha^{-1} in 2002. The mean sediment concentration (SC) was 1.6 g L^{-1} (between 0.3 and 3.5 g L^{-1}) in 2001 and 1 g L^{-1} in 2002. These results indicate that the mean runoff coefficient (R) and suspended sediment load (SL) did not significantly vary from 2001 to 2002. On the contrary, BL was greatly reduced in 2002.

Table 5. Main statistics (mean, minimum, maximum, standard deviation) for runoff and sediment yield variables in 2001

	R (%)	BL (t ha^{-1})	SL t ha^{-1})	SC (g^{-1})
Mean	22.3.	3.0	1.8	1.6
Min	0.4	0.0	0.0	0.3
Max	48.0	20.0	6.4	3.5
SD	17.8	4.9	2.0	1.0

R is the runoff ratio; BL, the bedload; SL, the suspended sediment load; SC, the sediment concentration.

Table 6. Main statistics (mean, minimum, maximum, standard deviation) for runoff and sediment yield variables in 2002

	R (%)	BL (t ha^{-1})	SL (t ha^{-1})	SC (g^{-1})
Mean	21.6	1.9	1.9	1.0
Min	0.3	0.0	0.0	0.0
Max	64.0	24.7	7.6	3.4
SD	18.0	4.7	2.3	0.9

R is the runoff ratio; BL the bedload; SL the suspended sediments load; SC the sediment concentration.

The comparison between the observed data collected in 2002 and predictions from the statistical models established in 2001 (Phommasack *et al.,* 2001) showed a root mean square error (RMSE) for runoff of 18.3 percent (Table 7). In the case of runoff, the regression model provided higher prediction errors. Maximum errors occurred for smaller catchments. For instance S6, S7, S8, and S9 in Laos showed ME of 46, 57, 31, and 49 percent respectively. In the case of Thailand, smaller catchments revealed an underestimation. The low runoff amount in Laos may be explained by the high infiltration capacity and sub-surface runoff on hillslopes as revealed by hydrologic investigations. In Thailand, higher runoff amounts may result from the large amount of tillage and water erosion that has occurred during the past 30 years under intensive agriculture, which in turn affect infiltration and runoff.

Table 7. RMSE[§] for runoff, bedload. and suspended sediment.

	Runoff %	Bed lLoad t ha^{-1}	Suspended lLoad t ha^{-1}
ME	8.20	3.82	3.24
RMSE	18.27	5.06	3.24

[§] root mean square error

$$RMSE = \{ \frac{1}{n}\sum_{i=1}^{n} [(\text{estimation})^{*} \_ \text{observation}]^{2} \}^{0.5}$$

$$ME = \frac{1}{n}\sum_{i=1}^{n} [(\text{estimation})^{*} \_ \text{observation}]$$

Accurate estimations occurred for SL for most of the sites and sub-catchments. However, high underestimation was observed in Laos, especially at S2 and S9 (the ME for SL was 8.3 and 10.2, respectively). Lower erosion may be explained by the presence of clay soil and limited tillage depth. In addition, the presence of flat areas downstream of S2 and S9 sub-catchments induced a decrease of flow velocity which in turn allowed sedimentation processes. The model for bedload prediction showed a mean error of 4.5 t ha^{-1}, which is a very weak prediction considering the bedload standard deviation of 4.73 t ha^{-1}. The worst estimation occurred at MC4, the smallest catchment of the Philippines with an ME for BL of -17. This illustrates that high erosion rates may be related to high rainfall intensities or land management conditions not captured in the data set of model generation.

Conclusion

The data generated from monitoring the five catchments and 24 sub-catchemnts in five countries of Southeast Asia in 2002 were used to validate the regression models generated from 2001 data. These models were used for the prediction of runoff and erosion annual budgets.

When considering large catchments, generated models were accurate for runoff and erosion amount predictions. In the case of smaller catchments, high prediction errors (both over- and underestimations) occurred. This illustrates that at these small areas, the areal percentages of crops, the mean slope angle of hillslopes, and the rainfall characteristics are not enough to explain runoff and erosion features as in the case for larger areas. Other factors which may need to be studied are soil aggregate stability, soil tillage, soil infiltration, and topographic conditions downstream of catchments. Other site specific factors may include surface stoniness, soil resistance to shear stress, or the mean depth of soil. Thinner soil with low soil water storage may also affect sediment losses (Burt, 2001).

The percentages of annual crops, rainfall characteristics, and topographic conditions were confirmed as the main factors controlling sediment yield, both in terms of suspended load and bedload under these sloping land conditions. Such statistical prediction models must, however, be based on data from catchments with different sizes that include a longer time series than two years, one for calibration and one for validation.

Finally, the modelling approach, aiming at better prediction of water and sediment loads at the catchment scale should further integrate mechanisms involved at different spatial scales.

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Effects of Land Use and Management Systems on Water and Sediment Yields: Evaluation from Several Micro Catchments in Southeast Asia

F. Agus, T. Vadari, R.L. Watung, Sukristiyonubowo and C. Valentin

Abstract

In an effort to develop economically promising and environmentally benign catchment-scale upland management systems, the Management of Soil Erosion Consortium (MSEC) initiated intensive soil erosion studies in selected catchments in the Philippines, Thailand, Laos, Vietnam, Nepal, and Indonesia. Hydrological stations were equipped with automatic water level recorders and staff gauges to measure water and sediment yields from each catchment and sub-catchment. Rainfall data were collected using automatic weather stations and manual rain gauges. Sediment and water yields were analyzed as these relate to land use and management systems at the micro catchment scale. The analysis showed that land use and management techniques greatly affect sediment and water yields. Catchments with good landscape filter systems such as orchards and forest with natural undergrowth, and catchments with grass strips as hedgerows showed better control of erosion than those under intensive cultivation of annual crops, or perennial trees but no undergrowth cover. Smaller sub-catchments used intensively for annual crops exhibited a shorter lag time between the peak of rainfall and the peak of runoff. Moreover, their runoff coefficients were relatively higher than those of catchments with perennial trees and good undergrowth and litter cover. This translates to the higher flood mitigation functions of better-covered catchments. Erosion from paddy fields is negligible and usually higher during tillage operation. Better regulation in water flow between plots can significantly control the sediment outflow from terraced paddy fields.

Introduction

Poverty and land degradation exist in a vicious cycle largely affecting the marginalized upland poor farmers in Southeast Asia. High population growth, for example 1.6 percent per annum in Indonesia, results in a continued increase in food demand and increased encroachment on the less suitable steep lands to produce more crops. Contrary to soil conservation principles, these steep lands have been inappropriately managed, unintentionally increasing runoff and accelerating soil erosion and sedimentation.

Because of the undividable link among the biophysical, socio-economic, and cultural factors, they should all be considered in developing options for improved soil management. Lack of implementation of research results may have been caused by the failure to take into

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account these interdependent concerns. In many cases, conserving the soil is given low priority by farmers on steep lands because most recommended conservation technology options are expensive and do not provide direct and short-term benefits to them. They are not able to address the reality of the rural poor (Garrity and Agus, 1999; Agus *et al.,* 1998). Researchers in many parts of the world have not successfully developed on-farm technologies that integrate both increased agricultural production and income and secure the upstream and downstream natural resource base (Shaxson, 1999). In Indonesia, for example, there have been many research and development projects dealing with conservation. However, many introduced measures have not been sustained by the farmers beyond the project life because most of them cannot generate intrinsic rewards to the farmers and project incentives are at their best within the project's duration.

Past failures to develop integrated, two-pronged (both for better production and conservation) management systems, led us to re-examine approaches to research on sustainable land management. A participatory catchment management research using an integrated and interdisciplinary approach has evolved and been adopted by the Management of Soil Erosion Consortium (MSEC) project of the International Water Management Institute (IWMI). National agricultural research systems from six countries, namely the Philippines, Vietnam, Laos, Thailand, Nepal, and Indonesia have been involved in this project.

Sediment yield and runoff data are important indicators of how different soil management systems keep the soil in place and potentially sustain soil productivity. In the Indonesian site, the earlier study by Agus *et al.* (2002) indicated lower direct runoff (fast flow) and sediment yields in smaller catchments probably because of the longer travel time for the runoff water and sediments to reach the catchment outlet (where measurement is done). Catchments with intensive annual upland farming systems had high water and sediment yields.

This report presents an analysis of the effect of land use and management systems on water and sediment yields of a number of catchments and sub-catchments in the Philippines, Vietnam, Laos, Thailand, and Indonesia. The analysis enables us to appreciate and further recognize the commonality and differences in hydrological behavior of catchments and helps us when formulating appropriate strategies for better land management. The information further provides valuable support to developing policies to promote environmentally sustainable land management and land use systems in Southeast Asia.

Materials and Methods

The catchment-scale research of MSEC was initiated in 1999 in six countries in Asia, but this paper covers only the results from Laos, the Philippines, Vietnam, Thailand, and Indonesia. The study catchments are described in Table 1 and further explained in a later section. This report presents the analysis of the 2002 observations with some reference to the data of the previous years.

Table 1. Characteristics of MSEC catchments and hydrological features in four countries in 2002

Catchment	Area (ha)	Soil order/subgroup	Land use/farming system	Dominant slope (%)
INDONESIA (Sep 01 to -May 02)				
Tegalan	1.1	Andic Eutropepts	Cassava, maize, some trees in 2000 and 2001 and fodder grass and some trees starting in December 2001	45-47(46)
Rambutan	0.9	Andic Dystropepts	95% rambutan, 5% shrubs	22-55(40)
Kalisidi	13	Andic Dystropepts	100% rambutan, lower catchment encroached for annual crops	22-55(37)
Babon	285	Typic Tropaquepts	All above + rice field	0-55(30)
PHILIPPINES				
MC 1	24.9	Ultisols	Falcata, bamboo,. grassland (98%), veg. aAnd root crops (2%)	33
MC 2	17.9	Ultisols	Forest, grassland (85%), cropland, shrubs (10%)	27
MC 3	8	Ultisols	Grassland (75%), cultivated (15%), settlement (10%)	22
MC 4	0.9	Ultisols	Grassland, trees (60%), cultivated and bare (40%)	15
Whole	84.5	Ultisols	Grassland, bamboo, eucalyiptus, etc 80%; vegetablesable and rootcrops (20%).	25
VIETNAM				
W 1	3.7	Ultiosols	Cassava, grass	25-40
W 2	7.7	Ultisols	Cassava, A. mangium	30-35
W 3	10.8	Ultisols	Cassava, tarro, A. mangium	40-45
W 4	7.2	Ultisols	Cassava, A. mangium, sec. forest	35-40
MW	45.5	Ultisols	Cassava, arrow root, sec. forest	20-25
LAOS:				
S0	1.3	Ult, Alf	69% bush fallow 31% teak	25
S1	19.6	Ult, Alf, Ent	76% bush fallow, 14% forest and teak, 9% annual and 1% perennial crops	29
S2	32.8	Alf, Ult, Ent	80% bush fallow, 15% forest and teak 2% annual and 3% perennial crops	27
S3	60.2	Alf, Ent, Ult	60% bush fallow, 10% forest and teak 20% annual and 10% perennial crops	25
S4	63	Alf, Ult, Ent	53% bBush fallow, 43% forest, teak 2% annual and 2% perennial crops	28
THAILAND				
W1	11.8		46% annual, 7% fallow, 35% orchard, 11% forest	34.4
W2	9.6		68% annual, 1% fallow, 5% orchards, 26% forest	34.3
W3	3.2		41% annual, 59% forest	42.7
W4	7.1		71% annual, 8% fallow, 3% orchards, 18% forest	40.6
W5-Whole	93.2		63% annual, 3% fallow, 10% orchards, 23% forest	23.1

1) Fertilizer application for rambutan (Nephelium lappaceum) was ceased in 1999 until mid-2001 because of encroachment by villagers. In November 2001 the company planned to resume the fertilization as well as regenerating some of the trees

2) Only sediment load was included

Hydrological Characterization

The biophysical aspect of research was initiated with the construction of V-notch weirs and sediment traps, and for some catchments, with perennial flow streams, also Parshall flumes. The pairs of sediment traps and V-notch weirs were equipped with both automatic water level recorders (AWLR) (Orphimedes or Thalimedes type) and manual recording staff gauges for water level and discharge measurements.

Four to five hydrological gauging stations were installed in each country. The distribution of the gauging stations in Laos and Thailand is shown in Figures 1 and 2, respectively. In Laos, the measuring stations are located at points along a common stream while in Thailand, four separate small sub-catchments are distributed within one whole catchment. The Lao case typifies the catchments in Vietnam and the Philippines while the Indonesian catchment is similar to the Thai catchment in terms of distribution of gauging instruments.

For perennial flow canals that are equipped with Parshall flumes, water discharge (water yield per unit time) was determined as the product of water velocity (determined either with a current meter or a float) and the cross-sectional area of the flowing water through the flume. For intermittent flow systems with sediment traps and V-notch weirs, water discharge was estimated before and when the water level reached the base of the V-notch. Before the water level reached the V-notch, discharge was calculated as the change in the water volume in the trap divided by the time interval between measurements. When the water level reached the V-notch, the discharge (in the Indonesian case) was calculated using the following relationship:

$$Q = 8/15 \times SQRT\,(2g) \times CD \times \tan\,(q/2) \times h^{2.5} \times 60000 \qquad \text{Eq. 1}$$

Where,

8/15 - a constant depending on the design of the V-notch weir

Q - discharge (L minute^{-1})

g - acceleration due to gravity (9.8 m sec^{-2})

CD - the correction factor of discharge

q - angle of V-notch

h - the water level, measured from the base of the V-notch

60 000 - conversion factor from m^3 h^{-1} to L min^{-1}

Some countries use rating curves, developed as a relationship between the height of water flowing through the V-notch and the volume of outflowing water from the V-notch per unit time. Success in developing the rating curves depends on the capability to calibrate within a wide range of water debit (water height passing the V-notch).

Water level data were obtained from each automatic recorder at 1- or 5-minute intervals and verified for accuracy with the readings of the staff gauges. The staff gauge readings were done three times daily at 08.00, 12.00, and 16.00. A continuous record of rainfall amount and intensity was kept every five or six (in the Indonesian case) minutes using the automatic weather station and manual rain gauges.

Total soil loss or sediment yield was taken as the sum of bed load and suspended load. Suspended load was estimated from a rating curve of each catchment for the relationship between sediment concentration and water discharge passing the V-notch. It is calculated as the product of discharge and sediment concentration. The oven-dry weight of the sediments collected in the sediment trap after each rainfall event represents the bed load (coarse aggregates and particles).

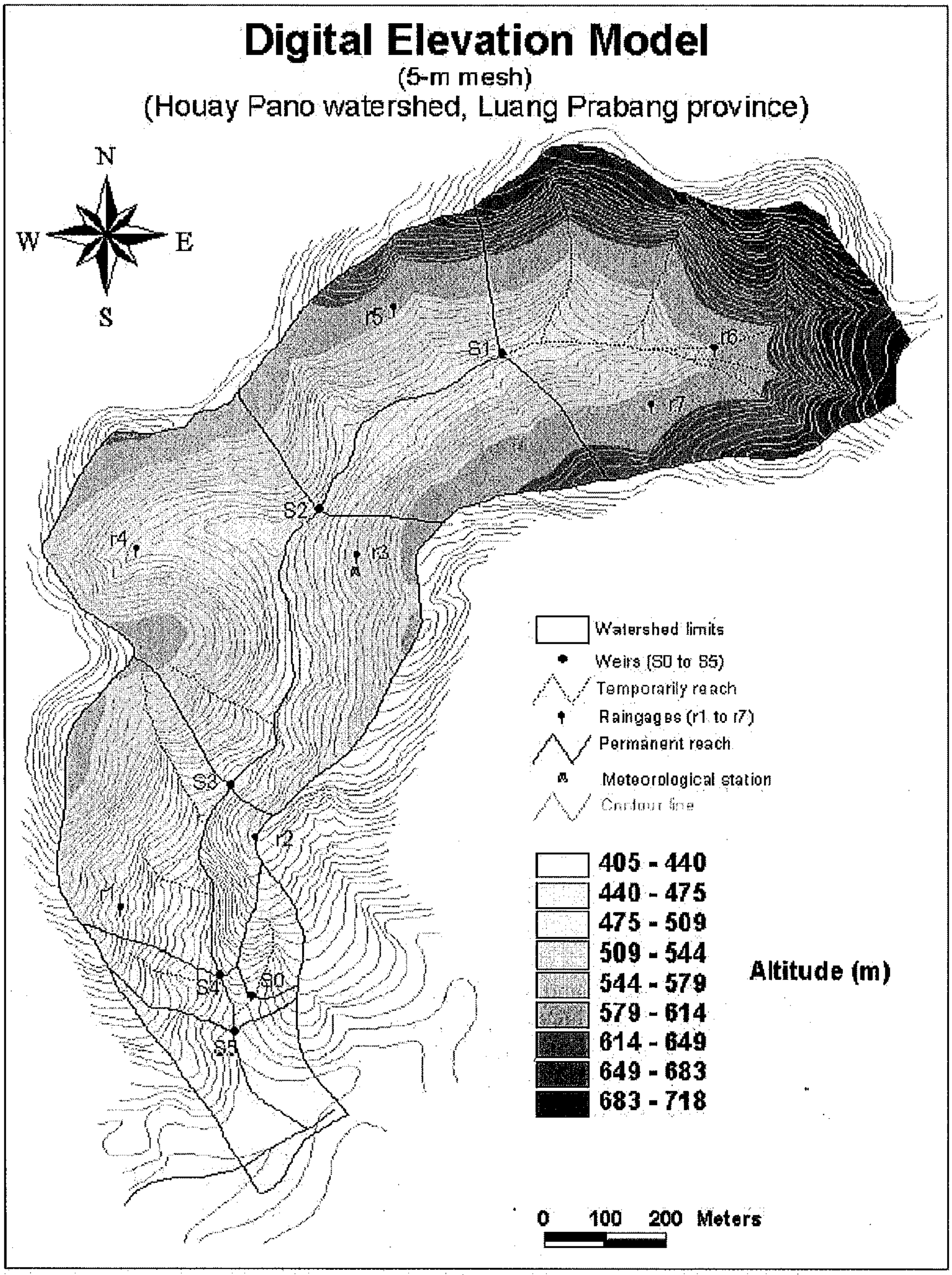


Figure 1. Digital Elevation Model (DEM) of the Houay Pano Catchment in Laos showing the different sub-catchments and the distribution of the weirs, rain gauges, and the meteorological station

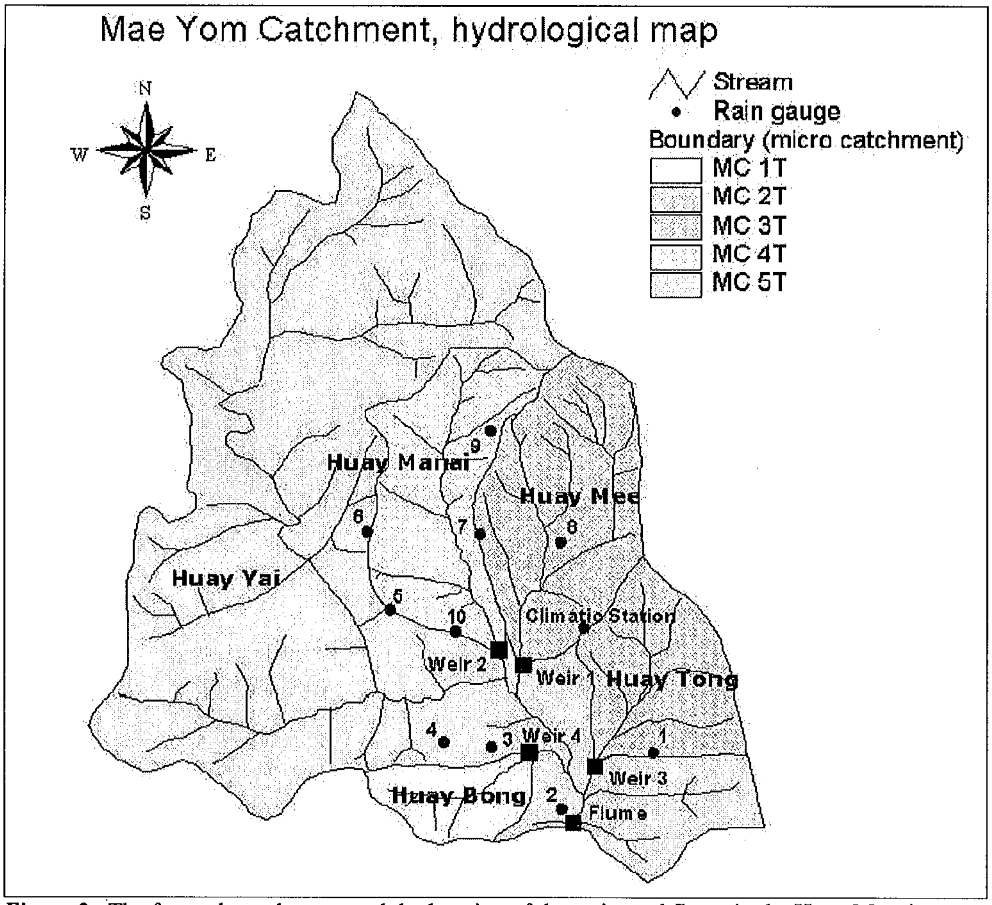


Figure 2. The four sub-catchments and the location of the weirs and flume in the Huay Manai Catchment in Thailand

The relationship between land use, catchment size, and sediment and water yields was described by grouping catchments of different sizes, but with similar land use systems, and those of comparable sizes, but with different land use and management systems.

Erosion in Terraced Paddy Fields

The quantification of erosion from terraced paddy fields was conducted in connection with ongoing research on the Multifunctionality of the Paddy Farming System (Agus *et al.*, 2003). Measurements were done in 18 terraced paddy fields, ranging from 12 to 358 m^2 (total area of 2,515 m^2) in two rice cropping seasons (31 October 2001 to 31 January 2002 and from 16 March to 1 July 2002). V-notch weirs made of GI sheets were installed in the water inlets and outlets. The water level at the inlets and outlets of each plot was recorded two times daily and a rating curve for the relationship between water level and discharge was generated. During and after each field operation (plowing, puddling, transplanting, weeding, and fertilization), intensive water sampling was done and sediment concentrations were determined using gravimetric procedures. Less frequent (weekly) sampling was done during the rest of the season when sediment concentrations are expected to be low. From sediment concentrations and water discharge data, the amount of sediment debits entering and leaving the paddy fields was calculated.

Results and Discussion

Catchment Characteristics and an Overview of 2001 Results

The common features of the sloping upland agricultural land areas in the collaborating countries are the predominantly steep slopes and the poverty of the people. Land use intensity varies from a transition from shifting cultivation to a more permanent agriculture in Laos, to a very intensive farming system in Java, Indonesia. Rainfall patterns, land management systems, and catchment sizes vary within and among countries (Table 1).

The catchments and sub-catchments that were studied intensively varied from 0.9 ha in Indonesia and Philippines to 63 ha in Laos (Figure 3). In Indonesia, the Tegalan, Rambutan, and Kalisidi sub-catchments have intermittent flow and discharge in the drainage canals can only be observed during and shortly after heavy rainfall events. Discharge in Kalisidi is intermittent but continues to flow for a longer time after each heavy rainfall event, and is still observed for several consecutive days during the peak of the rainy season. Lao and Vietnamese catchments have perennial flow while those in Thailand and the Philippines have intermittent streams.

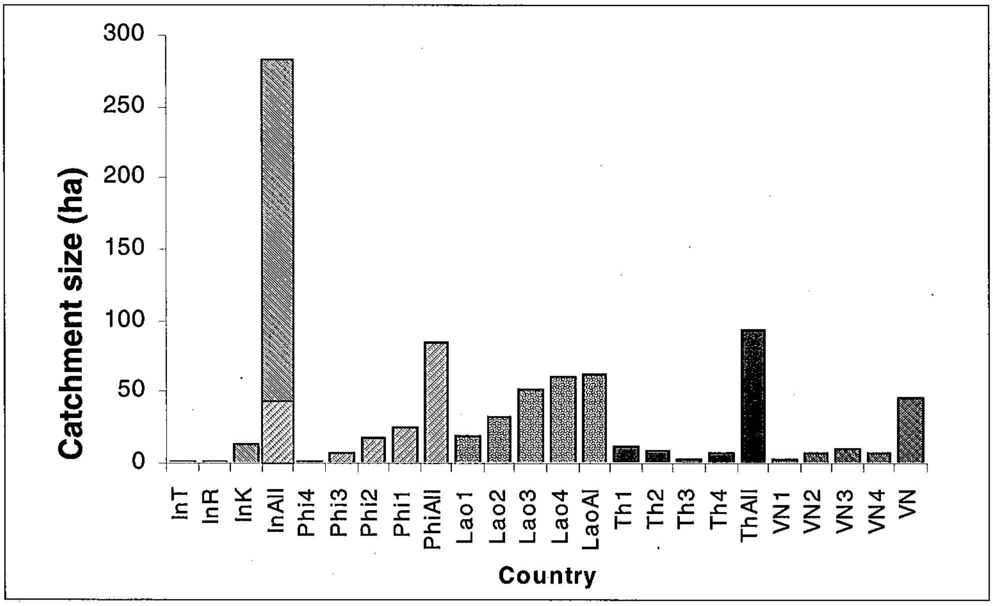


Figure 3. Size of the MSEC catchments in Indonesia (In), the Philippines (Phi), Laos (Lao), Thailand (Th), and Vietnam (VN). T, R, and K for Indonesia stand for Tegalan, Rambutan, and Kalisidi, and modifier 'All' means the overall catchment encasing all sub-catchments

The study site in Indonesia is located in Ungaran sub-district, Central Java Province. It is relatively close to urban development and farming constitutes the second or third source of income. The annual rainfall of about 2,800 mm and high intensity rains in the catchment typify the rainfall characteristics in the mountainous areas of West and Central Java. Despite the high rainfall, the proportion of runoff relative to rainfall (runoff coefficient) did not exceed 14 percent indicating the high infiltration capacity of the soil at the site. Sediment yields from the sub-catchments, except Tegalan (cultivated to annual crops) were less than 2 t ha^{-1} $year^{-1}$. Sediment yield of the Tegalan sub-catchment was about 20 t ha^{-1} $year^{-1}$. This higher yield can be attributed to the larger soil surface area exposed to raindrops, sparse litter cover, intensive tillage, steep slopes, and the small size of the sub-catchment (Agus *et al.*, 2001).

The Philippine catchment is located in Mindanao and ranges in size from 0.9 to 85 ha. Annual rainfall in 2001 was 2,574 mm. An annual sediment yield of 52 t ha^{-1} was observed from the smallest sub-catchment (MC4) of 0.9 ha and 40 percent being cultivated or bare. The higher yield was also because the bare and cultivated portion was relatively close to the sediment trap. For larger sub-catchments, sediment yields were not more than 1 t ha^{-1} $year^{-1}$.

The Vietnamese catchment where Dong Cao village is sited represents the typical cultivated mountainous uplands with slopes ranging from 15 to 60 percent. The altitude varies from 125 to 700 m above sea level. The main crops are cassava, taro, peanut, rice, maize, forest plantation such as eucalyptus, *Acacia mangium*, cinnamon, etc. The sub-catchments varied from 4.8 to 96 ha. With an annual rainfall of 2,000 mm in 2001, sediment yields ranged from 1.6 to 4.4 t ha^{-1} in 2001 (Toan, 2001).

The MSEC study site in Laos is located in Luang Prabang Province in the northern part of the country. Luang Prabang is predominantly mountainous, consisting of hills, steep and very steep slopes (8 to more than 55 percent). Gentle slopes (0 to 2 percent) lie on narrow foothills and at the valley bottom. Elevation varies from 290 to 2,257 m above sea level. The most common soil order is Ultisol, found on slopes ranging from 8 to 50 percent. The province has a wet-dry monsoon tropical climate. The dry season (November to March) is cold and mostly dry, while the wet season (April to October) is hot and humid. The annual rainfall in 2001 was 1,230 mm, lower than the average of 1,403 mm. The sub-catchment of 1.3 ha is planted to teak and covered by bush; it had sediment yield of only 0.01 t ha^{-1} $year^{-1}$. The other larger sub-catchments of between 20 to 65 ha and cultivated to annual upland crops, yielded sediments of 2.1 to 6.4 t ha^{-1} $year^{-1}$.

In Thailand, four sub-catchments namely, Huay Mee, Huay Ma Nai, Huay Bong, and Huay Tong were delineated within the study catchment. They are approximately 10.4, 8.6, 3.7, and 6.5 ha, respectively and dominated by annual upland crops and some patches of orchard and forest.

Rainfall and Water Yield in 2002

In 2002, among the sites, the Dong Cao Catchment in Vietnam had the lowest annual rainfall of 1,090 mm. The Indonesian site had the highest at 3,136 mm (Figure 4).

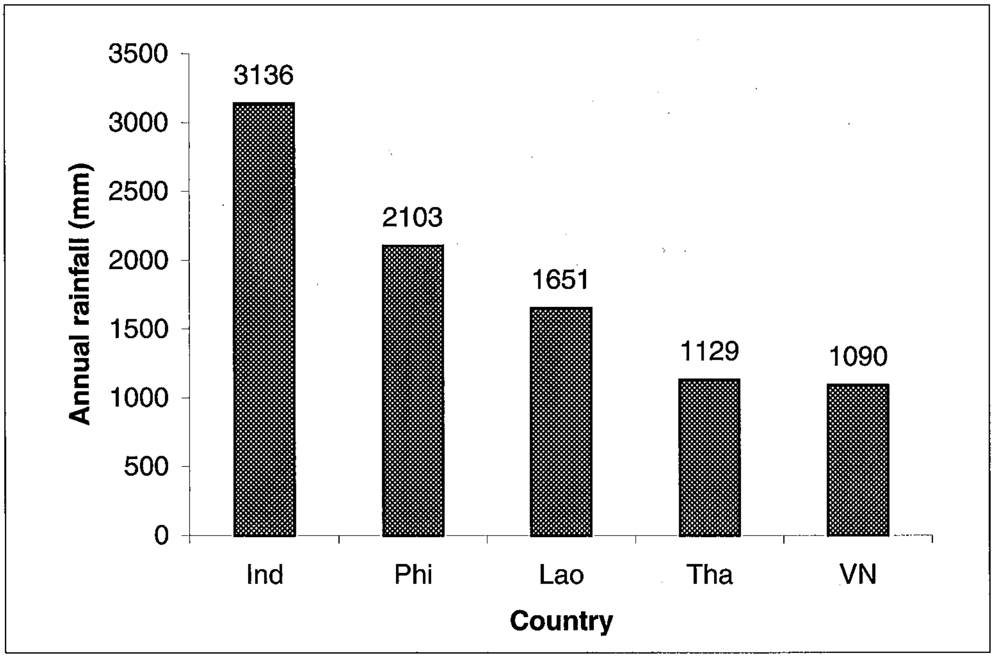


Figure 4. Annual rainfall (mm) at the different MSEC catchments in 2002

Figure 5 shows the variation in water yields expressed as runoff coefficients, R (%), or the fraction of rainfall that flows as runoff and reaches the measuring gauges of the different catchments and sub-catchments. They represent the sum of the direct runoff and the sub-surface flow and thus direct comparison of the management system and catchment size effects could not easily be made.

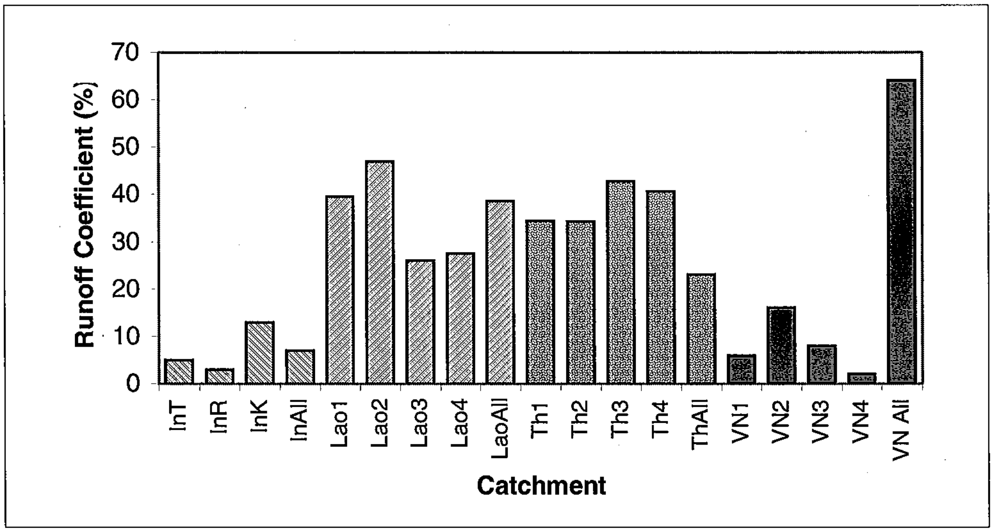


Figure 5. Runoff coefficient values (%) of the different MSEC catchments in 2002

The Indonesian sub-catchments were among the lowest, especially the Tegalan (InT) and Rambutan (InR) sub-catchments with R values values of 5 and 3 percent, respectively. With a land use system similar to the Rambutan sub-catchment, the Kalisidi sub-catchment had a much higher runoff coefficient of 13 percent. This seems to have reflected only the direct runoff because there was almost no tailing observed in the hydrographs of these two small sub-catchments (Figure 6). The hydrograph of Kalisidi was skewed indicating the effects of the long travel time of runoff water and/or the presence of sub-surface flow that reappeared on the soil surface near the measuring gauge Agus *et al.* (2002). The Babon Catchment (InAll) has a perennial stream, and its small total flow may have resulted from the unaccounted volume of water piped out for household use in the nearby village.

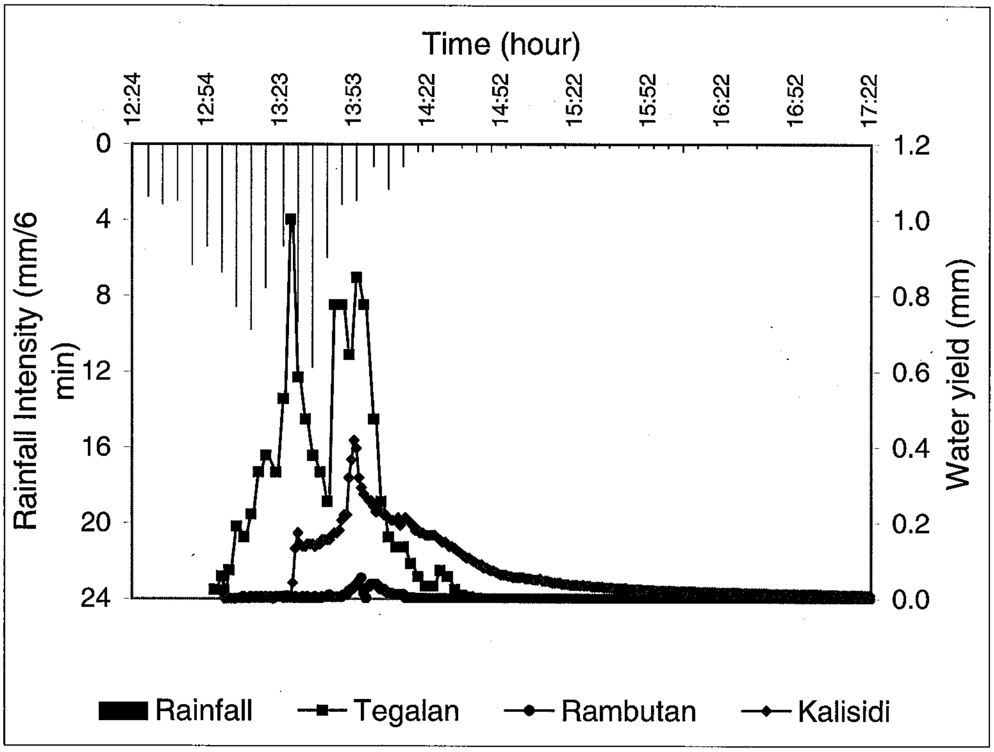


Figure 6. Hydrographs of Tegalan, Rambutan, and Kalisidi sub-catchments in Indonesia (rainfall event on 15 December 2001 with 102 mm)

The runoff coefficient of the Lao catchments was expected to be relatively high because of the perennial nature of the stream combining base flow and direct runoff. However, for the intermittent stream of the Thai catchment, the runoff coefficients seem to be high and the data currently available are insufficient to explain this phenomenon. Inclusion of soil property data and hydrographs of selected rainfall can better explain this observation. Although annual rainfall in the Vietnamese catchments was much smaller than that in the Indonesian catchment, the runoff coefficient was higher.

The runoff coefficient data (Figure 5) and hydrographs for the Indonesian case (Figure 6) clearly show the effect of land use systems on the hydrological response of each catchment.

The Tegalan Catchment planted to intensive annual crops had a higher R value and was more responsive (transmitting rainfall into runoff more readily) to rainfall than the Rambutan and Kalisidi sub-catchments with perennial tree cover. There was a shorter lag time between the peak of rainfall and the peak of discharge in the Tegalan Catchment than in the other two sub-catchments. Runoff also stopped earlier after the rain. The Rambutan sub-catchment was very nicely covered, not only by rambutan trees, but also by natural vegetation and a tree litter layer on the floor. Near its outlet, an area of about 5 percent of the sub-catchment was bush fallow. These conditions have resulted in high infiltration and low runoff even with a high amount (102 mm) and intensity of rainfall during this particular event.

Sediment Yield and Land Use

Sediment yields vary from catchment to catchment, with the highest of 24 t ha^{-1} $year^{-1}$ observed in the small (0.9 ha), cultivated, partially bare and grassland sub-catchment in the Philippines. This was followed by the Tegalan sub-catchment (InT) planted to annual upland crops (partially converted to fodder grass planting in 2002) in Indonesia, with sediment yield of 10 t ha^{-1} $year^{-1}$ (Figure 7). Sediment yield from InT was much greater than InR and slightly higher than InK; the latter two are dominated by rambutan trees. Although the Kalisidi Catchment in Indonesia was also covered by rambutan trees, about 30 percent of the orchard floor had been intensively cultivated to annual crops by the local villagers. This has created an erosion-prone zone as indicated by the higher sediment yield of the Kalisidi Catchment. The high proportion of suspended sediment in InK is an indication of the more dispersed aggregates in the exposed (intensively tilled) lower part of the catchment.

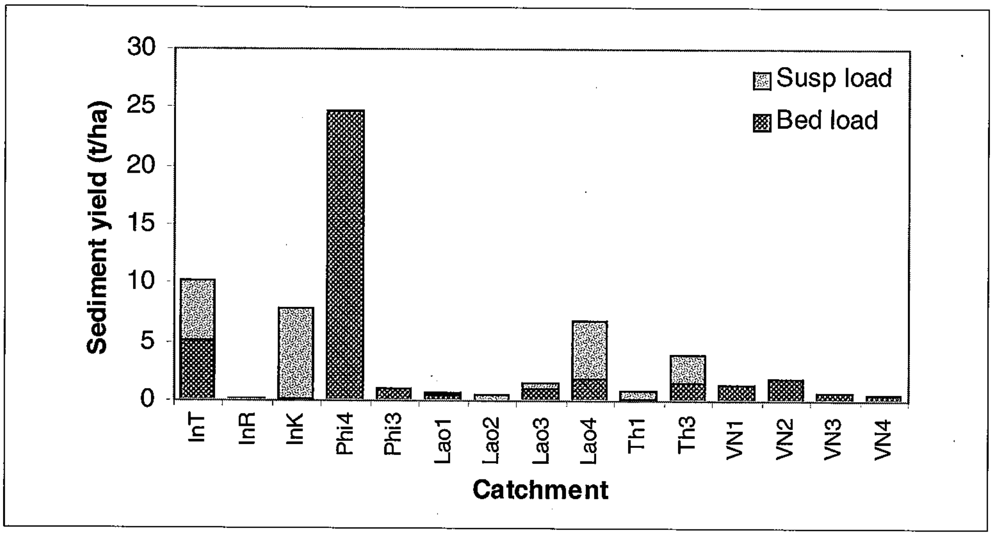


Figure 7. Sediment yields of selected MSEC catchments in the rainy season of 2002 (Nov. 2001 to April 2002 in the case of Indonesia)

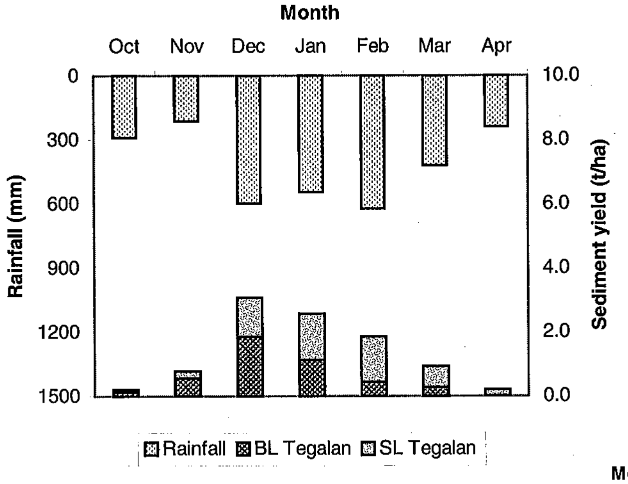
Lao catchments in general were used for shifting cultivation and bush fallow, especially in the lower sub-catchments (Lao3 and Lao4) and therefore sediment yields were relatively high for these two catchments compared to other Lao catchments.

In general, intensively cultivated catchments were observed to have higher sediment yields than other land uses. However, more specific and localized conditions, such as those in the Kalisidi sub-catchment in Indonesia, determine to a large extent the land susceptibility to erosion and this fact reemphasizes the importance of integrating the human dimension in formulating policies for natural resource management. As in the case of Lao4 and InK sub-catchments, equal attention should be given to the more open/exposed areas near the catchment outlet which greatly affect the total sediment yield. In developing soil conservation recommendations, this area near the catchment outlet (and this translates to the zone along the stream) should be paid more attention.

The Special Case of Indonesian Land Management Systems

Grass strips for annual upland crop-based catchment vs. cultivation at the floor of the orchard

Figure 8 illustrates more clearly the positive effect of grass cover in controlling erosion as exemplified by the Tegalan sub-catchment. As opposed to the cultivation of the orchard floor of the Kalisidi sub-catchment, there was less sediment yield in the former sub-catchment.



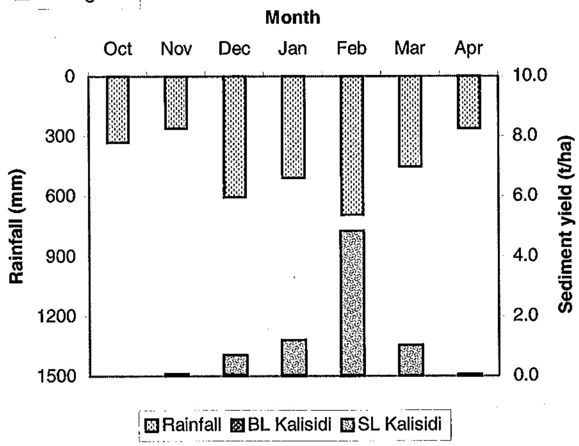


Figure 8. Monthly rainfall and sediment yields in the Tegalan and Kalisidi sub-catchments in Indonesia (measured from October 2001 to April 2002)

In December 2001, there was 600 mm of rainfall in the area, about 450 mm in January 2002 and 620 mm in February 2002. It was observed that the corresponding monthly water discharge from the sub-catchments followed the same pattern as the rainfall, also increasing from December 2001 to February 2002. Monthly sediment yields, however, did not follow the water yield pattern but showed the influence of the management systems. The planting of fodder grass in December 2001 (as part of the introduced option) combined with zero tillage in the Tegalan sub-catchment improved the catchment filter function with time as shown by the decrease in sediment yields in the succeeding months. For the Kalisidi sub-catchment, the monthly sediment yields followed those of the water yield pattern. These results confirm the effectiveness of the grass system in improving the filter function of the catchment. The planting of grass hedgerows in combination with cattle fattening, not only decreased erosion, but also promises higher profits. Hence, the system became the most preferred practice by the farmers (Watung *et al.*, 2003).

Soil Loss from Terraced Paddy Fields

Paddy fields, because of the terrace and dike system (Figure 9) can function as a filter for transported soil sediment in a landscape. In many cases, runoff from the upland system feeds into cutoff drains or irrigation canals. From here, it feeds into the terraced paddy system where the sediments and nutrients contained could be deposited. Despite this possible conservation function of paddy fields, not much is known about quantifying sediment transport into and out of a paddy field system.

Figure 9. Terraced paddy field, shortly after tillage (puddling), showing suspended sediment in a few terraces down slope

A recent study by Kundarto *et al.* (2002) showed that sediment transport in the paddy system is very small (<1.5 t ha^{-1} $season^{-1}$) and more than 50 percent of the paddy field erosion was associated with tillage operation (Table 2). Water flow in the system only occurred when the water level in the fields exceeded the normal water level (5-10 cm) during tillage and the vegetative stage of the rice plant. Thus, regulating and keeping the water from flowing to the lower terraces can further minimize sediment transport especially during tillage.

Table 2. Amount of sediment entering and leaving a series of 18 terraced paddy fields (size between 12 to 358 m2 and total area of 2,515 m2) during two rice cropping seasons (31 October 2001 to 31 January 2002 and from 16 March to 1 July 2002).

Variable	Cropping sSeason	
	First	Second
Duration of observation (day)	62	69
Sediment budget:		
Total sediment entering the system from irrigation canal (t /ha-1)	3.4 1)	6.2 1)
Total sediment leaving the system (t /ha-1)	1.4	0.8
Total sediment leaving the system during tillage operation (t /ha-1)	0.7	0.6
Net sediment deposition (t /ha-1)	2	5.4

Source: Adapted from Kundarto et al. (2002)
1) These values may have been overestimated because of the difficulty in controlling the water level in the erosion canal and that in the first terrace.

During and a few hours after tillage, mud from tilled terraces was transported to only a few terraces downslope. This means that particles reaching the stream originated from only a few plots/fields nearby. The general slope of this terraced paddy field is about 25 percent, but the level bench terraces and dike system could have minimized its effect on erosion. Table 2 also shows that if the irrigation water is loaded with sediments, most of these sediments would be deposited in the field, implying the filtering ability of the paddy fields to erosion in a landscape.

Conclusions and Recommendations

- Catchments with good filter systems such as orchards and forest with natural undergrowth or catchments planted to grass showed better control of erosion as compared to catchments used for intensive annual crops or perennial trees, but with cleared undergrowth. Tree cover *per se* without floor contact-cover such as litter and undergrowth cannot guarantee good erosion control.
- Mitigating sedimentation is very much influenced by the location of the erosion control measures which serve as filters. The zone along the stream is critical and needs to be covered with a good filter for stream protection. Conservation recommendations should emphasize the improvement of vegetative filters along the streams.
- Erosion from paddy fields is negligible compared to that from annual upland farming systems of similar general slope, and paddy fields can function as sediment filters in a landscape.

Acknowledgement

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Nutrient Loss and the On-site Cost of Soil Erosion under Different Land Use Systems

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Abstract

Nutrient loss and the on-site cost of soil erosion were evaluated in the MSEC study catchments in Indonesia, the Philippines, Vietnam, and Lao PDR. Nutrient loss by erosion was calculated from the production of sediment yield and nutrient concentration in the sediment. The on-site costs associated with nutrient loss were calculated as the equivalent cost of fertilizer materials that would be needed to replace the lost nutrients. In Indonesia, an additional study on nutrient lateral transport in a lowland rice system was conducted. Farmers' practice (45 kg N ha^{-1} crop^{-1}) and the improved technology (90 kg N, 40 kg P, and 50 kg K ha^{-1} crop^{-1}) were compared in terms of nutrient inputs (gains) and outputs (losses). Nutrient inputs included those coming from fertilizers, returned rice straw, and irrigation, while losses included crop removal and erosion. The changes of nutrients in the soil were not taken into account. Results show that in general high nutrient yield (especially N and K) was associated with intensive annual upland farming systems. Assuming that nutrient loss by erosion could be replaced with fertilizer application, the calculated cost of major nutrients was about US$27 per year as observed in the 0.9 ha sub-catchment planted to annual upland crops in the Philippines. The major proportion of nutrient loss in lowland rice farming was by crop removal as shown in the Indonesian case. Phosphorus and N were contained more in the rice grain while K was mostly in the rice straw. Except for P in the improved practice, the balances of N, P, and K were all negative, both in the farmers' practice and the improved technology. Recycling of a major portion (such as two-thirds) of the rice straw may solve the problem of K depletion.

Introduction

Over recent years, there has been improving awareness of the threat to agricultural sustainability and the general environment of soil erosion by water. Erosion by water, which is defined as the wearing away of the land by running water, has been a problem since time immemorial (Sys, 1989). Today, soil erosion threatens several million hectares of land in the world. In the Philippines, Lao PDR, Vietnam, and Indonesia, soil erosion has been identified as a major threat to sustainable agriculture in steep land areas (Agus *et al.*, 2001, 2002; Duque *et al.*, 2002; Phommasack *et al.*, 2002; Toan *et al.*, 2002). It causes negative on- and off-site environmental, economic, and social impacts.

On site, soil erosion reduces the chemical fertility of the soil through nutrient and organic matter depletion, and in some cases, could expose the acid subsoil. Erosion also damages the physical fertility by removing surface soil, reducing the soil depth, and decreasing water

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holding capacity. Ultimately, it reduces crop yields, farm incomes, and household nutrition (Agus *et al.*, 2002; Duque *et al.*, 2002; Phommasack *et al.*, 2002; Sukristiyonubowo *et al.*, 2001; Toan *et al.*, 2002).

Recognizing this problem, the Management of Soil Erosion Consortium (MSEC) initiated a collaborative project in Indonesia, Lao PDR, Nepal, the Philippines, Thailand, and Vietnam, with funding support from the Asian Development Bank (ADB). This paper reviews and discusses nutrient loss and costs as a consequence of water erosion in four countries, namely, Indonesia, the Philippines, Vietnam, and Lao PDR. It also presents the nutrient lateral transport in a lowland rice system in Indonesia.

Methodology

Measurement of Nutrient Loss and On-site Cost

In this project, soil loss or sediment yield represents the sum of bedload and suspended load, which are measured every rainfall event. Bedload was collected in the sediment trap with V-notch weirs, equipped with an automatic water level recorder and staff gauges. Since the sediments have different chemical composition due to different settling velocities, daily sampling of sediments for chemical analysis in the laboratory was done separately for the bedload and suspended load. In the case of Indonesia, selection was done taking into consideration rainfall amount and intensity and current farmers' activities. For other countries, nutrient contents in the bedload samples were determined periodically based on composite samples, but some countries like the Philippines were unable to take into account the soluble nutrient content in runoff water.

Sediment concentration was determined in the laboratory by oven drying a known volume of sediment samples and calculated by the following formula (Ciesiolka and Rose, 1998):

$$\textit{Sediment concentration} = \frac{\textit{Oven dry weight of sediment}}{\textit{Volume of sample (sediment + water)}}$$

Suspended load is then calculated as:

$$\textit{Suspended load = discharge x sedimentation concentration}$$

Nutrient loss is calculated as the product of soil loss and concentration of nutrients in the sediment (Hashim *et al.*, 1998):

$$\textit{Nutrient loss = soil loss x nutrient concentration in sediment}$$

The on-site costs associated with nutrient loss were calculated by determining the equivalent cost of fertilizer materials needed to replace the lost nutrients (Agus and Sukristiyonubowo, 2002). The fertilizer price referred to the current price of fertilizers in Indonesia.

Nutrient Balance in a Paddy Rice System

In this initial study, nutrient balance was calculated as the difference between inputs (nutrient gains) and outputs (nutrient loss). Nutrient inputs were counted from fertilizer addition, irrigation, and recycled rice straw, while nutrient losses were calculated from the soil loss by erosion and nutrient removal through harvest. The concentrations of N, P, and K were measured from rice grain and straw, soil, water, and suspended sediment samples and used in the nutrient balance estimates. The changes of nutrients in the soil were not taken into consideration.

Measurement of soil erosion was started from land preparation (plowing, harrowing, and puddling) to rice harvest. Since the study focused on soil and nutrient loss, samples of suspended sediment were taken from the main outlet, that is, the last terrace where the runoff went before flowing out to the river. A rating curve for the relationship of water level and water discharge of the inlet (where the water from the canal came to the first terrace) was determined as the product of water velocity (measured using the float method) and the cross-sectional area of the flowing water at the gauge. The discharge at the main outlet was determined using the tipping bucket method. During land preparation, suspended samples were taken every 10 minutes, starting from the first runoff flowing out of the V-notch of the main outlet until the color of suspension became almost the same as that of the water coming into the inlet. These samples were used to analyze the concentration of sediment. Selected suspended sediment and irrigation water samples were analyzed in the laboratory to determine the concentrations of N, P, and K. Selection was based on rainfall and farmers' activities. The daily water level was monitored three times, at 08.00, 12.00, and 16.00. Soil and nutrient loss were calculated using the formula mentioned above.

The estimate of nutrient balance was made for two simple treatments: farmers' practice, and improved technology. Most farmers in this village added only urea (about 45 kg N ha^{-1} cropping^{-1}). The improved technology considered the rate recommended by the Food Crop Institute at District Level which is 90 kg N, 40 kg P, and 50 kg K ha^{-1} cropping^{-1}. The study was conducted for two rice cropping seasons (31 October 2001 to 31 January 2002 and from 16 March to 1 July 2002). An estimate of the nutrient balance was also done for a system where 66 percent of the rice straw is recycled.

Results and Discussion

Profile of Selected Catchments

Table 1 shows some attributes of the catchments and sub-catchments in Indonesia, Lao PDR, the Philippines, and Vietnam. It also shows some runoff and erosion data in 2002.

Indonesia

The site in Indonesia is located in Ungaran sub-district, Central Java Province. The catchment is relatively close to urban development such that farming constitutes the second or third source of income. Annual rainfall of 3,800 mm in 2000/2001and 3,136 mm in 2001/2002 is considerably higher than that in other countries. Moreover, the rainfall amount was above the annual average of 2,800 mm. In spite of the high rainfall, the proportion of runoff relative to rainfall (runoff coefficient) was less than 14 percent (about 3-13 percent) indicating the high infiltration capacity of the soils at the site. Sediment yields in 2001/2002 were 0.2, 7.8, 10.2, and 6.1 t ha^{-1} year^{-1} for Rambutan, Kalisidi, Tegalan, and Babon catchments, respectively. For the Tegalan sub-catchment, dominated by cassava, sediment yield in 2000/2001 was about 20 t ha^{-1} year^{-1} and this was attributed to the relatively exposed surface soil, sparse litter cover, intensive tillage, steep slopes, and small catchment size. In 2001/2002, when about 60 percent of the area was planted to fodder grass (Benggala grass and King grass) and the rest to

Table 1. Characteristics of MSEC catchments in four countries in 2002

Catchment	Area (ha)	Rainfall (mm)	Runoff Coef.	Sediment yield	Soil order/ Subgroup	Land use/farming system	Dominant slope	Fertilizer application ($kg\ ha^{-1}$)
INDONESIA								
Tegalan	1.1	3,136	5	10.20	Andic Eustropept	Cassava (40%), fodder grass (60%)	45-47	For fodder grass: 100 urea, 100 TSP and KCl
Rambutan	0.9	3,136	3	0.20	Andic Dystropept	Rambutan, shrub	22–55	406 urea; 420 TSP; 658 KCl[1)]
Kalisidi	13	3,136	13	7.80	Andic Dystropept	Rambutan	22–55	406 urea; 420 TSP; 658 KCl[1)]
Parshall flume	285	3,136	7	6.10	Typic Tropaquept	All + rice	0–55	For rice only 100 kg urea
PHILIPPINES								
MC 1	24.9	2,102	2	0.00	Ultisol	Falcata, bamboo, grassland (98%), vegetables, and root crops (2%)	15-20	2 bags chicken dung and 6 bags complete fertilizer 14-14-14
MC 2	17.9	2,102	7	0.08	Ultisol	Forest, grassland (85%), cropland, shrubs (10%)	10-25	2 bags chicken dung and 6 bags complete fertilizer 14-14-14
MC 3	8	2,102	4	0.00	Ultisol	Grassland (75%), cultivated (15%), settlement (10%)	15-20	2 bags chicken dung and 6 bags complete fertilizer 14-14-14
MC 4	0.9	2,102	-	24.70	Ultisol	Grassland, trees (60%) Cultivated and bare (40%)	10-15	2 bags chicken dung and 6 bags complete fertilizer 14-14-14
Whole	84.5	2,623	4.44	1.07	Ultisol	Grassland, bamboo, Eucalyptus, etc 80%; vegetable and root crop (20%)	15-20	2 bags chicken dung and 6 bags complete fertilizer 14-14-14

VIETNAM								
W 1	4.8	2,035		4.40	Ultisol	Cassava, grass	25-40	-
W 2	9.4	2,035		3.90	Ultisol	Cassava, *A. mangium*	30-35	-
W 3	5.2	2,035		2.90		Cassava, taro, *A. mangium*	40-45	-
W 4	12.4	2,035		1.60		Cassava, *A. mangium*, Secondary forest	35-40	-
MW	96.0	2,035		1.90		Cassava, arrow root, sec.	20-25	-
LAOS								
S0	1.3	1,651	8.7	0.58	Ultisols Alfisols	69% bush fallow 31% teak	25	-
S1	19.6	1,651	31.4	0.72	Ult, Alf, Ent	76% bush fallow, 14% forest and teak, 9% annual and 1% perennial crops	29	-
S2	32.8	1,651	39.8	0.59	Alf, Ult, Entisols	80% bush fallow, 15% forest and teak 2% annual and 3% perennial crops	27	-
S3	51.4	1,651	67.1	1.47	Alf, Ent, Ult	60% bush fallow, 10% forest and teak 20% annual and 10% perennial crops	25	-
S4	60.2	1,651	44.8	6.83	Alf, Ult, Ent	53% Bush fallow, 43% forest, teak 2% annual and 2% perennial crops	28	-

1) Fertilizer application for rambutan *(Nephelium lappaceum)* was stopped in 1999 until mid-2001 because of encroachment by villagers. In November 2001 the company resumed the fertilization and regeneration of some trees

cassava, the sediment yield was only 10.2 t ha^{-1} $year^{-1}$. This may be due to better soil protection by fodder grass, less intensive tillage, and less soil disturbance during grass cutting and cassava harvesting. For the Kalisidi sub-catchment, sediment yield was doubled compared to the previous year. The reason was that in 2001/2002, all the cassava planted in the lower 1-2 ha area of the sub-catchment had been harvested (Agus *et al.*, 2000; Agus *et al.*, 2002). (Cassava has been planted by the local villagers since 1999; they claim a right to the land dating back to the Dutch colonial era.)

The Philippines

The Philippine catchment with an area of 85 ha is located in Mindanao Island. Annual rainfall was 2,907, 2,906, and 2,102 mm in 2000, 2001, and 2002, respectively. For the sub-catchments with an area of more than 8 ha, sediment yield was only 1 t ha^{-1} $year^{-1}$. Sub-catchment MC4 with an area of 0.9 ha and 40 percent cultivated or bare, had an annual sediment yield of 52, 29, and 25 t ha^{-1} in 2000, 2001, and 2002, respectively. These high values could be due to the close proximity to the sediment trap of the bare and cultivated area (Duque *et al.*, 2002). Otherwise, this value seems to be extremely high for catchment-scale measurement

Vietnam

The Vietnamese catchment has an annual rainfall of about 2,000 mm. It represents the typical cultivated mountainous uplands with slopes ranging from 15 to 60 percent. The altitude varies from 125 to 700 m above sea level. The main crops are cassava, taro, peanut, rice, maize, forest plantation such as eucalyptus, *Acacia mangium*, cinnamon, etc. Water from catchment streams is used for irrigation of 10 ha of paddy in Dong Cao village. With catchment sizes ranging from 4.8 to 45.5 ha, annual sediment yield ranged from 1.6 to 4.4 t ha^{-1} (Toan *et al.*, 2002).

Lao PDR

The MSEC study site in Laos is located in Luang Prabang Province, about 400 km north of Vientiane municipality. Luang Prabang is predominantly mountainous, consisting mostly of hills, steep and very steep slopes (8 to more than 55 percent) while the flat and gentle slopes (0 to 2 percent) represent less than 1 percent of the area and lie on the foothills, at the valley bottom. The elevation varies from 290 to 2,257 m above sea level. The most common soil order is Ultisols (*Soil Taxonomy*), which is found on slopes ranging from 8 to 50 percent. The province has a wet-dry monsoon tropical climate. The dry season (November to March) is cold and mostly dry, while the wet season (April to October) is hot and humid. The annual rainfall varies from year to year. In 2001, the annual rainfall was 2,153 mm but 1,661 mm in 2002. Sub-catchments of less than 1 ha and predominantly planted with annual crops yielded 2.5-5.7 t ha^{-1} $year^{-1}$ of sediments. Larger catchments ranging from 20 to 65 ha with annual upland crops and teak as their land use had sediment yield of 0.72-6.83 t ha^{-1} $year^{-1}$ (Phommasack *et al.*, 2002). This means that areas with annual crops, which are intensively farmed, tended to have high sediment yields.

Nutrient Loss by Erosion

Inherently, soil differs in fertility. However, human activities can easily manipulate and improve soil fertility through the addition of fertilizers, manure, amendments, and application of soil conservation measures. The amount of soil and nutrient loss could be an indicator of how effective the farmers manage their land.

The loss of nutrients was less in 2002 than in 2001 (Table 2). The most likely reason was the lower rainfall and soil loss in 2002 in all countries. In both 2001 and 2002, the highest N loss of 144 and 37 kg N ha^{-1} $year^{-1}$, respectively, was shown by MC-4 (the catchment planted to an annual upland crop) in the Philippines. As described earlier, this sub-catchment is less than 1 ha and intensively cultivated. The second highest loss was in the Tegalan sub-catchment in Indonesia. The N loss was 21 N ha^{-1} $year^{-1}$ in 2001 and 5 N ha^{-1} $year^{-1}$ in 2002. Incidentally, this is also a small sub-catchment and cultivated to annual upland crops.

Table 2. Nutrient losses from different MSEC catchments in 2001 and 2002

Catchment	Nutrient loss (kg ha^{-1} yr^{-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

The Tegalan sub-catchment in Indonesia showed the highest loss of P in both years. There was a loss of about 6 kg P ha^{-1} $year^{-1}$ in 2001 and 1.8 kg P ha^{-1} $year^{-1}$ in 2002. Considering that no external P input had been applied before the introduction of the fodder grass in late 2001 and the area was intensively cultivated with cash crops (maize, peanut, and cassava) that require high P, this level of loss may quickly deplete soil P.

The highest K loss in 2002 was in W1 sub-catchment in Vietnam at 4.7 kg K ha^{-1} year^{-1}. In 2001, this occurred in the Tegalan sub-catchment in Indonesia with a loss of 9 kg K ha^{-1} year^{-1}. The loss of K almost corresponds to the soil and N losses in the four countries. Interestingly, the pattern was almost the same as in 2001. Higher soil loss results in higher N and K losses.

On-site Cost of Soil Erosion

On-site cost as an end result of erosion varies among the countries. It depends on the total nutrient loss and the price of fertilizer. In 2002, the MC4 sub-catchment in the Philippines which had the highest N and second highest K loss presented the highest on-site cost of erosion (Table 3). This was followed by W1 of Vietnam, which had the biggest K loss, and then Tegalan of Indonesia, which had the highest P loss and the second highest N loss. The on-site cost was US$27.13, 9.50, and 8.48 ha^{-1} year^{-1} for the Philippines, Vietnam, and Indonesia respectively. These values mean that the farmers must pay as much as US$27, 10, and 8 ha^{-1} year^{-1} to replace the nutrients lost due to erosion. These costs were lower than those in 2001 which were about US$12 to 68 ha^{-1} year^{-1} (Agus and Sukristiyonubowo, 2002). The cost in 2002 was lower by 21 to 51 percent of the cost in 2001.

Table 3. 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
Parshal 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

From these data, it can be concluded that except in MC4 in the Philippines, nutrient loss and on site-cost were relatively smaller under the no or little fertilizer input. However, the data of soil loss signalled that MC4 in the Philippines, W1 of Vietnam, and Tegalan of Indonesia have soil loss higher than the permissible value of 2-11 t ha^{-1} $year^{-1}$ for agricultural lands (El-Swaify, 1989). Improved catchment management including additions of fertilizer and application of soil conservation measures should therefore be given priority to improve land productivity. Sediment yield from catchments of less than 1 ha and intensively planted to annual crops also reminds us of the importance of soil conservation to maintain better land productivity.

Nutrient Balance in Paddy Fields in Indonesia

Table 4 shows the total dry matter production (grain and straw) from two cropping seasons of rice under the farmers' practice and improved technology. Compared to the farmers' practice, the use of improved technology gave higher yields of rice grain and straw even if the second cropping was attacked by pests. The data also indicate that the improved technology increased the N, P, and K contents of grain and straw (Table 5). This information could be useful in evaluating the potential of recycling the rice straw to improve the nutrient balance in the soil.

Table 4. Rice grain and straw yield from the first cropping (February to March 2002) and second cropping (April to May 2002) at Babon Catchment, Indonesia

Production (t ha^{-1})	**Treatment**			
	Farmers' practice		**Improved technology**	
	1st crop	2nd crop	1st crop	2nd crop
Rice grain				
4.6	4.5	5.7	3.7*)	
Rice straw fed to cattle	2.7	2.6	4.1	5.2
Rice straw recycled	4.7	4.5	3.4	4.1

*) Pest attacks: rats and stink bugs (walang sangit)

Table 5. N, P, K content of the rice grain and straw under the farmers' practice and the improved technology

Component	**Nutrient content (%)**					
	Farmers' practice			**Improved technology**		
	N	**P**	**K**	**N**	**P**	**K**
Rice grain						
1.44	0.22	0.23	1.55	0.24	0.25	
Rice straw fed to cattle	1.02	0.08	1.91	1.09	0.13	1.88
Rice straw recycled	0.79	0.06	0.81	0.82	0.05	0.84

Nitrogen balance

In both the farmers' practice and improved technology, the N balance was in the negative, -71 and -93 kg N ha^{-1} $year^{-1}$, respectively (Table 6). This means that the N gain was less than the N loss. For the farmers' practice, the amount of added fertilizer urea was considered low (only

50 kg ha^{-1}). According to Wade *et al.* (1988), 100 kg urea or 45 kg N must be applied to satisfy the nutrient requirement of rice. Of the total N loss, about 91 percent was due to crop removal (68 percent to the grain and 32 percent to the rice straw used as cattle feed). The total N gains in the improved technology was higher than in the farmers' practice, but the N loss was much higher bringing a larger negative balance. Of the total N loss, about 93 percent was taken out by the crop harvest (about 59 percent in the rice grain and 41 percent in the straw fed to cattle). Of the total rice straw produced, about 45 to 63 percent had been used to feed the cattle. It follows that about the same percentage of N in the straw is lost in each harvest.

Table 6. Nitrogen balance of lowland rice fields based on two rice crops (October 2001 to June 2002)

Component	**Nitrogen balance (kg ha^{-1} yr^{-1})**	
	Farmers' practices	**Improved technology**
Gains:		
1. Fertilizer	45	90
2. Irrigation	22	22
3. Rice straw	73	62
Total gains	140	174
Losses:		
1. Removal by harvest:		
- Grain	131	146
- Rice straw	61	102
2. Soil Loss:		
- Suspended load	19	19
- Bedload	-	-
Total losses	211	267
Balance	- 71	- 93

Phosphorus balance

The addition of 100 kg TSP per season improved the balance of phosphorus. A positive 10.4 kg P ha^{-1} year^{-1} was estimated for the improved technology compared to the -18.82 kg P ha^{-1} year^{-1} for the farmers' practice (Table 7). The P gain in the improved technology was mainly due to the addition of fertilizer. Since the grain component has the highest P concentration and all is consumed, addition of P fertilizer becomes necessary to maintain soil fertility.

Potassium balance

As for N, both the farmers' practice and improved technology gave a negative K balance, –53 and –65 kg K ha^{-1} year^{-1}, respectively (Table 8). The use of rice straw as feed for cattle may have largely contributed to K loss. An equivalent amount of 103 and 171 kg K ha^{-1} year^{-1} was lost as cattle feed in the farmers' practice and improved technology, respectively. Because of the high K content of the rice straw, the K loss by crop removal was relatively high. Total input in the farmers' practice was mainly from irrigation and recycled straw (which was quite low). In the case of the improved technology, input from fertilizer addition did not improve the balance of K in the soil. Losses, especially through harvesting, were 193 kg K ha^{-1} year^{-1} (most of which was through rice straw removal) while the total gain was lower at 139 K ha^{-1} year^{-1}. Recycling of most, if not all of the rice straw, and application of manure or KCl fertilizer may improve the K balance in the soil.

Table 7. Phosphorus balance of lowland rice fields based on two rice crops (October 2001 to June 2002)

Component	Phosphorus balance (kg ha^{-1} yr^{-1})	
	Farmers' practices	**Improved technology**
Gains:		
1. Fertilizer	-	40.0
2. Irrigation	6.1	6.1
3. Rice straw	5.5	4.7
Total gains	11.6	50.8
Losses:		
1. Removal by harvest:		
- Grain	20.1	22.2
- Rice straw	4.3	12.1
2. Soil Loss:		
- Suspended load	6.0	6.1
- Bedload	-	-
Total losses	30.4	40.4
Balance	- 18.8	+ 10.4

Table 8. Potassium balance of lowland rice fields based on two rice crops (October 2001 to June 2002)

Component	K-balance (kg ha^{-1} yr^{-1})	
	Farmers' practices	**Improved technology**
Gains:		
1. Fertilizer	-	50
2. Irrigation	11	11
3. Rice straw	75	78
Total gains	86	139
Losses:		
1. Removal by harvest:		
- Grain	26	22
- Rice straw	103	171
2. Soil Loss:		
- Suspended load	10	11
- Bedload	-	-
Total losses	139	204
Balance	- 53	- 65

Recycling the rice straw

The nutrients contained in the rice straw can alter their balance if they are returned back to the soil. This can also substitute for even a small portion of chemical fertilizer requirement for rice, which is not subsidized by the government. The proposed recycling of 66 percent of the total rice straw produced can improve the balance of these nutrients in the soil. The expected gains from this system would be about 110 kg N, 11.2 kg P, and 166 kg K ha^{-1} $year^{-1}$ for the improved technology and 88 kg N, 6.6 kg P, and 111 kg K ha^{-1} $year^{-1}$ for the farmers' practice. The nutrient loss would be 45 kg N, 5.6 kg P, and 83 kg K ha^{-1} $year^{-1}$ for the improved technology and about 44 kg N, 3.3 kg P, and 55 kg K ha^{-1} $year^{-1}$ for the farmers' practice (Table 9).

Table 9. Estimated nutrient gains and losses with 66% of rice straw yield recycled

Component	Farmers' practices (kg ha^{-1} yr^{-1})			Improved technology (kg ha^{-1} yr^{-1})		
	N	P	K	N	P	K
Gains:						
Recycled rice straw	88	6.6	111	110	11.2	166
Losses:						
Removed rice straw	44	3.3	55	45	5.6	83

Using the nutrient gains from fertilizers and irrigation and the nutrient losses from rice grain removal and soil loss, recycling of 66 percent of the straw produced would yield a balance of +12 kg N, +23 kg P, and +112 kg K ha^{-1} $year^{-1}$ for the improved technology and –39 kg N, +17 kg P, and +30 kg K ha^{-1} $year^{-1}$ for the farmers' practices (Table 10). In terms of economics, this would save the farmers about US\$120 (with the price of urea at about US\$0.27, TSP US\$0.33, and KCl US\$0.33 kg^{-1}). Thus, recycling at least 66 percent of the rice straw combined with the addition of inorganic fertilizer at the recommended rate can be a good strategy to improve and maintain soil fertility.

Table 10. Estimated balance of nutrients in lowland rice fields with 66% of rice straw yield recycled

Treatment	Nutrient balance (kg ha^{-1} yr^{-1})		
	N	P	K
1. Rice straw is used for cattle feed:			
- Farmers' practice	- 71	- 18.8	- 53
- Improved technology	- 93	+ 10.4	- 65
2. 66% of rice straw recycled:			
- Farmers' practice	- 39.3	- 16.7	+ 30
- Improved technology	+ 12.4	+ 23.4	+ 111

Conclusion

High nutrient yield (especially of N and K) in general is associated with intensive annual upland farming systems. Assuming that nutrient loss with erosion will be replaced with fertilizer application, the cost of replacing the loss of the major nutrients could be as high as US$27 per year. This was observed in a small sub-catchment planted to annual upland crops in the Philippines.

For paddy rice farming, based on the Indonesian evaluation, the major proportion of nutrient loss was through crop harvesting. Nitrogen and P were higher in the rice grain while the rice straw contained high K. This means that while fertilizer input for K could be alleviated by recycling the rice straw, P and N loss through crop removal needs to be replaced with fertilizer or organic matter application.

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Soil Erosion and Land Use in the Dong Cao Catchment in Northern Vietnam

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Abstract

The general goal of MSEC is to support farmers to conserve land and water resources, minimize natural resource degradation, and alleviate poverty through the enhanced adoption of sustainable land and water management systems on sloping lands. During the last three years, soil erosion management research has been conducted in the Dong Cao Catchment in northern Vietnam. The site has an area of 45 ha and is cultivated mostly to cassava. It was equipped to measure water budget, soil loss, and soil and water quality. There was a high annual variability of soil loss (from 1-15 t ha^{-1} year^{-1}) and this depends on both the amount and intensity of rainfall and the kind of land use. For example, soil loss in 2001 was six times more than the other years. The year 2001 had the highest total annual rainfall and a large proportion of the catchment was cropped with cassava. The suspended load measured during a rising flow showed that it can be even higher than the bedload and represents a large proportion of the total soil loss. Farmers in Dong Cao village are now more aware of the impact of land use on soil loss and soil fertility decline. Dialogue with farmers and different stakeholders from the local government, agricultural institutes, and research programs has been conducted to develop better understanding of how river basins respond to socio-economic changes.

Introduction

Soil erosion is commonly observed in sloping lands especially in the tropical zones of Southeast Asia. Farming and other economic activities in these areas have become environmentally unsustainable causing deleterious on- and off-site effects. While there have already been many studies conducted on soil erosion control and management, the results have not had any significant impact on sustaining upland development. It is now recognized that soil erosion cannot be studied in isolation from agricultural practices, but as part of a more complex problem including both biophysical and socio-economic considerations.

In 1999, the Management of Soil Erosion Consortium (MSEC) initiated a project aimed at developing and promoting sustainable and socially acceptable community-based land management options through a participatory and interdisciplinary approach in six countries in Asia, with support from the Asian Development Bank (ADB). The approach considered the catchment as the unit of study to develop soil conservation practices that are economically

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acceptable to farmers; to promote better land management decisions at the field and basin levels; and to encourage knowledge sharing across national and disciplinary boundaries. In essence, the catchment has served as a field laboratory for research and capacity building with local partners.

In Vietnam, the research was conducted on a 45 ha catchment on the sloping area of Tien Xuan commune, Luong Son District, Hoa Binh Province, 80 km from Hanoi, inside the Red River Basin (Figure 1). The Red River Basin is now confronted with the increasing challenges of water scarcity, population increase, and environmental degradation. The catchment was furnished with instrumentation for soil erosion and hydrological monitoring to evaluate the interactions between rainfall, runoff, groundwater, topography, soil quality, land cover, and climate to assess and predict the impact of land use and land management on soil losses, soil fertility, and solute transport in and through the watershed. This paper presents the results of three years of observation and monitoring of the biophysical and socio-economic changes in the Dong Cao Catchment in Vietnam. An attempt was made to relate its hydrological behavior with soil erosion, land use, and farm productivity.

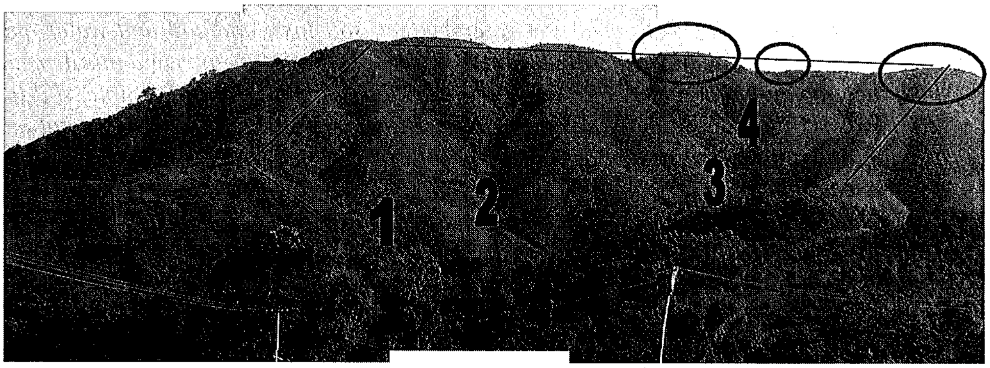

Figure 1. Overview of Dong Cao Catchment from the north (in June 2001). Watershed limit (red line) and mountain peaks (encircled in pink). The numbers indicate location of weirs

Approach and Methodology

The Study Site

The study site is about 45 ha and cultivated by farmers from Dong Cao village with mainly cassava in association with some trees (*Venitia montana, Acacia mangium*). The farmers (around 40 farm households and 200 inhabitants) share their work time between the lowlands to crop irrigated rice and the uplands to augment their income. The mean slope is 45 percent and the steepest slopes of around 120 percent are situated in the middle part of the basin, which is largely cultivated. The watershed was equipped to collect meteorological and hydrological data and evaluate soil losses on the sloping lands (Figure 2). The methodology for site characterization and instrumentation, data collection, monitoring and analysis for the evaluation of the on- and off-site effects of erosion was described in Toan *et al.* (2001).

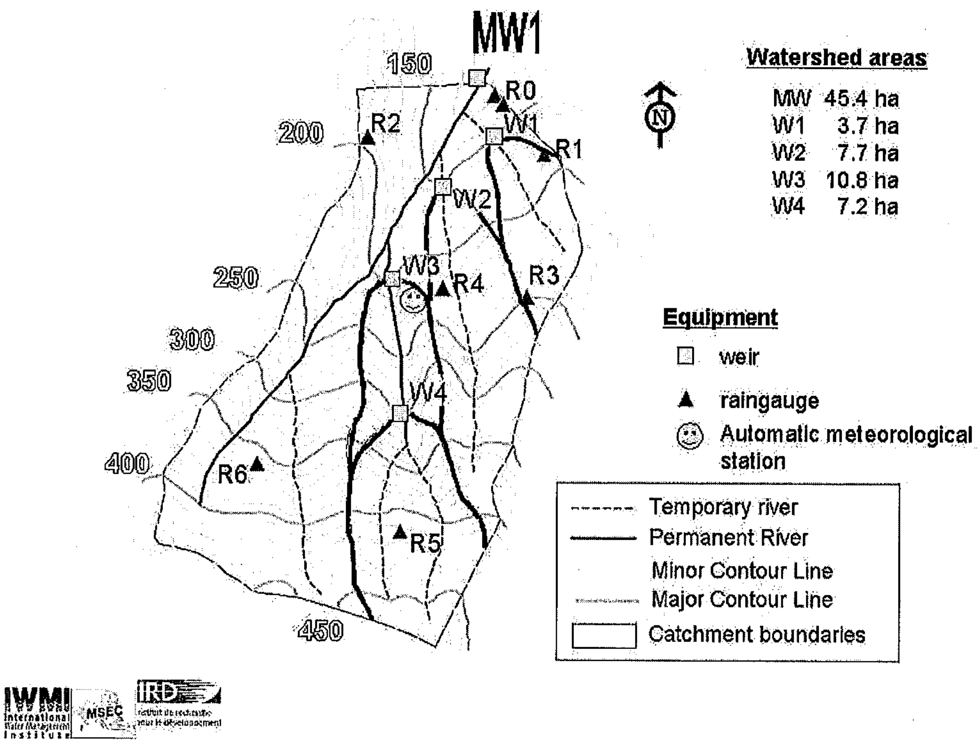

Figure 2. Distribution and location of equipment in the Dong Cao Catchment

Data Collection and Analysis

The catchment has four sub-catchments, identified as W1, W2, W3, and W4. Sub-catchments W1, W2, and W3 were equipped with sediment traps and weirs before they intersect with the main stream. One weir (MW) is on the main stream at the outlet of the catchment, and another (W4) is on the upper part inside the catchment above W3. Each sub-catchment has the same drainage intensity of around 8 m km^{-2}. The water level in each weir was recorded automatically (every five minutes) using Orphimedes-type automatic water level recorders. Water discharge calibration was also done. The total bedload sediments from each trap were weighed twice a month if it rained. Some soil, water, and sediment samples were analyzed at the NISF laboratory for chemical and physical properties. In 2002, three automatic sediment samplers (ASS) were set respectively on the main weir, W2 and W4. Since it was impossible to collect the water samples from each weir, the suspended sediment samples were collected only from the main weir and during four storm events. A survey via informal discussions with local farmers and key informants of the village was conducted to collect information from individual households on socio-economic conditions and agricultural practices.

Land Management Options

The hedgerow cropping system, a promising control practice, was introduced by the project as a land management option to reduce erosion and increase income. In this system, rows of shrubs, grasses, or perennial crops were planted at regular intervals across the slope of the field. Traditional crops are grown in the alleys between the hedgerows. The year 2002 was the last year for the diagnostic phase of catchment calibration. So now, new agro-ecological techniques have been proposed for evaluation in 2003. Moreover, a new weir has been installed to expand the results to a larger scale of around 120 ha.

Results and Discussion

Catchment Description

Soil distribution

The soils of the Dong Cao site have been mapped and represented as one single unit. The parent rock is volcanic-sedimentary schist, sometime presenting hard layers. The soil is deep (> 0.80 m) on hilltops and generally shallow (40-50 cm) on convex areas. Roots can however penetrate deeper through soft weathered rock beds between harder schist layers.

Very nice apparent runoff crusts with embedded stones occur on rectilinear slopes, especially on convex forms below matured cassava plants. This crust forms after weeding, which prevents the growth of new weeds. Soils located at surrounding summits where land is not totally cleared and with minimal erosion have a well-differentiated dark horizon. Other soils located on slopes or at the top of low hills (left bank, downstream of W3), show a very weak vertical differentiation of color, texture, and structure. The X-ray determination of four surface soil samples showed the strong predominance of kaolinite. This clay is accompanied with a very small amount of illite.

Climate

The climate of northern Vietnam (situated between 16 and 18 °N) is humid sub-tropical. The representative meteorological station of Dong Cao village is the Hoa Binh station, where the annual average is around 1,500 mm (average for 1961-2000). The main climatic characteristic is the strong yearly monsoon. In general, 80 percent of the rainfall occurs between May and October with a maximum in August. This season is also marked by a high rainfall hourly intensity of around 20-60 mm h^{-1}. During the winter, the air temperature is low, around 16-17°C between December and February; the monthly rainfall is less than 50 mm. Air humidity is high, often above 90 percent despite the low amount of rain.

The monthly rainfall has also a high interannual variability. For example, in August, the rainfall for the month could vary from 150-450 mm. Indeed one of the characteristics of the North Vietnam climate is its strong instability, which makes weather forecasting difficult. Thus, when the monsoon winds from the southwestern section are weakened by winds coming from Laos, periods of dryness can occur during the months which are usually the rainiest. The El Niño phenomenon also has an impact on the climate of this area: it leads to a period of dryness during the summer and a shift of the rainy season to September or October. In 1983, which was an El Niño year, it was dry in June, but October was especially humid (450 mm of rainfall against 150 mm in an average year). The rainfall deficit in June during the vegetable growing period has major consequences for the crop yields, since rainfall occurs when it is not needed.

This significant climatic variability creates some difficulties for farmers' food and income stability. Furthermore, at the beginning of the rainy season, all factors increasing the erosion process are present in the Dong Cao Catchment. These include high intensity rains, steep slopes, little ground vegetative cover, and inappropriate cultivation practices that generate erosion.

Catchment Hydrological Behavior

The monthly rainfall in the catchment showed similar behavior from 1999 to 2002 (Figure 3). The rainy season started at the beginning of April and ended in late September in 1999 and in October in other years. During the period, the Dong Cao Catchment was marked by one humid year, in 2001, with a total annual rainfall of 2,540 mm. Moreover, a total monthly rainfall of more than 600 mm was observed in July. It was an El Niño year in 2002 with July being especially dry and October being especially wet. However rainfall intensity behavior did not change: on the average, 60 percent of rainfall events have had an intensity of 5-25 mm h^{-1}, 15 percent with 25-50 mm h^{-1}, 10 percent with 50-75 mm h^{-1}, and 15 percent above 75 mm h^{-1}. The strong events occurred in June, July, and August in 2001 and in October 2002. The rainfall events varied from 81 in 1999 to 131 in 2001.

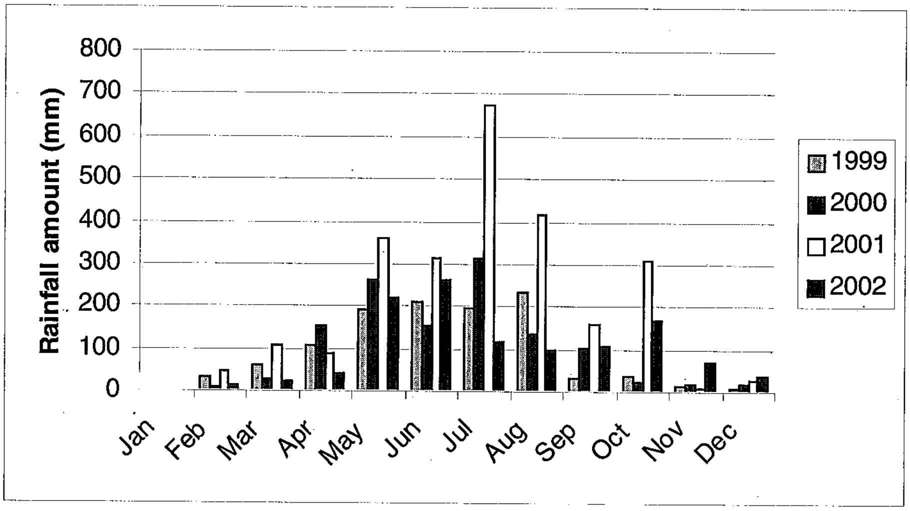

Figure 3. Monthly rainfall (in mm) in the Dong Cao Catchment from 1999 to 2002

The yearly runoff at the main outlet was around 15 L s^{-1}, with maximum flow in July and minimum flow in February. The largest monthly flow measured during 2000 to 2002 was in July 2001 with 60 L s^{-1} (Figure 4). The water volume which flowed in the stream during the whole year showed that the amount in 2001 was twice that in 2000. The runoff coefficient was about 50 percent in 2000 and 2001 and 65 percent in 2002. This means that a larger part of the rainfall in 2002 was lost by the watershed. This was certainly due to the major rainfall events in October 2002 (169 mm in five events). It was noted that the runoff coefficient was exceptionally high and the runoff of October recorded a second peak flow.

Only W3 and W4 recorded a continuous flow. In 2002, the annual runoff at the main weir (MW) was about 11.6 L s^{-1}. Runoff from W3 represents only 10 percent of this flow, while runoff from W2 and W4 accounted for 5 percent (Table 1). The runoff coefficient of these three sub-catchments ranged from 20-29 percent. The smallest sub-catchment, W1, recorded some flow only from May to July and in October. The runoff coefficient was very low indicating the high infiltration capacity of this sub-catchment, which incidentally was used for agroforestry.

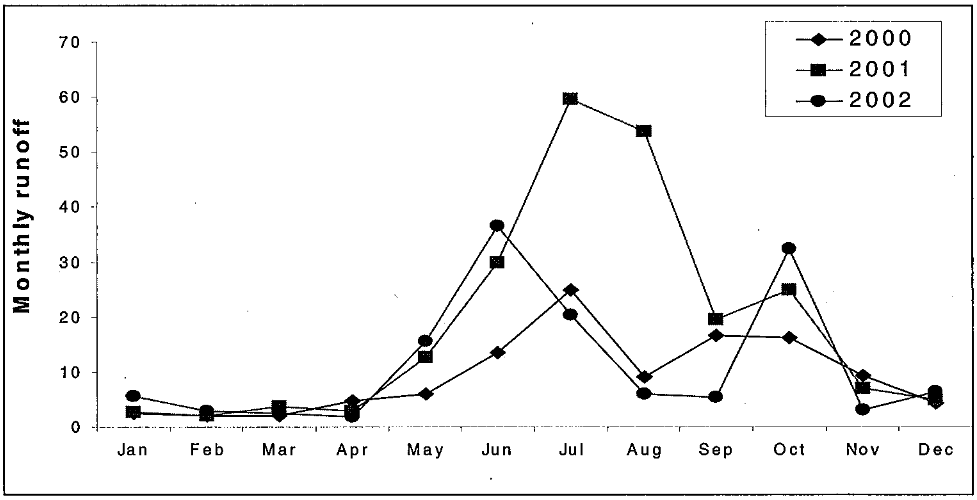

Figure 4. Monthly runoff (in L s^{-1}) in the Dong Cao Catchment from 2000 to 2002

Table 1. Monthly runoff of the main outlet and the outlets of each sub-catchment of the Dong Cao Catchment in 2002

Month	**Runoff (L s^{-1})**				
	MW	**W1**	**W2**	**W3**	**W4**
January	5.57	0.000	0.000	0.73	0.02
February	2.99	0.000	0.000	0.54	0.02
March	2.27	0.000	0.000	0.34	0.02
April	1.94	0.000	0.000	0.28	0.04
May	15.6	0.009	0.196	0.96	0.66
June	36.6	0.031	4.256	5.58	1.89
July	20.4	0.022	3.043	1.53	1.29
August	5.85	0.000	0.000	0.73	0.39
September	5.43	0.000	0.000	0.60	0.40
October	32.4	0.012	0.179	1.27	0.87
November	3.10	0.000	0.000	0.77	0.50
December	6.40	0.000	0.020	0.68	0.30
Yearly mean	11.6	0.006	0.641	1.17	0.53
Total water volume (m^3)	366,457	197	20,240	36,776	16,840
Surface area(ha)	45.5	3.7	7.7	10.8	7.2
Runoff (mm)	805	5	263	341	234
Rainfall (mm)	1,191	1,191	1,191	1,191	1,191
Runoff/rainfall ratio	0.68	0.0045	0.22	0.29	0.20

The monthly behavior of the runoff is the same for each weir (Figure 5). The rainfall had the same behavior in the entire catchment and consequently each weir showed a similar annual hydrograph in direct relation to the area of each sub-catchment, except for W1 where the flooding seemed quicker, presumably because of high infiltration.

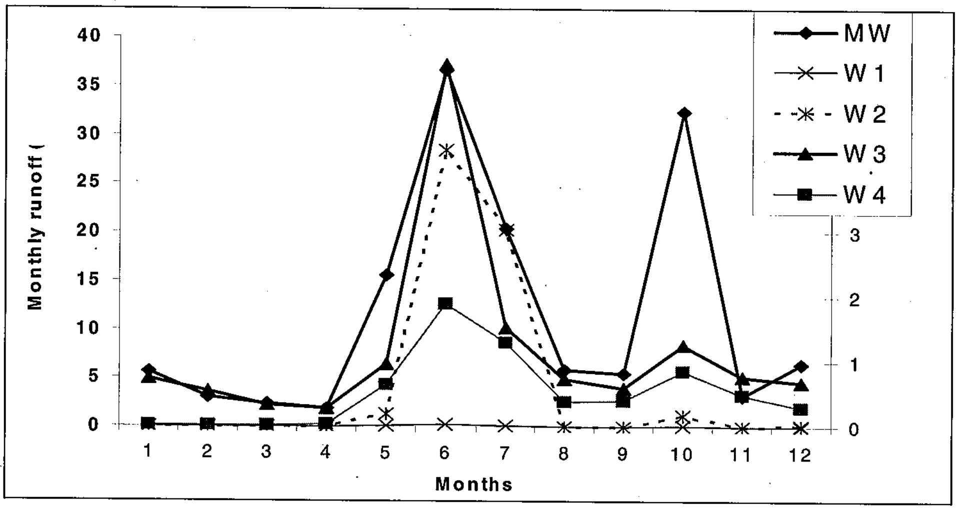

Figure 5. Monthly runoff (in L s^{-1}) during 2002 for each hydrological station of Dong Cao Catchment

The monthly runoff coefficient was very low from January to May and from August to December (around 20 percent for the main weir) and the largest part of the rainfall during this time was trapped by the soils and vegetation. Thus, the surface runoff becomes important only during June and July.

The hydrological behavior observed in the catchment showed that floods begin to occur with rainfall higher than 20 mm (and an average intensity of 50 mm h^{-1}). For example, there were only 14 rainfall events in 2002, which caused some flooding. It was also shown that the time lag between rainfall and runoff was very short, the rising runoff was maintained for about two hours on the average, and this rise took place during the night.

Soil Erosion and Nutrient Loss

Table 2 shows the total soil loss from the Dong Cao Catchment measured at the main weir. This represents the sum of the bedload and suspended load for 2001 and 2002 when measurement of the suspended load was done. No measurement of suspended load was conducted in 1999 and 2000.

Bedload

The yearly bedload measured at the main weir was estimated at 1.37 t ha^{-1} $year^{-1}$, ranging from 0.4 to 4 t ha^{-1} (Table 3, Figure 6). The observed monthly bedload for all years is shown in Figure 7. All the outlets of the sub-catchments showed the same behavior of the yearly bedload. The bedload also had a large monthly variability. The highest bedload was observed in May and July, with a range 0.2-0.3 t ha^{-1} per month. The same monthly behavior was observed in all sub-catchments.

Table 2. Total bedload measured at each weir and suspended load measured at main weir

Bedload (t ha^{-1})				
Weir (area, ha)	1999	2000	2001	2002
W1 (3.7)	0.93	1.23	6.69	1.30
W2 (7.7)	0.94	1.06	5.31	1.92
W3 (10.8)	0.43	0.37	1.59	0.78
W4 (7.2)	0.35	0.49	3.14	0.60
MW (45.5)	0.44	0.64	3.96	0.45
Suspended load (t ha^{-1})				
MW (45.5)	-	-	5.18	3.01
Total soil erosion (t ha^{-1})	0.44	0.64	9.14	3.46

Table 3. Yearly bedload measured from the outlets of the sub-catchments and main outlet of Dong Cao Catchment from 1999 to 2002

Year	**Bed load (t ha^{-1})**					
	MW	**W1**	**W2**	**W3**	**W4**	**Total**
1999	0.44	0.93	0.94	0.43	0.35	3.09
2000	0.64	1.23	1.06	0.37	0.49	3.79
2001	3.96	6.69	5.31	1.59	3.14	20.69
2002	0.46	1.30	1.93	0.79	0.60	5.08
Average	1.37	2.54	2.31	0.79	1.15	8.16

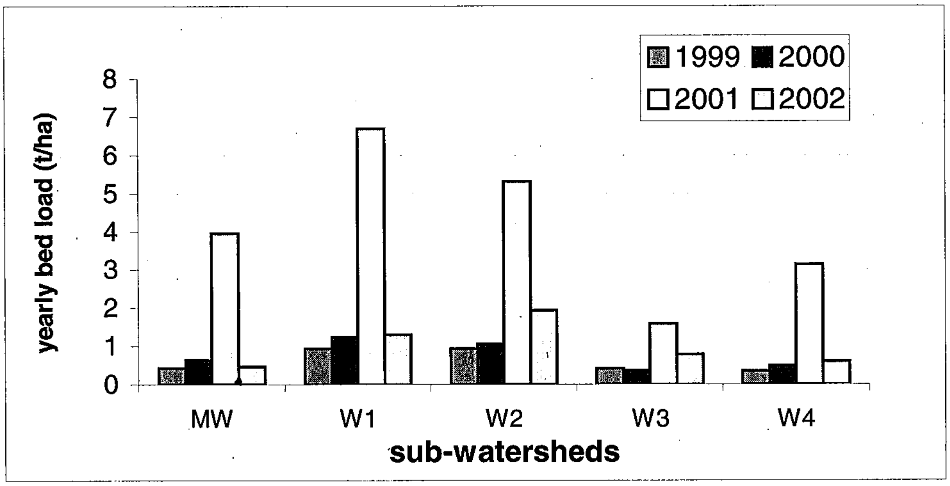

Figure 6. Yearly bed load (t ha^{-1}) from 1999 to 2002 for each weir of Dong Cao Catchment

It was observed that the bedload was relatively lower in 2002. The highest bedload was observed in W2 (2 t ha^{-1}) where cassava was planted. The other sub-catchments had bedloads of not more than 1 t ha^{-1}. This observation can be explained by the lower rainfall and the denser grass cover in 2002. Because 2002 was a relatively dry year, the area that was cultivated was smaller than the previous years and the areas earlier cultivated had been left with wild grasses. The effect of the hedgerows on soil erosion in W3 cannot however be accounted for.

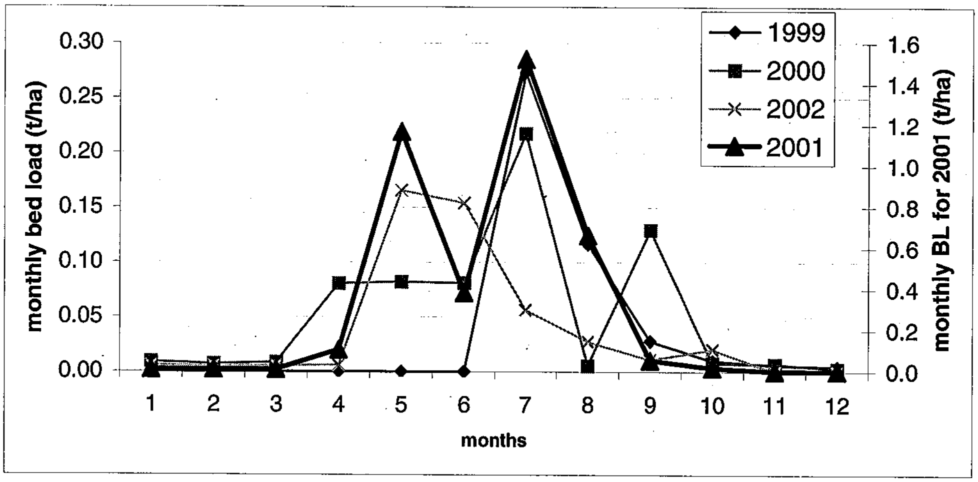

Figure 7. Monthly bedload (in t ha^{-1}) from 1999 to 2002 at main weir of Dong Cao Catchment

Suspended load

In 2002, the suspended sediments sampled from four rising events (7 July, 9 August, 30 August, 4 October) were measured on the main weir. The automatic samplers installed on W2 and W4 were not functioning. On the average, the mean suspended load during a rising period ranged from 0.9-2.9 g L^{-1} with a maximum load between 3 and 5 g L^{-1} (Table 4). This level of suspended load is high for stream water. It was noted that the suspended load remained high at around 0.5 g L^{-1} even after the discharge peak. Table 4 also shows that the highest suspended load was observed during the highest rainfall despite the fact that this occurred in October when the ground was well covered by vegetation.

Table 4. Suspended load measured at the main outlet of the Dong Cao Catchment during the rising phase of runoff at selected rainfall events in 2002

Characteristics	Event date in 2002			
	7 July	9 August	30 August	4 October
SL average (g L^{-1})	0.91	1.89	1.87	2.89
SL max (g L^{-1})	2.92	4.75	3.93	5.22
SL min (g L^{-1})	0.34	0.59	0.45	1.42
Event duration (min)	90 min	130 min	100 min	160 min
H / Q max (m) / (L s^{-1})	1.27 / 1, 120	1.04 / 120	1.02 / 76	1.1 / 305
H / Q min (m) / (L s^{-1})	0.87 / 8.6	0.83 / 3.5	0.82 / 2.6	0.82 / 2.6
Water volume (L)	1, 470 l	190 l	130 l	260 l
Rainfall amount (mm)	40 mm	20 mm	20 mm	64 mm

Figure 8 shows the behavior of the suspended load during the rising event of 9 August. This behavior was also observed in the other events, the maximum load occurring before the water peak and then decreasing in direct relationship with the water level decrease.

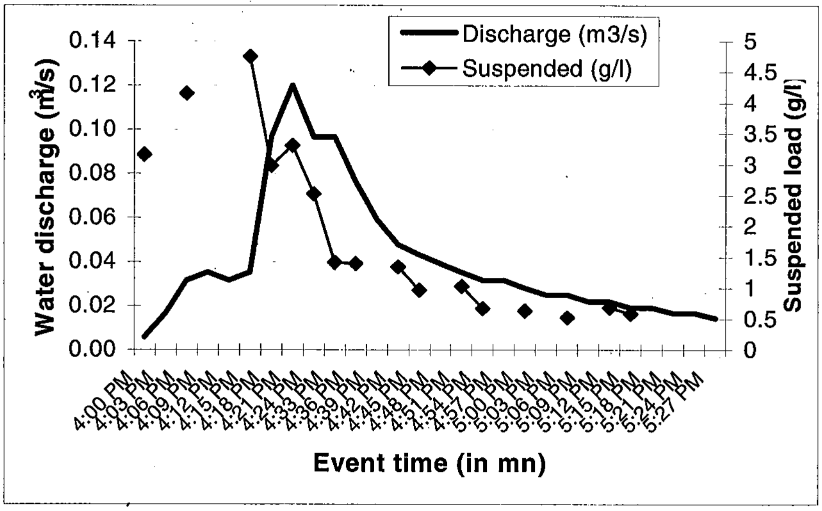

Figure 8. Suspended load (in g L^{-1}) during a rising event (August 9, 2002) in the main weir of Dong Cao Catchment

The suspended load measured in 2001 was estimated at 2.5 t ha^{-1} on the average compared to 3.4 t ha^{-1} in 2002. The value for 2001 was almost the same as the bedload while the suspended sediment was eight times the measured bedload in 2002. Thus, these few measurements of suspended load indicate the significance of this component in evaluating soil erosion in the Dong Cao Watershed.

Nutrient loss

Table 5 shows that the amount of suspended sediments carried by the runoff water measured at the main weir contained substantially higher amounts of nutrients than those contained in the bedload. In 2001, 380 kg ha^{-1} of OM, 21 kg ha^{-1} of N, 20 kg ha^{-1} of P_2O_5, and 8 kg ha^{-1} of K_2O were lost through water erosion. These amounts correspond to only 254, 7, 9, and 6 kg ha^{-1} of OM, N, P_2O_5, and K_20, respectively. The same trend was observed in 2002 but with a very much higher proportion of lost K_2O. This observation clearly indicates that soil erosion causes nutrient loss, which causes soil fertility decline on site and ultimately low crop yields and farmers' income.

The nutrients contained in the suspended sediments could be carried further down to rivers and reservoirs. In the study site, the Dong Cao River flows to the Cua Khau Reservoir. An analysis of the sediment samples from this reservoir showed some 1.6 percent OM, 0.15 percent N, 0.1 percent P_2O_5, and 1.3 percent K_2O (Table 6). These amounts are comparable with the nutrient contents in the uplands and the lost soil. In fact, it contains more OM and potassium than the upland soil. This shows that erosion seems to concentrate the fertility of the soil downstream.

Table 5. Total nutrient loss from the Dong Cao Catchment

	Nutrient in bedload (kg ha^{-1})											
	2000				2001				2002			
	O C	N	P_2O_5	K_2O	OM	N	P_2O_5	K_2O	OM	N	P_2O_5	K_2O
W1	58.1	1.6	3.4	2.2	342.5	16.5	16.8	7.8	26.3	3.5	1.3	5.7
W2	49.6	1.8	3.4	3.4	297.4	14.5	15.3	4.0	45.1	4.6	1.9	2.1
W3	18.3	0.9	1.3	1.2	86.8	4.7	4.9	1.7	15.5	1.6	0.9	1.7
W4	26.8	1.4	1.6	1.8	210.7	7.9	10.1	3.3	11.7	1.1	0.7	1.0
MW	20.1	1.0	1.7	2.5	253.8	7.3	9.1	6.4	8.4	0.9	0.5	0.9
Nutrient in suspended load (kg ha^{-1})												
MW	-	-	-	-	379.7	21.2	19.7	8.3	52.7	5.4	2.1	51.5

Table 6. Nutrient content of the suspended load (SL) and bedload (BL) sampled at the main weir, soil sample from W3, and the sediment sample from the Cua Khau Reservoir

Sample analyzed	Nutrient content (%)			
	OM	N	P_2O_5	K_2O
Suspended load (SL) from main weir	1.75	0.18	0.07	1.71
Bedload (BL) from main weir	1.95	0.22	0.10	0.2
Sediment from Cua Khau Reservoir	1.59	0.15	0.09	1.32
Soil sample from W3				
surface	1.12	0.17	0.24	0.09
middle	1.23	0.22	0.29	0.07

Land Management and Soil Erosion

Before 1970, the whole watershed was covered with primary forest. Deforestation led to the complete disappearance of the forest in the early 1980s. Since 1986, annual crops have been cultivated on the uplands with cassava as the most important crop. This indicates that the fertility of the soil is already low. It also shows that farmers do not give priority to farming the upland areas but simply use them to augment their income. They prefer to cultivated rice in the lowland areas.

In 1999, about 78 percent of the area of the catchment was cultivated to upland crops and about 5 percent was left forested. The forest species are *Venicia montana* (a small forest area of 0.9 ha near W1 at the bottom of the watershed) and 1.5 ha of eucalyptus on the left side of the main stream and covering a hill. Only cassava and a small area of taro were cultivated. These crops did not receive any fertilizers unlike the rice crops planted downstream.

In 2000 and 2001, the main annual crop was again cassava, representing more than 50 percent of the total watershed area (Figure 9). There was only about 0.35 ha of arrow root fields just below W2. The natural grass (10 ha, i.e. 22 percent of the total watershed area) was situated on the top of the watershed. In 1999, all the cassava was cultivated alone on the slope. In 2000, with the help of the government program and the MSEC program, some hedgerows of *Tephrosia candida* were planted on contour lines in W3. The farmers received financial support to plant *Acacia mangium* in association with cassava, on 9 ha in 2000 and 2 ha more in 2001. There was not much difference in the land use between 2000 and 2001. It is important to underline that there was no fallow during these two years.

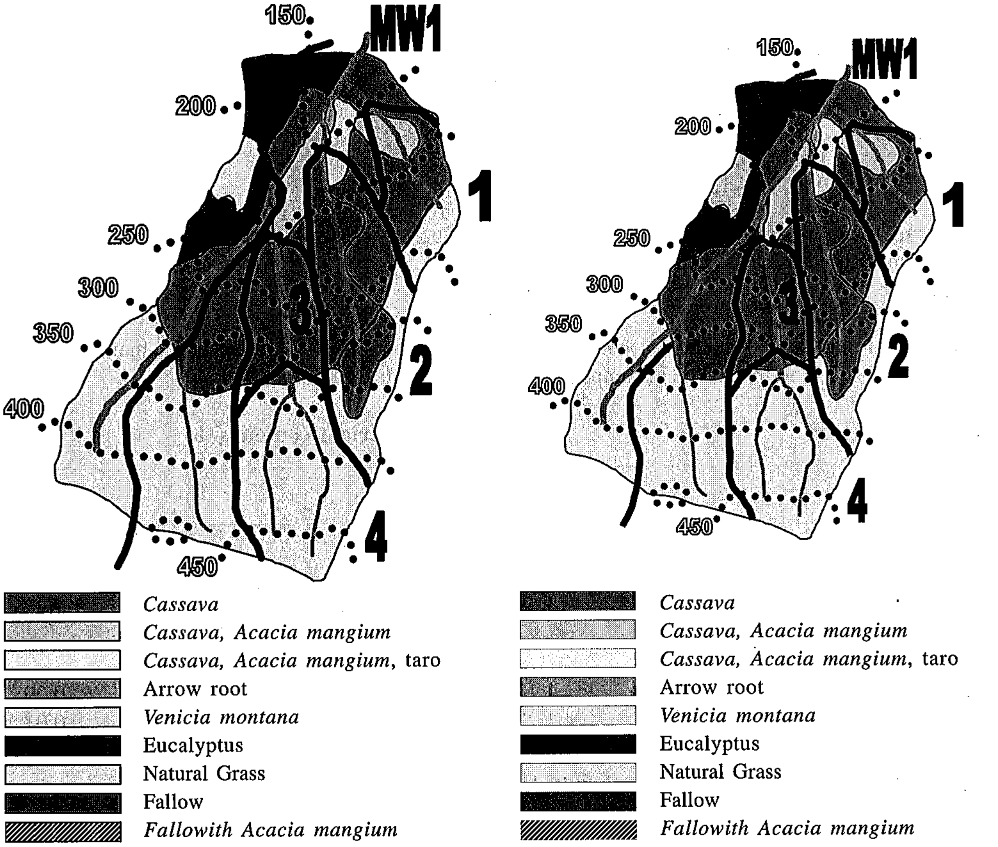

Figure 9. Land use in the Dong Cao Catchment for 2000 and 2001 (the legend in red shows what the use is). The dotted line is the contour line with indicated elevation in m

A large area was left fallow in 2002 and the area cultivated to annual crops was very much smaller (Figure 10). There was no cultivated area of cassava intercropped with *Acacia mangium* and cassava intercropped with taro during this year. There was only a small area (5 percent) cultivated to cassava monoculture in W2. The completely fallow area was about 14.8 ha (32 percent) and fallow with *Acacia mangium* of 11 ha (24 percent). The main reason for this large fallow area was the low and late rainfall in 2002. As mentioned earlier, this condition of the land use could have brought the lower erosion during the year. The highest bedload was observed in W2 (2 t ha^{-1}) where cassava was planted. The other sub-catchments had bedloads of not more than 1 t ha^{-1}.

Based on the observations of the hydrological behavior and soil erosion in the catchment and dialogue with the farmers, a number of land management options were introduced. These were: 1) contour planting of annual crops; 2) annual crop cultivation with hedgerows of *Tephrosia candida* and *Vetiveria zizanioides*; and 3) agroforestry, intercropping *Acacia mangium* with cassava. The effect of these options cannot yet be evaluated since little time has elapsed since their introduction. In addition, the high weather variability complicates the situation. The significant change in land use in 2002 made the evaluation of the effect of the hedgerows in W3 difficult.

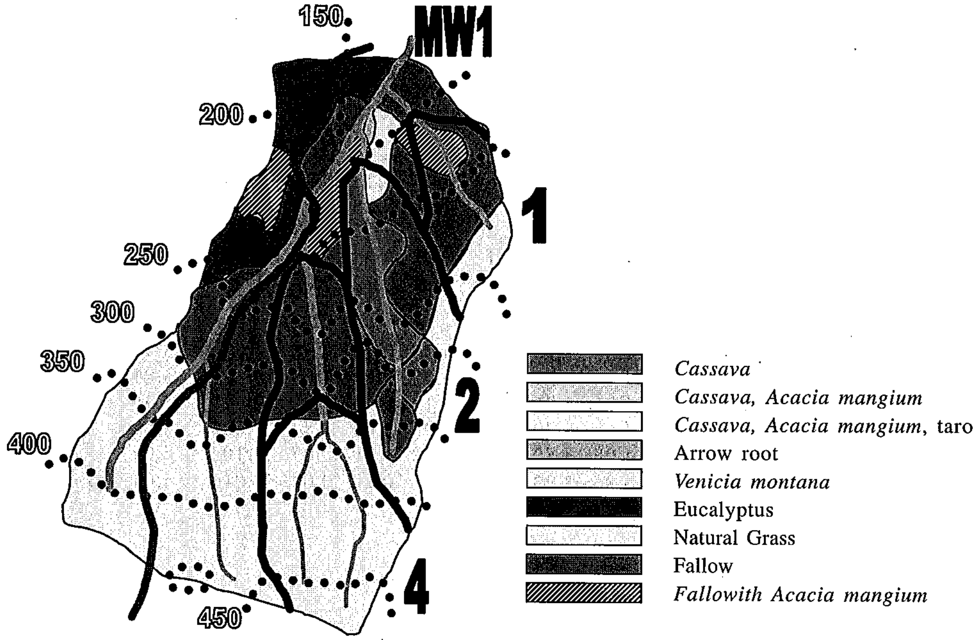

Figure 10. Land use in the Dong Cao Catchment for 2002 (the legend in red shows what the use is). The dotted line is the contour line with indicated elevation in m

Soil Erosion and Farm Productivity

Farming is the main source of livelihood of the people living in the watershed. Activities in the watershed are mostly undertaken in the middle slope of the watershed, where the slope is steep. The areas in the foothills already have low fertility because of long-term cultivation. Therefore, farmers move up to the middle part where the velocity of surface water runoff and erosion are lower. There is no more scope to move further up as this area should be maintained as forest land. Thus, in order to meet the increasing food demand, farmers need to take care of their own land and improve its soil fertility by using appropriate technologies for sustainable production.

Table 7 indicates that from 1999 to 2002 all indicators of soil fertility in the cultivated land as well as in the forest land of W3 are very low, especially organic carbon, nitrogen (N), phosphorus (P_20_5), and potassium (K_20). This nutrient content was generated by continuous cultivation and inappropriate methods to control erosion. From 1999 to 2002, the soil nutrients slightly increased. However, they are still inadequate for good plant growth and yield. Nevertheless, there are good signals that the soil condition can still be improved.

Table 7. Soil chemical properties of sample taken from W3 from 1999 to 2002

Year	Depth (cm)	Sample location	pH		Total (%)				Available elements (mg 100 g^{-1} soil)		Exchangeable cations (mg 100 g^{-1} soil)	
			H_2O	KCl	O C	N	P_2O_5	K_2O	P_2O_5	K_2O	Ca++	Mg++
Middle part of soil profile in W3												
1999	0-20	Cultivated land	4.60	3.86	1.05	0.09	0.16	0.36	1.56	7.70	1.10	1.01
		Forest land	4.50	3.6	0.62	0.09	0.13	0.99	1.58	4.51	0.56	0.41
2001	0-20	Cultivated land	4.98	3.82	1.28	0.19	0.28	0.04	1.08	4.52	3.85	3.07
		Forest land	4.75	3.86	2.40	0.15	0.09	1.18	1.29	4.52	3.07	2.36
2002	0-20	Cultivated land	4.95	3.79	1.12	0.17	0.24	0.09	1.15	5.21	3.97	3.07
		Forest land	4.79	3.83	1.19	0.12	0.12	0.08	1.09	5.03	3.74	3.24
Lower part of soil profile in W3												
1999	20-60	Cultivated land	4.80	3.90	0.89	0.06	0.14	0.36	0.99	5.90	0.50	0.06
		Forest land	4.80	3.9	0.79	0.05	0.08	1.05	0.87	3.01	0.15	0.37
2001	20-60	Cultivated land	4.91	3.96	1.71	0.13	0.24	0.06	0.82	3.76	3.84	3.84
		Forest land	4.68	3.79	2.47	0.08	0.09	1.84	1.02	4.52	3.07	2.32
2002	20-60	Cultivated land	4.98	3.82	1.23	0.22	0.29	0.07	1.10	5.04	3.81	3.02
		Forest land	4.86	3.73	1.28	0.17	0.24	0.04	1.01	5.01	3.63	3.15

Conclusions and Perspective

The results of three years of research and monitoring showed a high interannual variability of soil loss (from 1 to 15 t ha^{-1} year^{-1}) in the Dong Cao Catchment in northern Vietnam. Moreover, this variation depends on both the amount and intensity of rainfall and the kind of land use. Soil loss in 2001 was six times more than in the other years. It is notable that during this year, the total annual rainfall was highest and a large proportion of the catchment was cropped with cassava. There was relatively less erosion in 2002 when the rainfall was lower and the land use was significantly changed to fallow and natural grass.

The suspended load measured during a rising flow showed that it can be higher than the bedload and can therefore represent a larger proportion of the total soil and nutrient loss. The amount of nutrients that are carried away indicates the need to reduce erosion to maintain soil fertility in the uplands.

The project has proved to be very useful for farmers, not only in terms of understanding soil erosion and nutrient loss, which cause land degradation and reduce productivity, but also in terms of farmers' enhanced capacity and improved information dissemination strategies. The farmers are now more aware of the need to conserve soil fertility to sustain high agricultural productivity. Some of the technologies they have become aware of include contour hedgerow farming, agroforestry, intercropping systems, etc. Dialogue with farmers and different stakeholders from the local government, agricultural institutes, and research programs has been conducted to develop better understanding of how river basins respond to socio-economic changes. With this program of research and development, it is expected that the local government will change their thinking on soil management. The research activities in the Dong Cao Watershed have demonstrated to farmers, policy-makers, and extension workers how much sediment yield and bedload would be lost if appropriate soil and water management technologies were not used.

Reference

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Soil Quality under Different Land Uses in Kaligarang Watershed, Indonesia

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Abstract

For a small agricultural watershed in Java, Indonesia, land use specific soil quality is described. The objectives of this study were to determine statistically significant soil quality indicators using a minimum data set (MDS) and calculate soil quality indexes for different land units in a typical agricultural watershed. Field surveys were conducted to identify the biophysical conditions and to compile an inventory of land use. On the basis of ground slope, soil type, and land use, land units have been identified, which are assumed to represent typical soil quality conditions. Soil sampling for the determination of soil chemical and physical characteristics was based on these land units. Principal components' analysis (PCA) was used to identify the overall soil quality attributes for the area. Generally, the soil fertility status of the watershed is low, especially for land planted to annual food crops. Five statistically significant soil quality indicators (i.e. soil attributes) have been identified for the watershed, i.e. texture (silt), total N, water stable aggregates (WSA), soil organic carbon (SOC), and bulk density.

The study revealed that low soil quality is a major problem in the area. To address declining land productivity in the context of land degradation and sustainability of land use, land use systems and practices in the area should be examined in more detail. Locally appropriate soil fertility enhancement measures should be identified to build up overall soil quality – and hence fertility – in the area, leading to better and more sustainable land productivity under smallholder land use.

Introduction

Soil is a critically important component of the earth's biosphere, not only for the production of food and fiber but also for the maintenance of local, regional, and global environmental quality (Doran and Parkin, 1994). In Indonesia, about 20 million ha (33 percent) of arable land have been degraded into marginal land, due to inappropriate land use practices that have led to a loss of soil quality and, hence, land productivity. Because of its importance, in 1993, the US National Research Council recommended that protecting soil quality should be a fundamental goal of any national environmental program (Brejda *et al.*, 2000). The term soil quality has been defined by the Soil Science Society of America (SSSA) as "Soil quality is inherent attributes of soil that are inferred from soil characteristics or indirect observations (e.g. compactibility, erodibility, and fertility)" (Doran and Parkin, 1994). Larson and Pierce

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(1991) suggested a definition of soil quality as the "capacity of a soil to function within the ecosystem boundaries and interact positively with the environment external to that ecosystem". Several other similar definitions of soil quality have been proposed (Doran and Parkin, 1994; Diack and Stott, 2001). A more comprehensive definition of soil quality was proposed by Karlen *et al.* (1997) stating that "soil quality is the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation".

Soil quality has become an important issue. Research on soil quality has notably increased within the last decade, but there is still a significant need to develop appropriate soil quality indexes. A soil quality index helps to assess the soil quality of a given site or ecosystem and enables comparisons between the conditions at the plot, field, or watershed levels under different land use and management practices.

The objectives of this study were to identify important soil quality indicators and develop soil quality indexes for different land uses and land management practices in a typical agricultural watershed in Java, Indonesia

Materials and Methods

Description of the Site

The study was conducted at Babon sub-catchment, Kaligarang Watershed, Java, Indonesia. The altitude of the area ranges between 400 and 550 m above sea level. The research sites were on two soil orders – Alfisols and Inceptisols – that were formed by Central Ungaran ashes and volcanic rocks and originated from the Pleistocene-Holocene (quaternary) age (MSEC, 2000). The soils are well-drained, very deep (>150 cm), dark reddish brown to very dark brown friable clays. The average topsoil bulk density is 1.17 g cm^{-3}.

The area has a humid climate with tropical rainforest vegetation. According to the Schmidth–Ferguson Classification, the study area falls into climate type B (Schmidth and Ferguson, 1951). The average rainfall of the two driest months is less than 60 mm, while the average rainfall of the nine wettest months is more than 100 mm. The dry months fall between July and August, while the wet months usually fall between October and June. The mean annual rainfall of the research site is 3,181 mm (12 years of available data).

The watershed has an area of 30.7 ha, of which 17.4 ha are terraced paddy rice fields in the valley bottom. Only the remaining 13.3 ha of sloping rainfed lands are included in the study. The watershed is subdivided into three catchments with distinct land uses, i.e. (i) Kalisidi Catchment (11.2 ha) is dominated by rambutan and mixed garden cultivation; (ii) Rambutan Catchment (1.1 ha) is dominated by rambutan cultivation and some bush, which is not used; (iii) Tegalan Catchment (1.0 ha) is cultivated for annual food crops of cassava, groundnut, and maize, and also has some grassland. To reduce soil erosion in the upland crop areas, the farmers constructed forward-sloping bench terraces. These terraces are irregularly shaped. For their annual food crops, especially maize and groundnut, most farmers apply only urea (50-120 kg ha^{-1}) and farmyard manure (cattle and buffalo dung at a rate of approximately 5 t ha^{-1}), but some farmers only apply manure. For cassava, most farmers do not use fertilizers at all. For the rambutan orchards, since 1997, the manager decided to reduce the level of management of the plantation due to rising insecurity of the land holding. Therefore, no fertilizers and other chemicals were applied, leading to a reduction of yields. Previously, urea, TSP, and KCl, were applied two times a year, usually at the beginning and the end of the rainy season. For each tree, 4 kg urea, 2.5 kg TSP, and 1.25 kg KCl used to be applied.

Field Survey and Identification of Land Units

A field survey was conducted to identify the biophysical conditions of the study area and develop an inventory of land management practices, rainfall pattern, and the natural land resources. On the basis of slope, soil type, and land use, land units were identified by overlaying existing base maps. In total, 11 distinct land units have been identified in the area, i.e. three for Tegalan, three for Rambutan, and five for Kalidisi. Table 1 shows the distribution of land units and their determinants.

Table 1. Distribution of land units and their determinants

Catchment	Land unit	Total area	Slope (score*), % slope)	Description Soil type with subgroup *)	Land use
Tegalan	1	0.51	V (30-45)	Inceptic Hapludalfs	Cultivated land. Crops: cassava, maize, and groundnut.
	2	0.34	VI (45-65)	Inceptic Hapludalfs	Grasses
	3	0.13	VI (45-65)	Vertic Hapludalfs	Cultivated land. Crops: cassava, maize, and groundnut.
Rambutan	4	0.12	VI (45-65)	Vertic Paleudalfs	Bushes
	5	0.24	VI (45-65)	Typic Hapludalfs	Rambutan orchard
	6	0.76	V (30-45)	Typic Hapludalfs	Rambutan orchard
Kalidisi	7	2.69	VI (45-65)	Humic Eutrudepts	Rambutan orchard
	8	1.31	V (30-45)	Humic Eutrudepts	Rambutan orchard
	9	2.05	VI (45-65)	Ruptic-alfic Eutrudepts	Rambutan orchard
	10	1.21	V (30-45)	Ruptic-alfic Eutrudepts	Rambutan orchard
	11	3.97	V (30-45)	Humic Eutrudepts	Mixed gardens: coffee, mahogany, bamboo, banana, hibiscus, cloves, mangoes, rambutan, bushes, and grasses.

*) USDA classification system (Soil Survey Staff, 1996)

Soil Sampling and Determination of the Soil Properties

Based on the identified land units, 11 soil profiles were made. Each profile was selected on the basis of five auger holes. For each profile, composite topsoil samples were taken, air-dried, sieved through a 2 mm screen and analyzed for physical and chemical properties. For the analysis, the methods described by Westerman (1990) were used. The physical properties determined were particle-size distribution (pipette method), saturated hydraulic conductivity (double Haube permeameter), aggregate stability (dry and wet sieving method), and bulk density (core method); the chemical characteristics determined were pH in H_2O (1: 2.5 soil/water), soil organic carbon (SOC) (Walkley-Black method), total N, C/N ratio, available-P (Bray-I method), exchangeable cations K, Ca, Mg, and Na (ammonium acetate extraction at pH 7), CEC (ammonium acetate extraction at pH 7), and base saturation. From the particle-size distribution data and the soil organic matter content, the soil erodibility index (*K*-index) was calculated for each land unit using the formula developed by Kirkby and Morgan (1980).

Statistical Analysis

We used the technique proposed by Wander and Bollero (1999) and Andrews *et al.* (2002) to construct a soil quality index (SQI). The three main steps of this technique are to (i) select a minimum data set (MDS) of indicators that best represent the soil functions; (ii) score the MDS indicators based on their performance of soil functions; and (iii) integrate the indicator scores into a comparative index of soil quality (Andrews *et al.*, 2002).

To select a representative MDS for the three catchments, a principal components' analysis (PCA) of selected soil attributes was made (Doran and Parkin, 1994). Principal components (PCs) for a data set are defined as linear combinations of the variables that account for maximum variance. It was assumed that PCs receiving high values best represent system attributes (Andrews *et al.*, 2002). Therefore only the PCs with eigenvalues ≥ 1 were examined. Eigenvalues are the amount of variance explained by each factor, while communalities estimate the portion of variance in each soil attribute explained by the factors (Brejda *et al.*, 2000). Factor analysis was used to group the initially identified 18 soil attributes into statistical factors based on their correlation structure. The correlation structure of soil attributes was analyzed using bivariate correlation. Principal components' analysis was used for the factor extraction using the factor-data reduction procedure in the SPSS 10.0 (SPSS Inc.) Software.

In this PCA, each variable received a weight or factor loading that represents its contribution to the PC. As suggested by Andrews *et al.* (2002), we retained only the highly weighted variables from each PC. Highly weighted variables were defined as those within 10 percent of the highest factor loading. When more than one variable was retained within a PC, we observed their significance correlation. If these weighted variables were not correlated (i.e. $r < .60$), then each was considered important and was retained in the MDS. If the variables were significantly correlated, one of the variables could be considered redundant and, therefore, eliminated from the MDS. Among the significantly correlated variables within a PC, the variable with the highest sum of correlation coefficients was chosen for the MDS (Andrews *et al.*, 2002).

The second step was to score the MDS indicators and the conversion of the selected soil data into a 0 to 1 scale. We used two equations proposed by Diack and Stott (2001). These equations are:

$$y = (x-s)/(1.1t-s) \qquad \text{for "more is better"} \qquad [1]$$

and,

$$y = 1-\{(x-s)/(1.1t-s)\} \qquad \text{for "less is better",} \qquad [2]$$

where, y is the score of the soil data; x is the value of the soil property converted into a 0 to 1 scale value; s is the lowest possible value of the soil property, we have decided that s = 0; and t is the highest value for that soil property.

The third step was to calculate the soil quality index (SQI) using the formula described by Andrews *et al.* (2002):

$$SQI = \mathop{S}\limits_{I=1}^{n} Wi \times Si \qquad [3]$$

where W is the PC weighting factor and S is the indicator score (named *y* in Eq. 2). The weighting factor (i.e. the weight of the PC) is determined by the percent of variation in the data set explained by the PC that contributes the indicator variable (i.e. the soil attribute), divided by the total percentage of variation explained by all PCs' eigenvectors >1.

We also compared the 11 land unit means using one-way ANOVA. Treatment means' separations were interpreted from the LSD results.

Results and Discussion

Soil Properties

The soil physical and chemical properties of the different land units in the study area are shown in Table 2. To assess the levels of the chemical properties, the scales provided by Landon (1991) and Black (1965a and 1965b) were used. The soils of the watershed can generally be considered to be of low fertility. Soil pH is rated low; soil organic carbon very low; total-N low; available-P slightly low to low; exchangeable K slightly low; the levels of exchangeable Ca medium; exchangeable Mg high, and the CEC medium.

Matrix Correlation and Soil Quality Index

Significant ($p = 0.05$) to highly significant ($p = 0.01$) correlations were shown by 49 (about 32 percent) out of 153 soil attribute pairs (Table 3). These can be used for grouping soil attributes into factors based on their correlation pattern.

Table 3 shows highly significant correlations between silt content and sand content, pH, exchangeable Ca, Mg, total exchangeable bases, base saturation, and the *K*-index. It also shows that total N is highly correlated with sand content, available P, and CEC. These observations can be used to refine the factors of the PCs (see Table 4).

The principal components' analysis (PCA) identified five soil attributes contained in six PCs with an overall cumulative variance of about 88 percent. The order of significance of these soil characteristics was determined by the magnitude of their eigenvalues. These five soil attributes constitute the soil quality indicators for the MDS, which can be used to construct soil quality indexes (SQI) for the different land units. The five soil quality indicators that make up the MDS for the study area are silt content (representing texture), total N, WSA, SOC, and bulk density. The indicators and their factor loadings within their respective PCs are shown in Table 4.

The computed factor weightings were 0.38 for PC1, 0.22 for PC2, 0.14 for PC3, 0.11 for PC4, 0.09 for PC5, and 0.06 for PC6. After weighting, we scored the attributes of each principal component using Eq. [1] and [2] (Diack and Stott, 2001). We used Eq. [1] i.e. the "more is better" scoring function, for total N, WSA, and SOC, because of their positive effect on soil fertility, water partitioning, and structural stability (Andrews *et al.*, 2002). We used Eq. [2], i.e.

Table 2. Soil properties of the different land units in the study area.

Parameters	Land unit 1	2	3	4	5	6	7	8	9	10	11
Sand (%)	14 ± 1.0 bc*	21 ± 2.5 d	17 ± 3.0 cd	10 ± 1.7 ab	11 ± 2.5 ab	11 ± 2.7 ab	18 ± 1.5 cd	10 ± 1.5 ab	9 ± 1.5 a	19 ± 3.1 d	17 ± 3.5 cd
Silt (%)	39 ± 4.5 e	33 ± 2.7 d	39 ± 3.6 e	6 ± 2.1 a	3 ± 0.6 a	16 ± 3.5 b	28 ± 2.1 d	20 ± 2.0 bc	21 ± 2.7 bc	22 ± 3.1 c	30 ± 2.7 d
Clay (%)	47 ± 4.2 ab	46 ± 1.2 ab	44 ± 5.3 a	84 ± 2.3 e	86 ± 2.7 e	73 ± 5.6 d	54 ± 3.6 c	70 ± 1.5 d	70 ± 4.0 d	59 ± 5.3 c	53 ± 1.2 bc
pH (in H_2O)	5.4 ± 0.2 def	5.5 ± 0.1 ef	5.7 ± 0.2 f	5.2 ± 0.2 bcd	5.0 ± 0.1 abc	4.9 ± 0.2 ab	5.2 ± 0.2 cde	4.7 ± 0.3 a	5.1 ± 0.1 bc	5.2 ± 0.1 cde	5.1 ± 0.2 bcd
SOC (%)	1.35 ± 0.13 b	1.54 ± 0.14 c	1.27 ± 0.03 b	1.78 ± 0.11 d	1.01 ± 0.09 a	1.82 ± 0.15 d	2.28 ± 0.06 f	1.99 ± 0.12 e	0.99 ± 0.09 a	2.28 ± 0.05 f	1.37 ± 0.03 b
N (%)	0.15 ± 0.03 abc	0.23 ± 0.03 de	0.16 ± 0.01 bc	0.11 ± 0.03 a	0.16 ± 0.03 bc	0.17 ± 0.02 bc	0.14 ± 0.02 ab	0.17 ± 0.02 bc	0.18 ± 0.02 bc	0.27 ± 0.02 e	0.20 ± 0.04 cd
C/N	9.0 ± 2.4 bcd	6.7 ± 0.8 ab	7.9 ± 0.6 abc	16.4 ± 3.8 e	6.3 ± 1.3 ab	10.7 ± 1.1 cd	16.3 ± 2.9 e	11.7 ± 1.6 d	5.5 ± 0.1 a	8.4 ± 0.8 abc	6.9 ± 0.7 ab
Available P (cmol kg^{-1})	9.7 ± 2.1 ab	20.3 ± 2.1 de	15.3 ± 3.8 bcd	8.0 ± 2.0 a	13.0 ± 2.7 abc	17.0 ± 2.0 cd	12.3 ± 2.1 abc	17.3 ± 3.8 cd	16.3 ± 3.8 cd	24.7 ± 4.5 e	18.0 ± 4.6 cd
Exch. Ca (cmol kg^{-1})	12.6 ± 0.9 ef	8.4 ± 0.7 abc	10.1 ± 0.4 bcd	6.2 ± 0.2 a	6.6 ± 0.8 a	7.9 ± 0.4 ab	13.4 ± 1.6 f	6.7 ± 1.0 a	10.7 ± 1.9 cde	7.8 ± 1.2 ab	11.2 ± 3.3 def
Exch. Mg (cmol kg^{-1})	2.4 ± 0.2 e	2.1 ± 0.2 e	2.1 ± 0.2 e	1.1 ± 0.1 bc	1.1 ± 0.4 bc	1.1 ± 0.4 bc	1.5 ± 0.1 d	0.4 ± 0.1 a	1.2 ± 0.2 cd	0.8 ± 0.2 b	1.5 ± 0.2d
Exch. K (cmol kg^{-1})	0.28 ± 0.01 b	0.28 ± 0.03 b	0.31 ± 0.02 bc	0.13 ± 0.03 a	0.18 ± 0.02 a	0.42 ± 0.05 de	0.35 ± 0.03 cd	0.25 ± 0.04 b	0.48 ± 0.09 e	0.28 ± 0.02 b	0.59 ± 0.04 f
Total exch. cations (cmol kg^{-1})	15.5 ± 0.9 e	10.9 ± 1.0 bc	12.7 ± 0.4 cd	7.9 ± 0.4 a	8.2 ± 0.7 ab	9.6 ± 0.8 ab	15.6 ± 1.6 e	7.5 ± 1.0 a	12.6 ± 2.17 cd	9.1 ± 1.0 ab	13.7 ± 3.3 de
CEC (cmol kg^{-1})	18.4 ± 1.0 abc	23.6 ± 3.4 de	20.9 ± 0.4 bcde	15.5 ± 0.4 a	19.0 ± 1.9 abcd	22.4 ± 2.8 cde	19.6 ± 2.4 abcd	17.0 ± 2.3 ab	21.7 ± 2.5 cde	24.8 ± 4.5 e	25.3 ± 2.3 e
Base saturation, BS (%)	84.4 ± 5.7 e	46.3 ± 3.7 abc	60.8 ± 1.4 d	51.1 ± 1.3 bcd	43.4 ± 2.5 ab	43.0 ± 5.5 ab	79.7 ± 9.2 e	43.9 ± 3.7 ab	58.9 ± 16.5cd	37.2 ± 6.11 a	53.7 ± 8.0 bcd
Bulk density (g cm^{-3})	1.14 ± 0.02 a	1.16 ± 0.04 ab	1.14 ± 0.03 a	1.13 ± 0.03 a	1.12 ± 0.02 a	1.10 ± 0.11 a	1.20 ± 0.05 ab	1.15 ± 0.05 a	1.26 ± 0.08 b	1.18 ± 0.05 ab	1.10 ± 0.06 a
WSA (%)	84.5 ± 8.3 b	64.1 ± 7.5 a	56.5 ± 26.2 a	88.8 ± 2.9 b	84.9 ± 2.94 b	59.4 ± 2.5 a	83.0 ± 15.2 b	58.4 ± 1.7 a	83.8 ± 11.8 b	85.4 ± 2.4 b	84.2 ± 5.3 b
Hydraulic conductivity (cm h^{-1})	1.89 ± 0.11 cde	1.98 ± 0.57 de	1.53 ± 0.17 bcd	0.97 ± 0.30 ab	1.62 ± 0.37 bcd	23.5 ± 0.31 e	1.38 ± 0.57 bcd	1.17 ± 0.36 b	0.54 ± 0.10 a	1.26 ± 0.41 bc	1.53 ± 0.14 bcd
K-index	0.21 ± 0.05 ef	0.18 ± 0.04 de	0.26 ± 0.04 f	0.09 ± 0.03 abc	0.09 ± 0.04 abc	0.08 ± 0.05 a	0.13 ± 0.05 abcd	0.09 ± 0.04 abc	0.15 ± 0.02 bcde	0.16 ± 0.01 cde	0.09 ± 0.02 ab

Notes: SOC = soil organic carbon; CEC = cation exchange capacity; WSA = water-stable aggregates
* Values within each row, followed by the same letter, are not significantly different (Duncan's multiple range test at $P = 0.05$)
‹ Significance of ANOVA comparisons between land units

Table 3. Pair-wise correlations between soil characteristics (attributes) in the study area [1)]

Soil attributes	Sand	Silt	Clay	pH H_2O	SOC	Total N	C/N ratio	Available P	Exch. Ca	Exch. Mg	Exch. K	Total exch. bases	CEC	BS	Bulk density	WSA	Hydraulic conductivity
Silt	0.584(**)																
Clay	-0.764(**)	-0.970(**)															
pH H_2O	0.556(**)	0.603(**)	-0.646(**)														
SOC	0.227	-0.029	-0.045	-0.161													
Total N	0.454(**)	0.204	-0.298	0.054	0.159												
C/N ratio	-0.137	-0.194	0.195	-0.148	0.653(**)	-0.601(**)											
Available P	0.284	0.168	-0.219	-0.060	0.207	0.699(**)	-0.361(*)										
Exch. Ca	0.238	0.635(**)	-0.576(**)	0.321	-0.079	-0.017	-0.059	-0.145									
Exch. Mg	0.452(**)	0.678(**)	-0.674(**)	0.757(**)	-0.389(*)	-0.113	-0.204	-0.245	0.570(**)								
Exch. K	0.168	0.352(*)	-0.330	-0.092	-0.179	0.191	-0.321	0.293	0.497(**)	0.125							
Total exch. bases	0.297	0.678(**)	-0.628(**)	0.426(*)	-0.148	-0.049	-0.085	-0.181	0.986(**)	0.691(**)	0.483(**)						
CEC	0.493(**)	0.293	-0.381(*)	0.124	-0.057	0.709(**)	-0.546(**)	0.537(**)	0.255	0.104	0.507(**)	0.249					
BS	0.053	0.509(**)	-0.421(*)	0.375(*)	-0.077	-0.424(*)	0.238	-0.486(**)	0.816(**)	0.629(**)	0.162	0.834(**)	-0.310				
Bulk density	-0.035	0.076	-0.050	0.098	-0.026	0.177	-0.132	0.115	0.226	-0.062	0.089	0.175	0.113	0.136			
WSA	-0.154	-0.254	0.248	-0.070	-0.052	-0.011	0.031	-0.183	0.249	-0.010	-0.052	0.222	0.015	0.226	0.083		
Hydraulic conductivity	0.187	0.242	-0.249	0.124	0.052	-0.006	0.019	0.196	-0.013	0.305	0.041	0.046	0.085	0.012	-0.423(*)	-0.327	
***K*-index**	0.410(*)	0.695(**)	-0.675(**)	0.761(**)	-0.247	0.076	-0.231	0.035	0.343	0.633(**)	-0.081	0.405(*)	0.093	0.375(*)	0.248	-0.241	0.102

[1)] Significance levels: (*) p = 0.05; (**) p = 0.01

the "less is better" scoring function, for silt content and bulk density, because of the significant influences of silt content on soil erodibility and of bulk density on the porosity of soils (Lal, 1988).

Table 4. Component matrix for the first 6 principal components

PCs‹	PC1	PC2	PC3	PC4	PC5	PC6	
Eigenvalue:	6.02	3.46	2.15	1.73	1.46	1.02	
Percent of variance:	33.42	19.21	11.97	9.59	8.10	5.66	
Cumulative percent:	33.42	52.62	64.59	74.18	82.28	87.94	Communalities
Eigenvectors:Œ							
Sand (%)	0.64	0.38	-0.33	0.22	0.15	0.28	0.81
Silt (%)	<u>0.91</u>§	0.06	-0.17	0.10	-0.01	-0.17	0.91
Clay (%)	-0.92	-0.16	0.24	-0.15	-0.04	0.05	0.95
pH H_2O	0.73	-0.10	-0.33	-0.28	0.31	0.20	0.85
SOC (%)	-0.18	0.09	-0.34	<u>0.86</u>	0.27	0.04	0.97
Total N (%)	0.20	<u>0.86</u>	0.14	0.08	0.20	0.19	0.88
C/N ratio	-0.30	-0.57	-0.37	0.61	0.12	-0.04	0.93
Available P (cmol kg^{-1})	0.07	0.84	-0.02	0.18	0.02	-0.13	0.76
Ca (cmol kg^{-1})	0.77	-0.30	0.43	0.29	-0.09	-0.03	0.96
Mg (cmol kg^{-1})	0.83	-0.29	-0.15	-0.28	-0.13	0.19	0.92
K (cmol kg^{-1})	0.40	0.27	0.50	0.23	-0.47	-0.30	0.86
TEB (cmol kg^{-1})	0.83	-0.32	0.35	0.21	-0.12	0.02	0.98
CEC (cmol kg^{-1})	0.40	0.73	0.29	0.08	-0.11	0.18	0.83
BS (%)	0.61	-0.72	0.16	0.17	-0.02	-0.06	0.95
Bulk density (g cm^{-3})	0.15	0.05	0.44	-0.02	<u>0.66</u>	-0.42	0.83
WSA (%)	-0.07	-0.26	<u>0.58</u>	0.11	0.15	<u>0.67</u>	0.89
Hydraulic conductivity (cm h^{-1})	0.21	0.12	-0.54	0.04	-0.60	0.03	0.71
K-index	0.72	-0.05	-0.28	-0.35	0.35	-0.15	0.87

‹ PC, principal component

ŒSOC, soil organic carbon; TEB, total exchangeable bases; CEC, cation exchange capacity; BS, base saturation; WSA, water stable aggregates *K*-index, soil erodibility index

§ Underlined factor loadings correspond to the indicators included in the MDS

Then, the soil quality indexes (SQI) were determined for all land units in the study area using the formula proposed by Andrews *et al.* (2002) [Eq. 3]. The soil quality indexes of all land units and their significant differences are shown in Table 5. The lowest SQI (0.37) was found on Land Unit 3, which is characterized by Vertic Hapludalfs and cultivation of annual rainfed crops (i.e. cassava, maize, and groundnut). The highest SQI (0.70) was found on Land Unit 5, which is characterized by Typic Hapludalfs and perennial crops (i.e. rambutan orchards). Both land units are on very steep land (slope class VI, 45-65 percent).

Table 5. Soil quality index of each land unit

Land unit	SQI
1	0.42 ± 0.05 ab
2	0.49 ± 0.04 bc
3	0.37 ± 0.07 a
4	0.68 ± 0.04 e
5	0.70 ± 0.02 e
6	0.59 ± 0.03 d
7	0.53 ± 0.06 cd
8	0.56 ± 0.03 cd
9	0.56 ± 0.04 cd
10	0.67 ± 0.01 e
11	0.50 ± 0.06 c

Note: SQI = soil quality index
‹ Significance of ANOVA comparisons between land units.

Conclusions

Five significant soil attributes (indicators) have been identified, which reliably explain soil quality in the study area, i.e. texture (percentage silt), total N, WSA, SOC, and bulk density. Overall, soil quality in the study area can be described as low to medium. The indicator with the highest weight was texture (expressed in terms of silt content). This soil attribute cannot be changed by land management practices, and is therefore considered inherent.

However, the overall soil quality can undoubtedly be improved considerably by enhancement of the other identified soil attributes through better land management practices and the introduction of more appropriate cropping systems.

An example for Land Unit 3 in Tegalan Catchment would be to replace the low-value annual food crops with high-value crops, such as fruits (e.g. rambutan, longan, mangoes) or with grass cultivation for cattle and buffalo grazing. Also, soil fertility conservation needs should receive more attention, such as the application of organic matter and more appropriate fertilizer usage.

To address declining land productivity in the context of land degradation and sustainability of land use, land use systems and practices in the area should be examined in more detail. Locally appropriate soil fertility enhancement measures should be identified to build up overall soil quality – and hence fertility – in the area. The study clearly confirms the general wisdom that in tropical steeplands, which are subjected to high risks of soil degradation – especially soil erosion – minimum soil disturbance will contribute significantly to the maintenance of soil quality, and hence soil productivity and the sustainability of land use.

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

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Abstract

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

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

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

Introduction

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

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

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

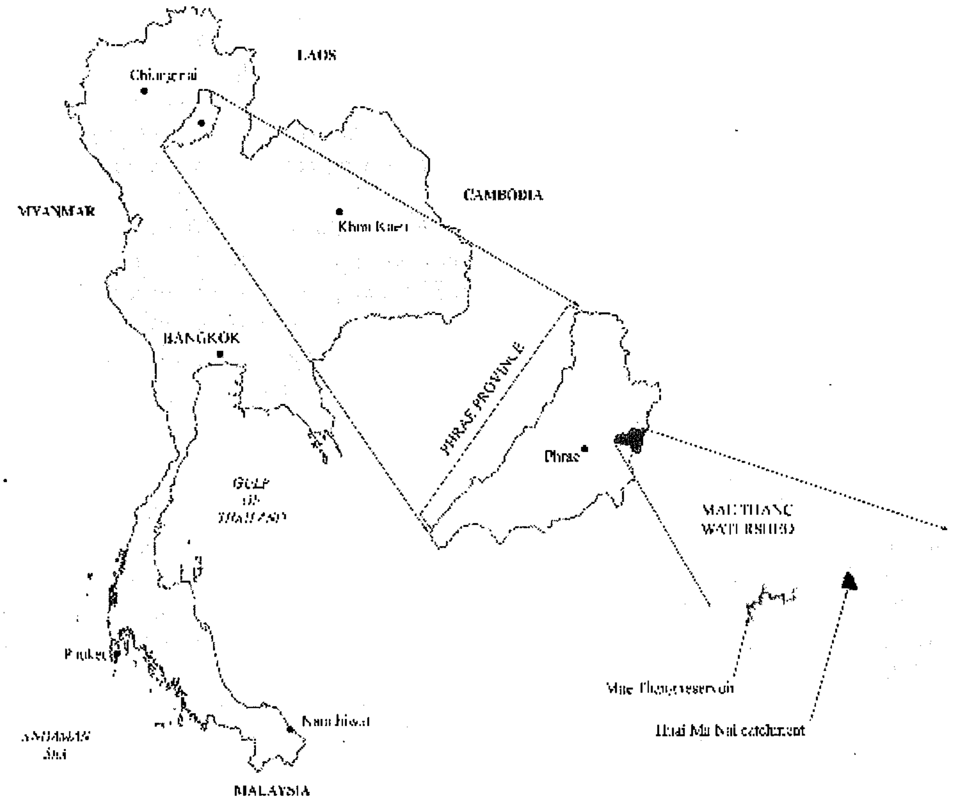


Figure 1. Location of the MSEC study site in Thailand

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

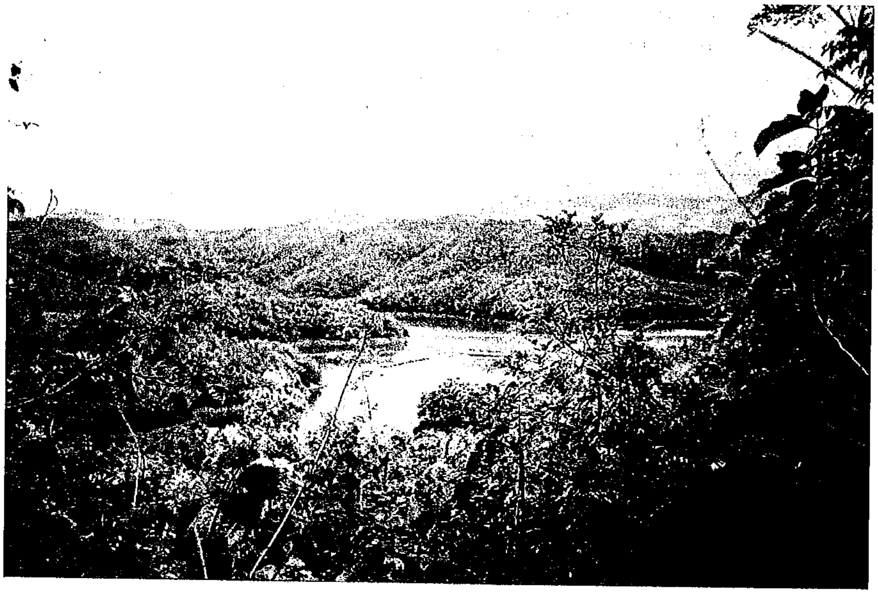


Figure 2. Overview of Mae Thang Watershed and Reservoir

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

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

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

Table 2. Estimated land use of the Mae Thang Watershed

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

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

Methodology

The Experimental Site

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

Evaluation of Soil Erosion

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

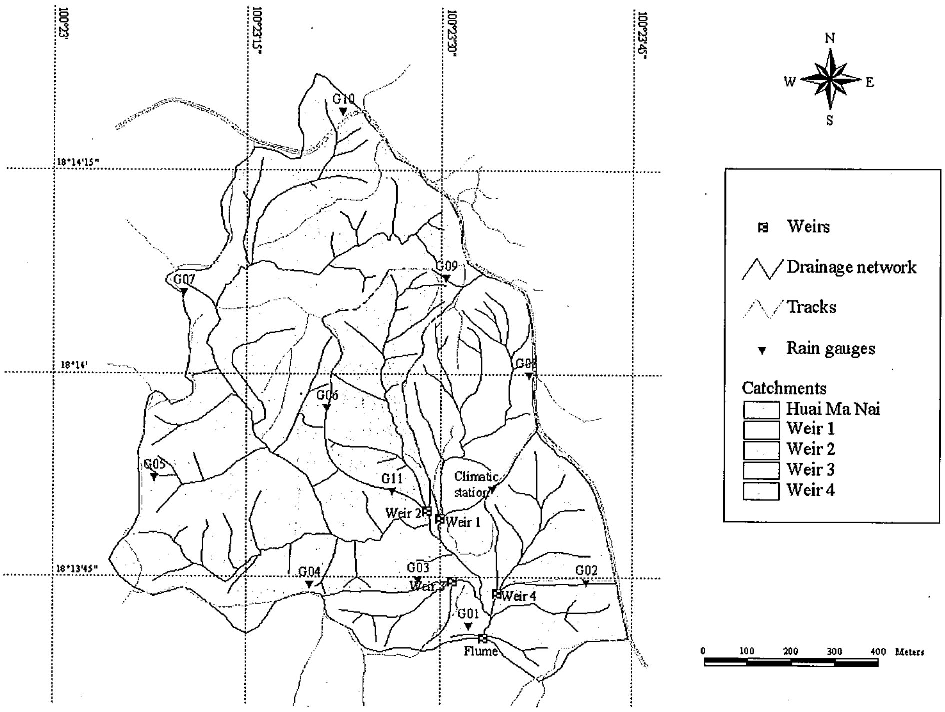


Figure 3. Different sub-catchments and the location of measuring structures at Huai Ma Nai

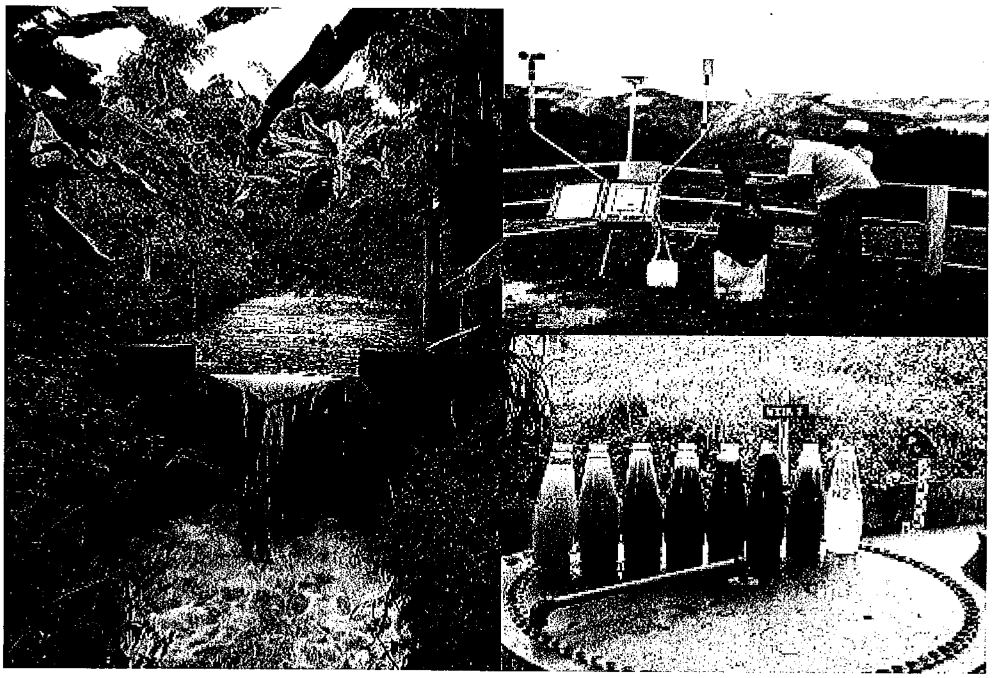


Figure 4. Sediment traps, automatic water sampler, and weather station installed in the catchment

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

Sedimentation in the Reservoir

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

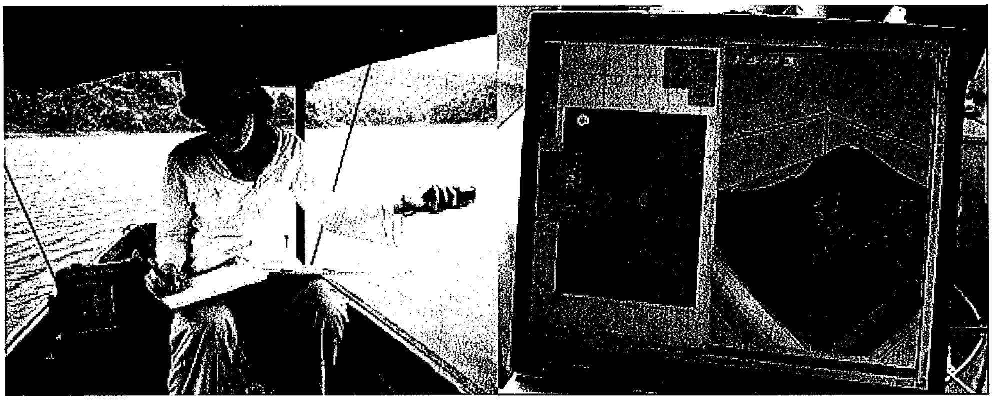


Figure 5. Bathymetric survey of the reservoir (left side) and result of echo sounder with Max Sea software

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

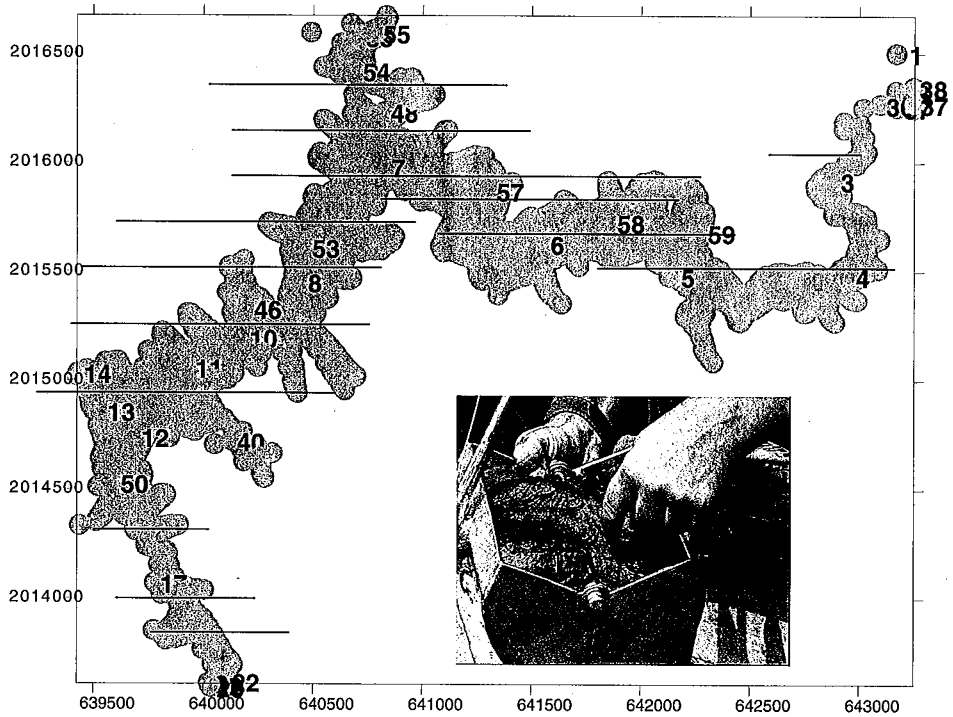


Figure 6. Reservoir configuration showing the location of transects and sediment sampling sites (coordinates in UTM)

Results and Discussion

Soil Erosion in the Small Catchment

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

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

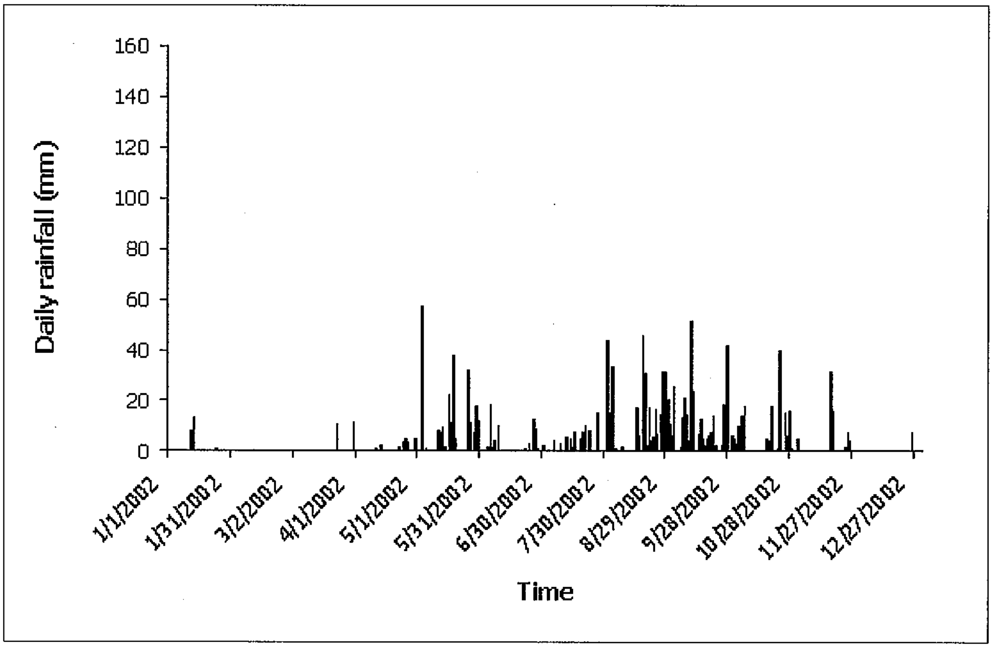
Table 3. Land use, rainfall, runoff, and sediment yield measured in the MSEC catchment and sub-catchments in 2001 and 2002

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

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

Reservoir Siltation and Soil Erosion

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



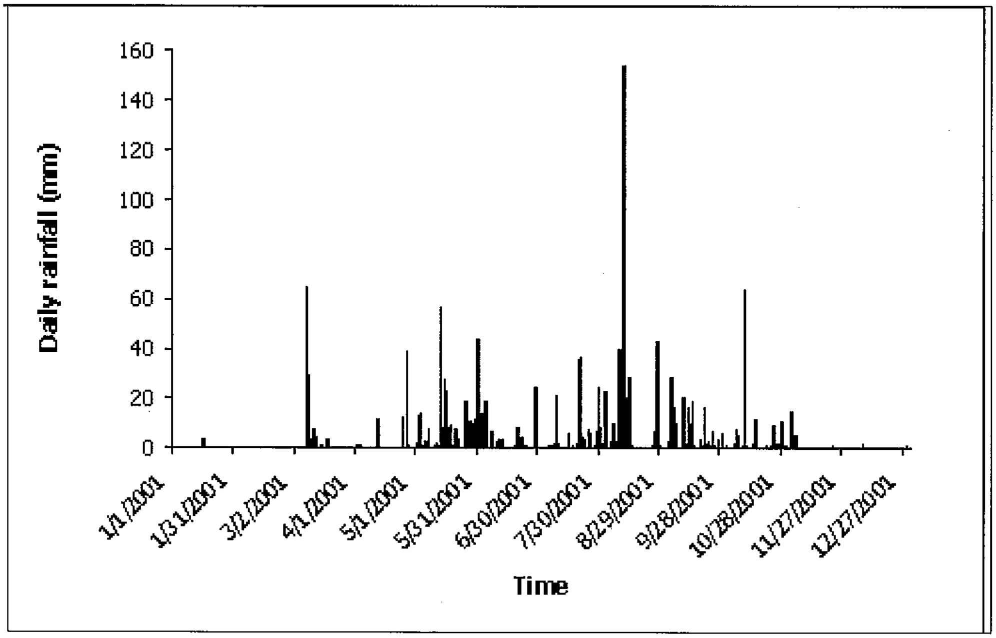


Figure 7. Daily rainfall in the catchment during 2001 (a) and 2002 (b)

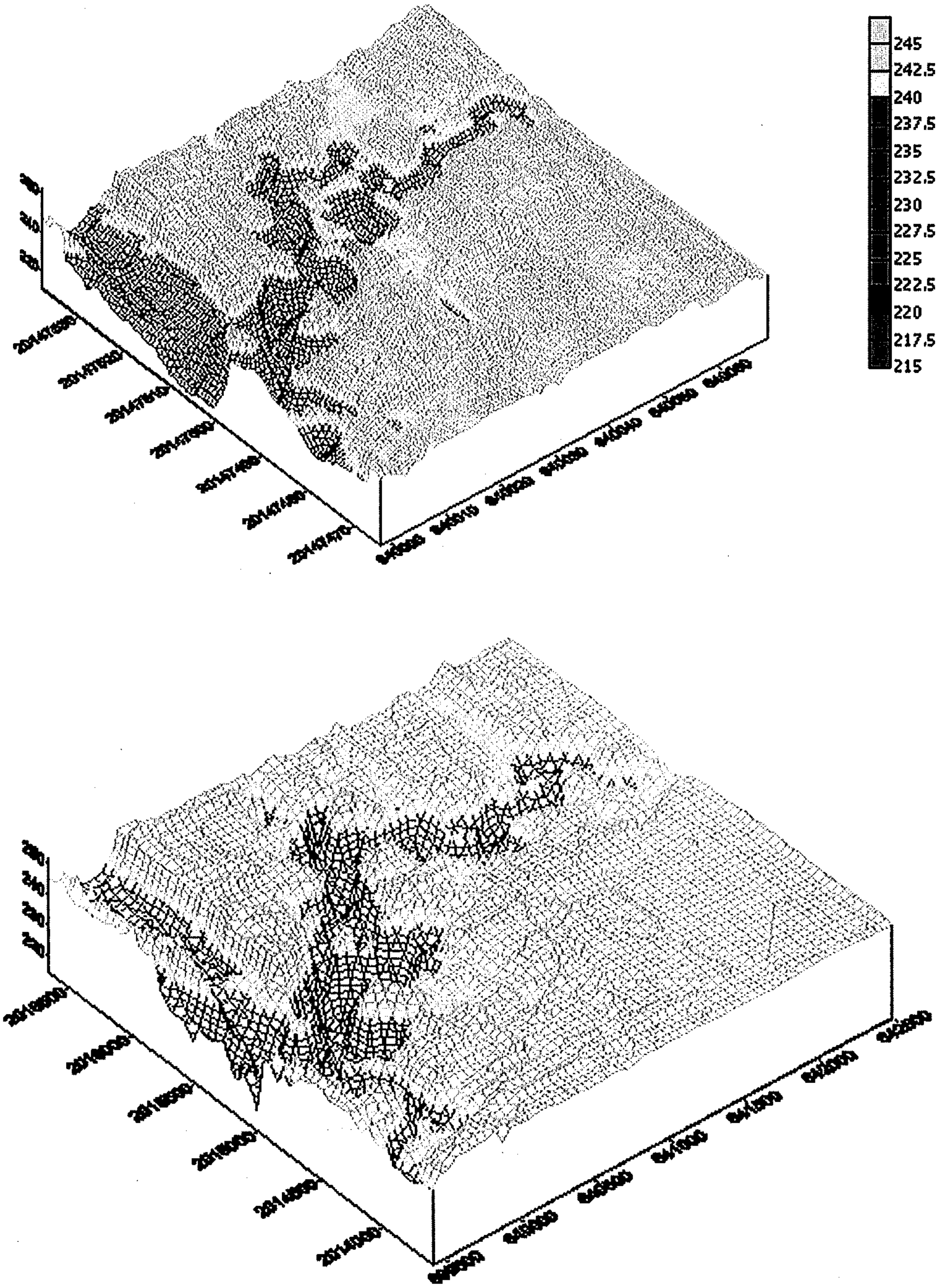


Figure 8. Surfer diagram of the reservoir bottom in 1995 (above) and in 2002 (below)

Table 4. Estimated erosion at different scale studies

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

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

Conclusion

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

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

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Impact Assessment: Methodology and Its Application to the Management of Soil Erosion Consortium (MSEC) Project

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Abstract

A simple questionnaire was devised to make an initial evaluation of the impact of the Management of Soil Erosion Consortium (MSEC) project implemented in Indonesia, Lao PDR, Nepal, the Philippines, Thailand, and Vietnam. The impact was evaluated based on the responses by the researchers to the change indicators related to five project outputs and by farmers to two project outputs.

The highest positive response was in the effect of improved information dissemination strategies. This implies that the conduct of regular meetings with the farmers has resulted in very positive effects. For both researchers and farmers, the effect of the introduced intervention has not yet been strongly felt. While it may be too early to assess the impact in terms of productivity improvement, the responses by farmers clearly indicated their positive anticipation. The usefulness of the tools and guidelines and program management outputs has also not yet been fully realized by researchers.

In all identified outputs, it appears that there has been no positive change by the project in Thailand. The same is true for researchers in Nepal except for information dissemination strategies, which received a positive response.

While the study has provided some indications of the impact of the MSEC project, further evaluation of the methodology and analysis of the data are needed to complete the requirement of the framework. It should consider particularly the biophysical and economic impact of the project.

Introduction

Impact assessment is an important and integral part of research management. Nowadays, economic rationalism dictates that every enterprise justifies its existence in an explicit, preferably quantitative way. Impact assessment and evaluation is therefore subject to close attention in the international agricultural research community, especially among donors. Baur *et al.* (2001) state that impact assessment improves accountability for investments in development cooperation by trying to ensure that they truly effect changes in the lives of people, especially the poor.

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A variety of different methods and tools for assessing impact has been conceptualized and applied. These include indicators; spatial models and GIS, economic surplus models, farmer participatory techniques, and empirical surveys (Maglinao, 1998; Pachico *et al.*, 1998; Buenavista *et al.*, 2001; Rusike *et al.*, 2001; Meinzen-Dick and Adato, 2001; Kristjanson *et al.*, 2002; Ticehurst, 2002; Gottret and White, 2002). Particularly in cases of multistakeholder management of natural resources, impact assessment can be of direct relevance to communities, not just to scientists and research managers. Impact assessment is best implemented as an integral part of the entire research process rather than as a retrospective exercise that comes at the end of a research project.

The International Water Management Institute (IWMI) has recently incorporated impact assessment as a built in component of its research programs (IWMI, 2001). It has devised a road map for translating research into impact by 2005. A conceptual framework for impact assessment was designed to identify not only the types of impacts IWMI expects from its activities but also the pathways, both internal and external, to achieve these impacts (Giordano, 2002).

This paper presents an initial step in undertaking an in-depth evaluation of the impact of the Management of Soil Erosion Consortium (MSEC) project. The analysis is limited to benefits derived from the project's outputs by collaborating NARES and participating farmers. Analysis primarily focused on the changes in the knowledge, attitudes, and skills of researchers and farmers regarding soil erosion problems and solutions. It is anticipated that this will lead to a more comprehensive assessment of the impacts of the project from a broader perspective.

Assessment Methodology

The assessment used the framework employed by Maglinao (1998) in the evaluation of the impact of IBSRAM as an institution (Figure 1). This framework followed the analysis adopted by the CGIAR in its analysis of ex-post studies of the impacts of international research centers, which shows linkages between the programs, activities, and expected outputs of the center and their potential or actual impacts (CGIAR, 1997). For most projects, the expected outputs and indicators that are used to monitor its progress are shown in the project logical framework.

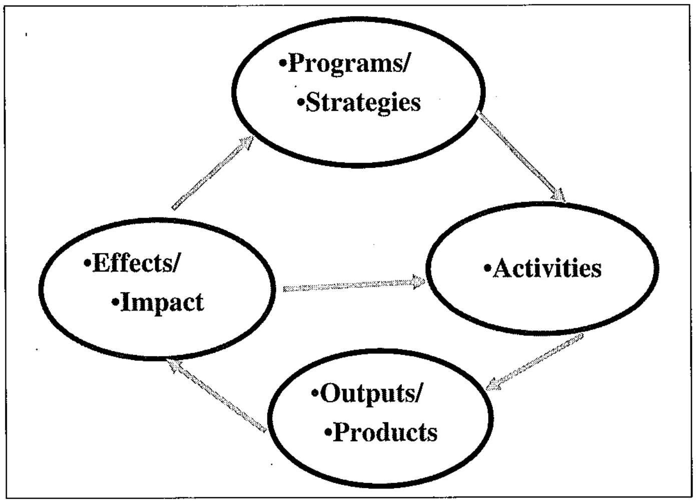

Figure 1. Conceptual framework for the analysis of project impact (Maglinao, 1998)

Design of the Questionnaire

The design of the guide questionnaire was based on the project's expected outputs as identified in the logical framework (Maglinao and Penning de Vries, 2002). These are: 1) decision support tools, guidelines, and methodologies for a better understanding of the on- and off-site effects of soil erosion; 2) alternative technologies and land management systems that are socially and institutionally acceptable to communities within catchments; 3) information and communication strategies to effectively disseminate the results of the research to farmers and other land users; 4) enhanced NARES capacity in integrated catchment management research; and 5) improved program management for catchment management research.

Questions were framed to gather information on changes that may have occurred for various stakeholders of the project. These clients include primarily the researchers and farmers, but could also apply to other stakeholders such as policy-makers and extension workers. The questions were translated into the local language and pretested, particularly for farmer respondents.

Conduct of Surveys and Interviews

The surveys and interviews were conducted in all six MSEC-participating countries. In most countries, the respondents were mainly researchers and farmers, except for Nepal and Thailand, which did not have any farmer respondents.

A total of 116 respondents from the six participating countries answered questions related to the change indicators defined under each of the project's expected outputs. Of this number, 33 were researchers who responded to 37 questions corresponding to five outputs. There were 83 farmers who responded to 13 questions corresponding to two outputs.

The surveys and interviews were conducted by the national researchers. Answers to the questions ranged from strong disagreement to strong agreement with the change indicator. As the questionnaire only serves as a guide, follow-up questions were asked to further clarify the responses.

Data Analysis

The weighted average of the answers of respondents to each question under each of the output categories was calculated and tabulated by stakeholders (researchers and farmers) and by country. The degree of agreement to a question was ranked according to the Likert Scale, which is derived by item-analysis techniques (Nunnaly, 1979). The Likert Scale is classified as a summated rating scale of a set of attitude items to which subjects respond with degrees of agreement or disagreement (intensity). The scores of the items of such a scale are summed and averaged to yield an individual's attitude score.

The Likert scaling procedure helps to ensure that the final score concerns only one general attitude and that each respondent can be located with at least moderate precision at different points on the scale. All identified outputs were evaluated for researchers, while only output 2 (alternative technologies) and output 3 (information dissemination strategies) were analyzed for the farmers.

On the final scale, the subject marks each statement in one of the categories of: 1.00-1.50 (strongly disagree), 1.51-2.50 (disagree), 2.51-3.50 (undecided), 3.51-4.50 (agree), and 4.51-

5.00 (strongly agree). The individual's final score is obtained by summing the item scores. The responses are then summarized by the respondent group by output and by country.

Results and Discussion

The average response ratings of the researcher respondents according to the outputs of the project and by country are shown in Table 1 and Figure 2. The corresponding response ratings of farmers for outputs 2 (alternative technology options) and 3 (information dissemination strategies) and by country (except Nepal and Thailand) are presented in Table 2 and Figure 3. On average, the perceptions of both respondent groups agreed on a positive change that the project has made.

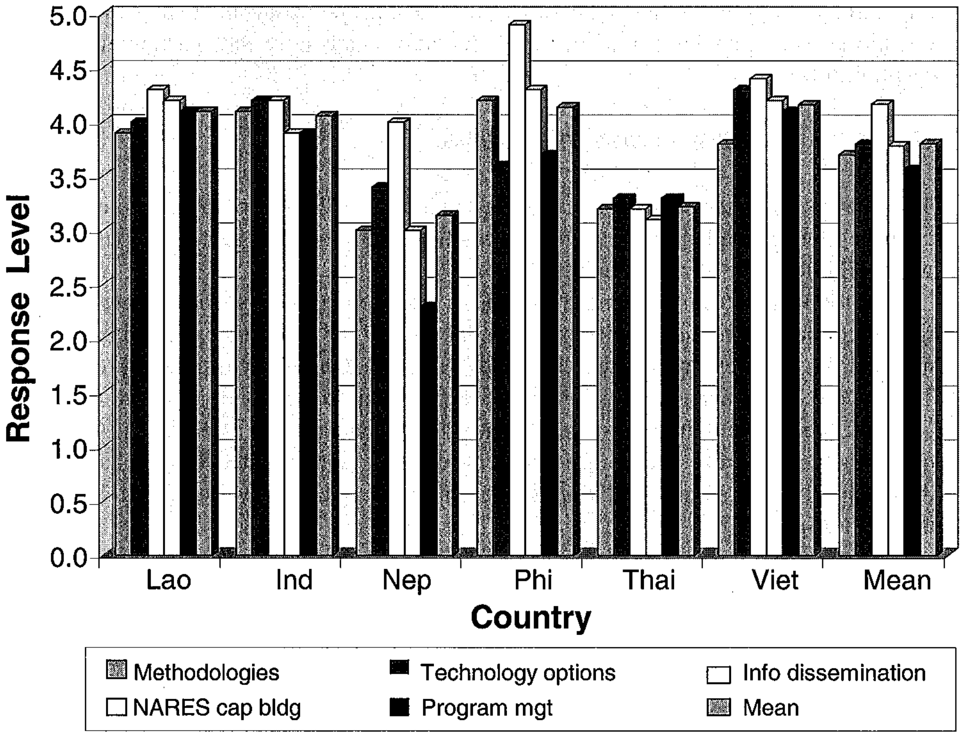

Figure 2. Response level of researchers to the change indicators with respect to expected output by country

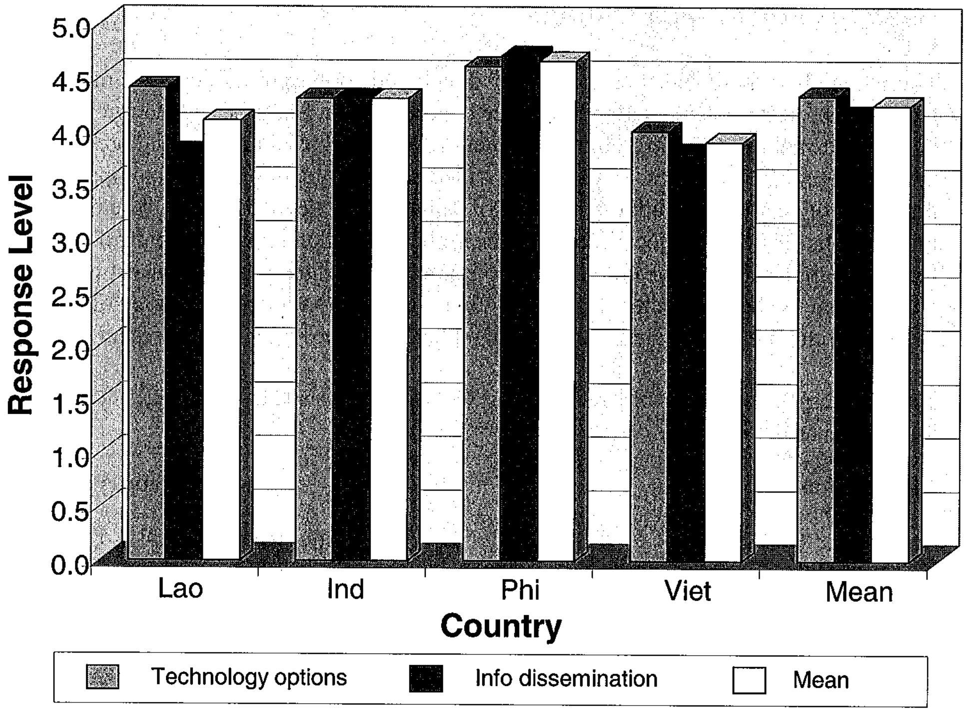

Figure 3. Response level of farmers to the change indicators with respect to the expected output by country

Table 1. Response of researchers with respect to expected outputs identified by the project by country

	Response level						
Expected outputs	**Lao**	**Ind**	**Nep**	**Phi**	**Thai**	**Viet**	**Mean**
1. Tools, guidelines, methodologies	3.9	4.1	3.0	4.2	3.2	3.8	**3.7**
2. Alternative technologies	4.0	4.2	3.4	3.6	3.3	4.3	**3.8**
3. Information dissemination strategies	4.3	4.2	4.0	4.9	3.2	4.4	**4.2**
4. NARES capacity building	4.2	3.9	3.0	4.3	3.1	4.2	**3.8**
5. Improved program management	4.1	3.9	2.3	3.7	3.3	4.1	**3.6**
Grand mean	**4.1**	**4.1**	**3.1**	**4.1**	**3.2**	**4.2**	**3.8**

Table 2. Response of farmers related to the expected outputs identified by the project by country

	Country				
Expected outputs	**Lao**	**Ind**	**Phi**	**Viet**	**Mean**
	n=6	n=21	n=35	n=7	**n=69**
2. Alternative technologies	4.4	4.3	4.6	4.0	**4.3**
3. Information dissemination strategies	3.8	4.3	4.7	3.8	**4.2**
Grand mean	**4.1**	**4.3**	**4.7**	**3.9**	**4.2**

Response by Project Outputs

The researchers believed that the use of developed tools, guidelines, and methodologies facilitated project implementation; improved data collection, analysis, and interpretation; helped in decision-making; increased innovativeness/resourcefulness; increased appreciation of the project; optimized use of resources; and provided easier evaluation of project impact. However, this did not result in a reduced degree of supervision needed by the researchers in the implementation of the project (Table 3). The highest rating of 4.5 was given by the Philippines for the positive effect of the outputs in helping in decision-making. The lowest was a score of 2.6 as given by the researchers from Nepal in being able to reduce the degree of supervision. In most of the indicators, Nepal and Thailand had a lower degree of agreement.

Table 3. Response of researchers related to the tools, guidelines and methodologies developed by the project

Change indicator	Country						
	LAO n=7	IND n=5	NEP n=5	PHI n=6	THA n=3	VIE n=7	GM
1. Improved/facilitated project implementation	3.4	4.2	3.4	4.3	3.7	3.7	3.8
2. Reduced degree of supervision	3.5	3.9	2.6	4.0	3.0	3.6	3.4
3. Improved data collection, analysis, and interpretation	4.0	4.3	3.4	4.4	3.0	3.6	3.9
4. Helped in decision-making	4.0	4.1	3.8	4.5	3.0	3.6	4.0
5. Increased innovativeness/resourcefulness	4.4	3.9	3.4	4.3	3.0	3.9	3.8
6. Increased appreciation of the project	4.0	3.8	3.8	4.3	3.4	4.3	3.9
7. Optimized the use of resources (time, effort, money)	4.0	3.9	3.6	4.0	3.0	3.9	3.7
8. Provided easier evaluation of project impact	3.5	4.3	3.2	3.9	3.5	3.7	3.7
Grand mean	3.9	4.1	3.0	4.2	3.2	3.8	3.8

Response scale: 1.00-1.50 = Strongly disagree; 1.51-2.50 = Disagree; 2.51-3.50 = Undecided; 3.51-4.50 = Agree; 4.51-5.00 = Strongly agree

With respect to responses related to alternative technologies, researchers did not agree that they have noticed any change in erosion rate because of the technology option (Table 4). However, they considered that erosion problems in their area are very severe and can be addressed through the application of appropriate technologies. They also believed that there will be better production because of the new technologies. Moreover, they agreed that observations at the study sites changed their thinking and improved their appreciation of the problem. The farmers in four countries agreed to all change indicators on alternative technologies (Table 5).

Table 4. Response of researchers related to alternative technologies identified by the project

Change indicator	Country						
	LAO n=7	IND n=5	NEP n=5	PHI n=6	THA n=3	VIE n=7	GM
1. Erosion problem very severe	4.2	2.6	4.8	4.5	3.7	4.4	4.0
2. Problem can be addressed by appropriate technology	4.4	4.3	4.0	4.3	3.3	4.6	4.1
3. Observations changed thinking about the problem	4.0	4.7	3.2	3.2	2.3	4.9	3.7
4. Better appreciated the problem	4.2	4.7	2.6	4.0	3.0	4.6	3.8
5. Ways by which options are introduced acceptable	3.8	4.3	3.0	4.2	3.0	4.6	3.8
6. Willing to continue to practice management options introduced	4.2	4.4	2.6	3.7	3.7	3.6	3.7
7. Noticed any change in erosion rate because of the technology	3.7	4.2	3.2	1.7	2.7	4.1	3.3
8. Agreed that there will be better production because of new technology	4.0	3.9	3.8	4.5	4.7	4.3	4.2
Grand mean	4.0	4.1	3.5	3.6	3.2	4.4	3.8

Response scale: 1.00-1.50 = Strongly disagree; 1.51-2.50 = Disagree; 2.51-3.50 = Undecided; 3.51-4.50 = Agree; 4.51-5.00 = Strongly agree

Table 5. Response of farmers related to alternative technologies identified by the project

Change indicator	Country				
	LAO n=6	IND n=21	PHI n=35	VIE n=7	GM
1. Erosion problem very severe	4.8	2.9	4.7	4.3	4.2
2. Problem can be addressed by appropriate technology	4.3	3.3	4.7	4.4	4.2
3. Observations changed thinking about the problem	5.0	3.5	4.6	4.0	4.3
4. Better appreciated the problem	3.8	4.0	4.6	4.4	4.2
5. Ways by which options are introduced acceptable	4.8	4.2	4.7	4.4	4.5
6. Willing to continue to practice management options introduced	4.7	4.1	4.9	3.3	4.3
7. Agreed that income will increase with new option	3.8	3.7	4.4	3.1	3.8
8. Noticed any change in erosion rate because of the technology	4.0	4.2	4.3	4.3	4.2
9. Agreed that there will be better production because of new technology	4.7	4.5	4.7	4.1	4.5
Grand mean	4.4	4.3	4.6	4.0	4.2

Response scale: 1.00-1.50 = Strongly disagree; 1.51-2.50 = Disagree; 2.51-3.50 = Undecided; 3.51-4.50 = Agree; 4.51-5.00 = Strongly agree

Both the researchers and farmers agreed that the information dissemination strategies were helpful. In this respect, both groups concurred that regular meetings with stakeholders helped in collaboration and adoption (Tables 6 and 7). They appreciated the regular meetings conducted, considering them useful and enabling them to enhance their research capacity.

Table 6. Response of researchers related to the information dissemination strategies

Change indicator	Country						
	LAO n=7	IND n=5	NEP n=5	PHI n=6	THA n=3	VIE n=7	GM
1. Regular meetings with stakeholders helped in collaboration and adoption	4.7	4.2	3.8	5.0	3.9	4.4	4.3
2. Appreciated regular meetings conducted	4.3	4.1	4.0	5.0	2.7	4.7	4.1
3. Considered the meetings useful	4.3	4.3	3.8	5.0	2.7	4.4	4.1
4. Meetings enhanced capacity	4.0	4.0	4.4	4.8	3.5	3.9	4.1
Grand mean	4.3	4.2	4.0	4.9	3.2	4.4	4.1

Response scale: 1.00-1.50 = Strongly disagree; 1.51-2.50 = Disagree; 2.51-3.50 = Undecided; 3.51-4.50 = Agree; 4.51-5.00 = Strongly agree

Table 7. Response of farmers related to the information dissemination strategies

Change indicator	Country				
	LAO n=6	IND n=21	PHI n=35	VIE n=7	GM
1. Regular meetings with stakeholders helped in collaboration and adoption	4.2	4.2	4.6	4.3	4.3
2. Appreciated regular meetings conducted	3.7	4.3	4.7	3.9	4.2
3. Considered the meetings useful	4.5	4.3	4.9	4.4	4.5
4. Meetings enhanced capacity	2.8	4.4	4.8	2.7	3.7
Grand mean	3.8	4.3	4.7	3.8	4.2

Response scale: 1.00-1.50 = Strongly disagree; 1.51-2.50 = Disagree; 2.51-3.50 = Undecided; 3.51-4.50 = Agree; 4.51-5.00 = Strongly agree

All farmers in the Philippines strongly agreed that they appreciated the regular meetings conducted and that these meetings with stakeholders were very useful and helped in collaboration and adoption. Farmers in Lao PDR, Indonesia, and Vietnam likewise agreed.

The effect of the training conducted by the project, on the average, did not have positive impacts on researchers in Thailand and Nepal (Table 8). All change indicators were rated low by Thailand while researchers in Nepal strongly disagreed that it increased their involvement in policy- and decision-making and increased their chances of job promotion. However, Nepal researchers believed that the training increased their interest and motivation, enhanced their opportunity to write scientific papers, and increased their confidence as trainers.

In terms of program management, the project did not contribute to a reduction in the cost of research, change of policy in the institute, improved resource generation, and optimal use of resources (Table 9). However, it improved the ability to share resources with others, broadened the collaboration base, and improved the evaluation of project results.

Table 8. Response of researchers related to NARES capacity building

Change indicator	Country						
	LAO n=7	IND n=5	NEP n=5	PHI n=6	THA n=3	VIE n=7	GM
1. Improved capacity	4.3	3.7	3.8	4.7	3.7	4.3	4.1
2. Assigned higher responsibility	4.3	4.3	1.8	4.5	3.3	4.1	3.7
3. Increased participation in scientific meetings	3.8	4.1	3.0	4.5	3.7	4.4	3.9
4. Chance of better job increased	4.0	3.4	1.0	4.0	2.3	3.9	3.1
5. Increased confidence as trainer	4.5	4.1	3.8	4.6	2.7	4.1	4.0
6. Increased confidence in dealing with colleagues	4.3	3.8	3.4	4.5	3.0	4.4	3.9
7. Enhanced opportunity to write scientific articles	4.3	4.1	4.0	4.0	3.0	4.0	3.9
8. Increased involvement in policy- and decision-making	4.7	4.2	1.0	4.0	3.0	3.7	3.4
9. Increased interest and motivation	4.0	3.4	4.4	3.4	3.0	4.3	3.7
10. Improved interaction with others	4.0	4.0	3.4	4.8	3.4	4.4	4.0
Grand mean	4.2	3.9	3.0	4.3	3.1	4.2	3.8

Response scale: 1.00-1.50 = Strongly disagree; 1.51-2.50 = Disagree; 2.51-3.50 = Undecided; 3.51-4.50 = Agree; 4.51-5.00 = Strongly agree

Comparing the relative proportion of the responses *vis à vis* the project outputs, showed that more than 80 percent of the responses were rated as "agreed" and "strongly agreed" with the questions posed to the researchers indicating positive changes brought by the outputs of the project (Figure 4).

Considering the two outputs that were evaluated by the farmers, an average of 87 percent of the responses were rated as "agreed" and "strongly agreed" (Figure 5). The highest positive response was in the effect of improved information dissemination strategies with 25 percent of the responses strongly agreeing to the change indicators from both the researchers and farmers. This implies that the conduct of regular meetings with farmers has resulted in a positive effect. Frequent interaction increased appreciation of the project by both the researchers and farmers.

Table 9. Response of researchers related to improved program management

Change indicator	Country						
	LAO n=7	IND n=5	NEP n=5	PHI n=6	THA n=3	VIE n=7	GM
1. Improved ability to share resources with others	4.0	4.2	3.6	4.0	3.7	3.9	3.9
2. Increased collaboration base	4.4	4.3	3.2	4.3	3.7	4.1	4.0
3. Optimized use of resources	4.5	3.4	1.6	4.0	3.5	4.0	3.5
4. Improved evaluation of project results	4.3	3.9	3.8	4.0	3.7	4.0	4.0
5. Improved resource generation	4.2	3.8	1.6	3.4	3.0	4.0	3.3
6. Changed policy in institute	3.8	4.1	1.4	2.8	3.0	4.0	3.2
7. Reduced cost of research	3.2	3.3	1.0	3.4	2.7	4.3	3.0
Grand mean	4.1	3.9	2.3	3.7	3.3	4.1	3.6

Response scale: 1.00-1.50 = Strongly disagree; 1.51-2.50 = Disagree; 2.51-3.50 = Undecided; 3.51-4.50 = Agree; 4.51-5.00 = Strongly agree

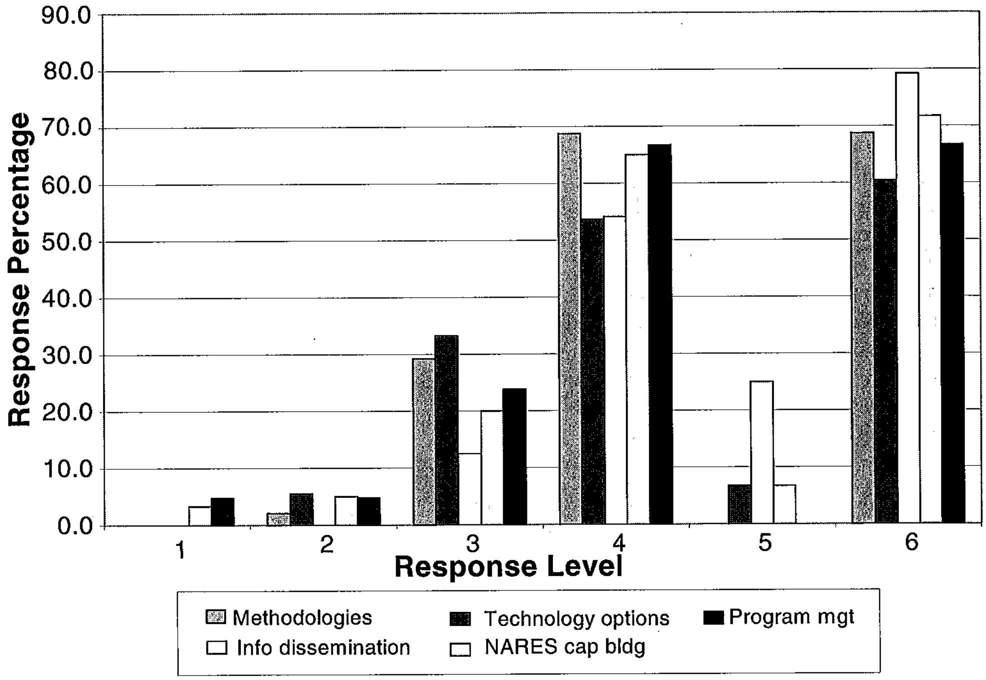

Figure 4. Percentage distribution of the response of researchers to the change indicators with respect to the expected output

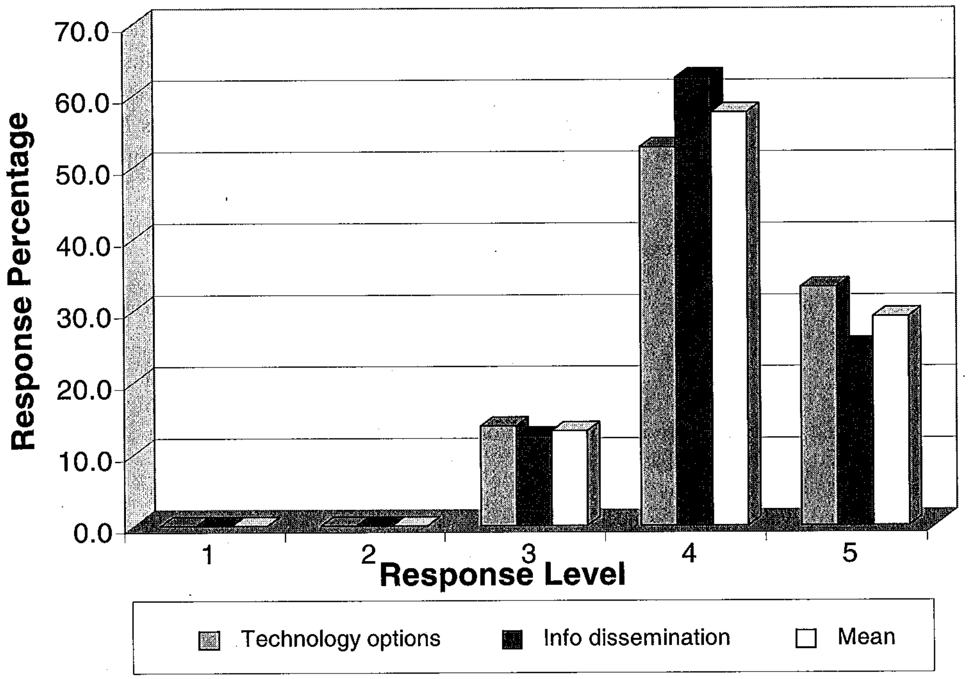

Figure 5. Percentage distribution of the response of farmers to the change indicators with respect to the expected output

For both the researchers and farmers, the effect of introduced intervention has not yet been strongly felt. The effect of this output still needs more time to be reflected in the productivity of the system of the farmers. While it may be premature to assess the impact in terms of productivity improvement, the responses by the farmers clearly indicated some degree of positive anticipation. The usefulness of the tools and guidelines and program management outputs has yet to be fully realized by the researchers.

The proportion of the "undecided" responses ranged from 12 to 33 percent with most of the responses being related to the effect of improved technology options. The researchers have yet to see changes in their institutes' policy supporting natural resource management, improvement in their resource generation, optimization of the use of resources, and the related benefits of reducing the cost of research. In essence, much more time is needed to see the effect on policy-makers.

Response by Country

All countries, except Nepal and Thailand, agreed with all indicators related to tools and guidelines as indicated in Table 3. In Nepal, the tools and guidelines only resulted in positive responses in terms of helping in decision-making, increasing appreciation of the project, and optimizing the use of resources. In Thailand, these helped only in facilitating project implementation.

Table 4 indicates that all researchers, except in Indonesia, acknowledged a high severity of soil erosion and all except Thailand agreed that the problem can be addressed by appropriate technology. All agreed that better production will result because of the new technologies, but only Indonesia and Vietnam concurred that income will increase with the new technology options. Lao PDR, Indonesia, and Vietnam agreed that there were observed changes in the erosion rate because of the technologies.

In Lao PDR and the Philippines, all responses were in agreement with the change indicators related to alternative technologies. In fact, in both countries, the farmers strongly agreed with six of the nine questions. In Indonesia and Vietnam, the farmers agreed that they now better appreciated the problem, and considered the ways in which options are introduced to be acceptable. In Vietnam, however, farmers were undecided whether their income would increase with the new option and whether they would continue with the practice introduced. In the case of Thailand, the farmers were undecided whether the identified technologies would bring benefits to them. In Vietnam, two change indicators did not get any positive feedback from the farmers.

All researchers, except those in Vietnam, remained undecided whether there is reduction in the cost of research (Table 9). All except Thailand agreed that it improved evaluation of project results. Only Lao PDR, the Philippines, and Vietnam considered the management of the program to optimize the use of resources.

In all identified outputs, it appears that the project has yet to produce positive change in Thailand. The same is applicable to the researchers in Nepal except for information dissemination strategies, which received a positive response.

In Lao PDR, the researchers believed that a positive change has been manifested by the project except for their perception that the approach that the project has employed has not brought a reduction in the cost of research. In Indonesia and the Philippines, the researchers did not believe that training increased their interest and motivation and that there is better optimization on the use of resources and no reduction in the cost of research. Vietnamese researchers responded positively to all change indicators.

The relatively low agreement to the positive effect of the project on researchers in Thailand and Nepal seems to be a reflection of the problems that both countries have encountered in project implementation. Both countries experienced the problem of rapid turnover of staff involved. In the case of Thailand, some of the researchers who have been trained for the project were assigned other responsibilities. The project started rather late in Nepal and has likewise encountered security problems. Moreover, the project leadership in Nepal has been affected by the other internal problems within the organization.

Summary and Conclusion

A simple questionnaire was devised to make an initial evaluation of the impact of the Management of Soil Erosion Consortium (MSEC) project implemented in Indonesia, Lao PDR, Nepal, the Philippines, Thailand, and Vietnam. The impact was evaluated based on responses by the researchers to the change indicators related to five project outputs and by farmers to two project outputs.

The highest positive response was in the effect of improved information dissemination strategies with a high proportion of the responses strongly agreeing with the change indicator. This implies that the conduct of regular meetings with the farmers has resulted in a positive impact and the frequent interactions have increased appreciation of the project by both the researchers and farmers.

For both researchers and farmers, the effect of the introduced interventions has yet to become evident. This implies that the effects of this output are all to be reflected in the productivity gains by farmers. While it may be too early to assess the impact in terms of productivity improvement, the responses by the farmers clearly indicated their positive anticipation. The usefulness of the tools and guidelines and program management outputs has not yet been fully realized by the researchers.

The researchers have yet to see changes in their institutes' policy supporting natural resource management, improvement in their resource generation, and optimization of the use of resources and the related benefits of reducing the cost of research. In essence, much more time is needed to see the effect on policy-makers.

In all identified outputs, it appears that there is still no positive change that the project has made in Thailand and Nepal.

While the study has provided some indications of the impact of the MSEC project, further evaluation of the methodology and analysis of the data are needed to complete the requirement of the framework. It should consider particularly the biophysical and economic impact of the project.

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Development and Validation of the PLER (Predict and Localize Erosion and Runoff) Model

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Abstract

The development of simple models, which can be used even by those who do not have much knowledge about computers and/or modelling science is one major activity of the Management of Soil Erosion Consortium (MSEC). The PCARES (Predicting Catchment Runoff and Soil Erosion for Sustainability) model was the first model that was evaluated and tested for applicability to MSEC using the data from the Philippine catchment (Paningbatan, 2001). The model can predict the spatial and temporal distribution of soil erosion processes and rate and also the runoff and sediment discharge rates at the catchment outlet. Based on the concept developed by Rose and Freebairn (1985), it simulates overland flow and soil erosion for each erosive rainfall event. Predicted and observed values, however, were not close to each other. A second model (MSEC-1) was then developed, also based on the GUESS model (Eiumnoh, 2002). A major constraint, however, was a fixed runoff coefficient, which is not realistic according to the observations in the catchments. A further refined model, PLER (Predict and Localize Erosion and Runoff) has been developed in Bangkok considering the problems inherent in the first two models. It integrates the infiltration capacity of the soil and can simulate overland flow and soil erosion for each erosive rainfall event. The data on water discharge and soil erosion collected and monitored for two years in the Thai catchment were used to calibrate and validate the PLER model. Results showed closer agreement between the predicted and observed values of discharge and total runoff than the results using the first two models.

Introduction

Hydrology and soil erosion models could be a valuable tool in simulating hydrological processes and in planning land management strategies for a watershed. If properly validated, they can be used to great advantage in testing research hypotheses, seeking alternative intervention, and predicting results of management options before they are carried out or implemented in the field. Innovative interventions or mitigating measures could then be properly formulated and targeted to the critical areas in watersheds that require soil conservation treatments.

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The development of simple models that can be used even by those who do not have much knowledge of computers and/or modelling science is one major activity of the Management of Soil Erosion Consortium (MSEC). As such, the models should take into consideration the following: (a) compatibility of data input-output requirements of the model with the methodology of MSEC; (b) applicability to the MSEC approach; (c) user friendliness with minimum data input; and (d) cost of acquisition of the software needed to run the simulation model. Simple concept, structure, and operation of the models are positive indications of user friendliness considering that most MSEC researchers are computer literate but not necessarily simulation model users or model developers.

Spatial analyses of hydrological parameters and processes at a watershed scale have been limited to cartographic techniques or overlaying of thematic maps. However, recent advances in computer and information technology have enabled researchers to deal with these complexities. Advances in geographic information system (GIS), global positioning systems (GPS), and remote sensing, for example, have now facilitated not only cartographic but also dynamic modelling of the time- and space-dependent hydrological processes at a watershed scale.

This paper describes the development of soil erosion and hydrology models that are applicable on a catchment scale. It is expected that these will serve as tools to scale up to larger catchments if further refined and validated.

Model Development

Because it was important for MSEC to have a dynamic model (that means a model which gives a dynamic view of the erosion location and its importance), model development and evaluation were focused on those capable of running with PCRaster. PCRaster is a GIS software package capable of cartographic and dynamic modelling that allows easy simulation of the hydrologic and sediment transport processes occurring on a three-dimensional landscape. It was developed in the Netherlands by the University of Utrecht (van Deursen, 1995).

PCRaster has provided an infrastructure allowing the simple localized rules to be implemented in a way that formation and evolution of global virtual landscape structures can be observed. It is set up in a way that the researcher concentrates on the rule sets of the landscape itself in a high-level modelling language. By concentrating on processes rather than programming, one is able to make contributions to the science of landscape formation rather than computer science issues.

PCARES (Predicting Catchment Runoff and Soil Erosion for Sustainability) Model

Paningbatan, (2001) started the development of the soil erosion model for MSEC by conducting a search from the Internet and published literature. After testing the applicability of three of the existing erosion models to the MSEC research undertaking using the data obtained from the Philippine catchment, the PCARES (Predicting Catchment Runoff and Soil Erosion for Sustainability) model was selected. PCARES is a physical model that simulates runoff and soil erosion of a catchment during each erosive rainfall event (Paningbatan, 2001).

The model can not only predict the spatial and temporal distribution of soil erosion processes and rates but also the runoff and sediment discharge rates at the catchment outlet.

It incorporates a sediment transport routine described by Rose and Freebairn (1985), which calculates the soil loss, SL (kg s^{-1}) from the product of sediment concentration, c (in kg m^{-3}) and water discharge rate, Q ($m^3 s^{-1}$). Sediment concentration was estimated using the simplified equation,

$$c = 2700\lambda S (C_r) \quad (1)$$

Thus, the sediment loss (kg s^{-1}) at each cell was calculated from Eq. 2:

$$SL = 2700\lambda S (1 - C_o)(Q) \quad (2)$$

where:
SL is soil loss (kg s^{-1}),
λ is the efficiency of sediment entrainment,
S is the sine of the slope angle,
$(1 - C_o) = C_r$ where C_o is the ratio of the area not exposed to runoff or the contact cover fraction,
Q is the water discharge rate ($m^3 s^{-1}$).

To run the model, time series rainfall rates (mm h^{-1}) for each rainfall event selected for model validation and calibration were set to a five-second time step. Calibration was done using the data from the Lao catchment. The results showed that the predicted and observed water discharge started at the same time (Figure 1). Despite showing similar values of maximum discharge (close to 400 L s^{-1}), predicted values sharply increased but also immediately decreased after the peak flow. The total discharge was highly underestimated probably due to the contribution of groundwater that is not taken into account in PCARES. Similarly, the predicted and observed erosion (kg L^{-1}) occurred simultaneously with maximum values of the same order of magnitude (close to 15 kg s^{-1}, Figure 2). However, total erosion was also underestimated.

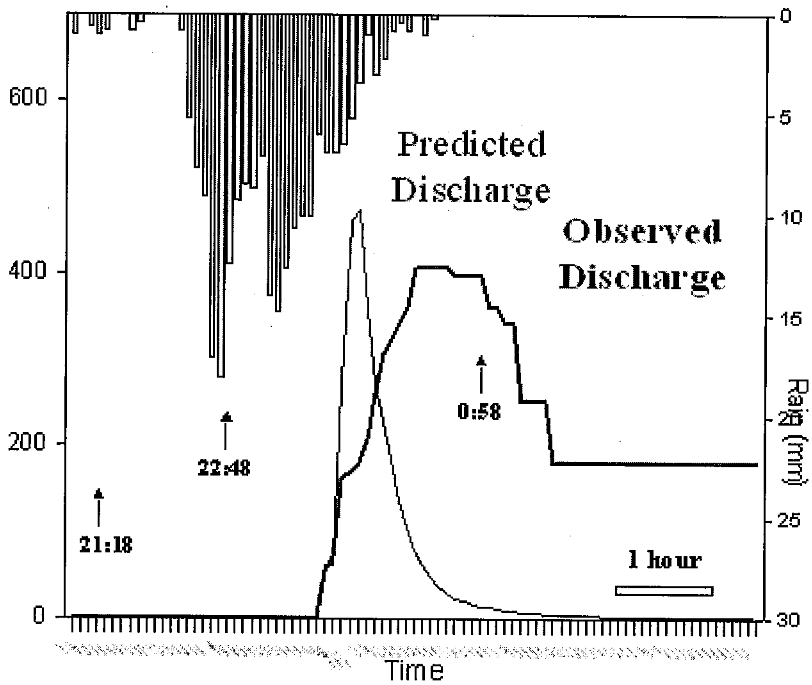

Figure 1. Predicted and observed discharge (L s-1) at the weir (Lao catchment) resulting from validation of the PCARES model using a rainfall event (September 3, 2001) of 90 mm and intensity of 90mm h^{-1}

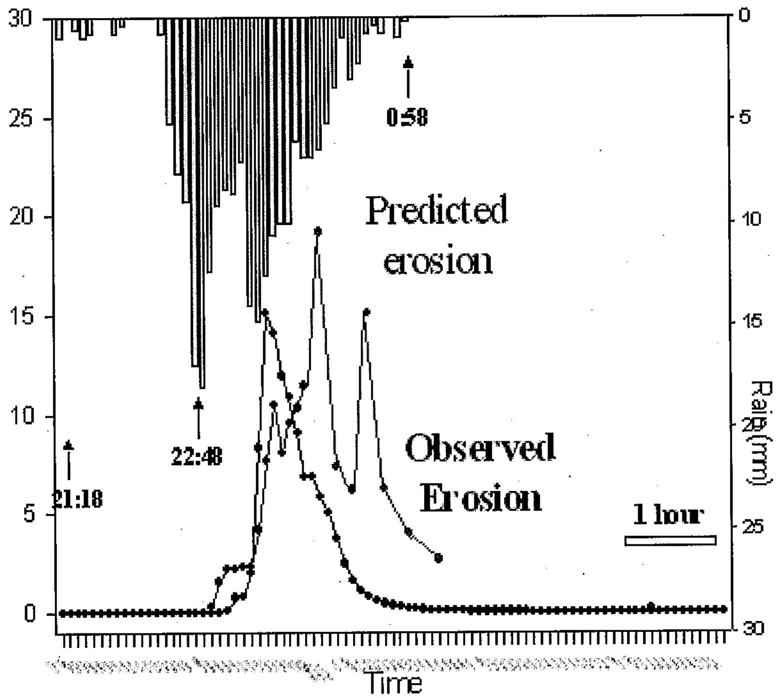

Figure 2. Predicted and observed erosion (kg s^{-1}) at the weir (Lao catchment) resulting from validation of the PCARES model using a rainfall event (September 3, 2001) of 90 mm and intensity of 90 mm h^{-1}

MSEC-1 Model

A second model, called MSEC-1, which is also an extrapolation of GUESS (Griffith University Erosion Sedimentation System) and integration within PCRaster language was later developed by Eiumnoh *et al.* (2001). The GUESS model for soil erosion, which was developed by Rose *et al.* (1983) illustrated the processes of soil erosion, transportation, and deposition. Therefore, the model can be used to predict on- and off-site effects. The concept of the model is to use the equilibrium of sediment in the area. It calculates the movement of sediment for each rainfall event by considering both the transport and deposition of the sediments during runoff. Generally, two types of soil are considered, original soil and newly deposited soil. The original soil has different cohesion and aggregation to the newly deposited soil. Therefore, in each rainfall event, the soil cohesion in the area will not be the same. The capability for leaching, eroding, and transporting of sediments varies according to Eq. 3.

$$\frac{\partial Q_{si}}{\partial \chi}+\frac{\partial (C_i h)}{\partial t}=e_i+e_{di}+r_i+r_{di}-d_i \qquad (3)$$

where;

Q_{si} = Sediment load of sediment class *i*

C_i = Concentration of sediment class *i* in the flow

e_i = The rate of detachment of particles of sediment class *i* in the original soil by raindrop impact

e_{di} = The rate at which recently detached soil of sediment class *i* is re-detached by raindrop impact

r_i = The rate of detachment of particles of sediment class *i* by flow

r_{di} = The rate at which recently detached soil of sediment class *i* is re-detached by flow

d_i = The rate of deposition

The idea behind integrating GIS-PCRaster in the GUESS model is to simulate soil erosion in a real situation or as virtual simulation in each rainfall event. Soil erosion is calculated by time steps or rainfall events. The results would then show the direction of flow according to the topography or DEM or LDD. Calculation starts from the first time step or the first rainfall event and sediments transported and deposited before the second time step or second rainfall event begins. The calculation process continues until the last time step or the last rainfall event. The amount of sediments transported and deposited may be obtained at the pit or outlet of the catchment or watershed.

The model also provides changes of sediments during each rainfall event according to the LDD. Therefore, it is possible to plan measures to reduce soil loss from the field. The raster format helps in the calculation of the movement or transportation of sediments through the LDD map.

The GUESS model, however, requires a runoff rate (Q) ($m^3 sec^{-1}$), which essentially is the total amount of runoff per event (åQ), since there are only event data. From the study of ICRAF (2001), the total amount of runoff per event, åQ is about 15 percent of the amount of rainfall per event. This value of runoff is used by the model. This is probably the main limitation of the MSEC-1 model. Using a fixed value of runoff could be unrealistic and dangerous as the runoff coefficient may vary from 2 to 60 percent. It is necessary to collect more information of each rainfall event to obtain the actual value of runoff.

The PLER (Predict and Localize Erosion and Runoff) Model

The MSEC-1 model was completely rewritten to address its limitation of using a fixed runoff coefficient and the need for clear code lines for the PCRaster. For the runoff calculation, the Curve Number as defined for the SWAT model (Arnold *et al.*, 1994) was used. This enables an estimation of the runoff at each time step or every rainfall event. The new model named the PLER (Predict and Localize Erosion and Runoff) model now combines the runoff determination of the PCARES model and the erosion calculation of the MSEC-1 model.

To further improve the prediction of erosion and runoff, the total infiltration capacity of the soil was incorporated as a new parameter. Thus the final model has five input maps, seven parameter tables, and two time series. The general design of the PLER model is shown in Figure 3. It is a distributed rainfall-runoff-erosion model taking into account the influences of topography, precipitation amount and intensity, antecedent soil moisture content, land use type, and soil type.

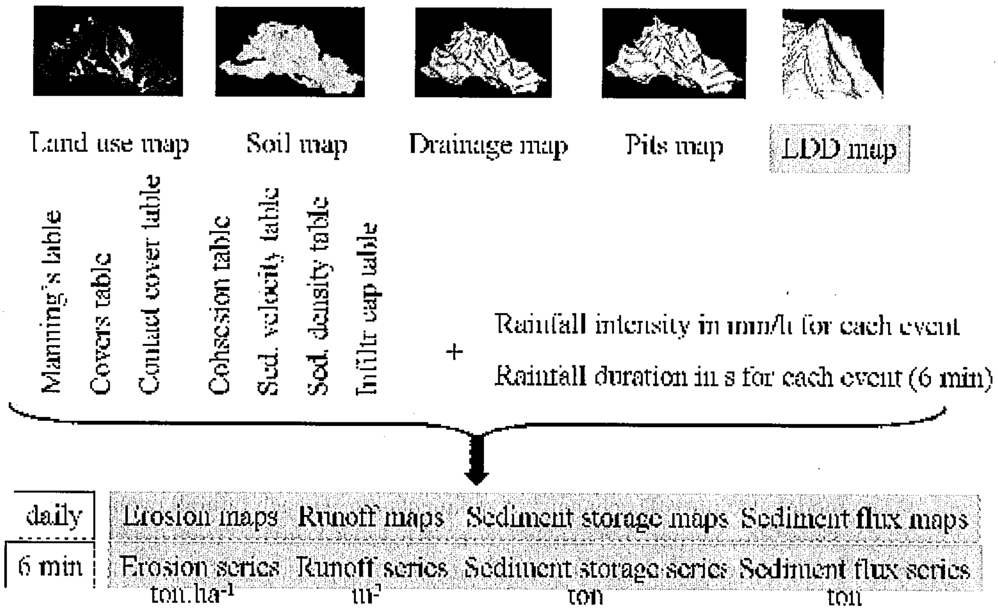

Figure 3. Flowchart of the PLER (Predict and Localize Erosion and Runoff) model

The model was built using the PCRaster Dynamic Modelling Language. Thus, it uses square grids to represent the landscape. The grid size is user defined and the maximum number of grids is limited by computer memory only. The simulation time step can also be defined by the user. The model has a very flexible structure and is easily adaptable. It contains about 250 code lines.

The outputs of the PLER model are hydrographs, total runoff, total erosion, and erosion fluxes at user-defined catchment outlets. Final maps of runoff and erosion and a series of maps showing changes in time can be produced.

PLER Model Calibration

The first calibration of the model was conducted with data gathered from a sub-catchment (Weir 1, 11.2 ha) in the Huai Ma Nai Catchment in Thailand. The DEM was built with a 2x2 m grid (Figure 4). Before running the model, the soil and land use parameters were defined as shown in Table 1. Manning's coefficients for the various land uses were derived from Morgan (1995).

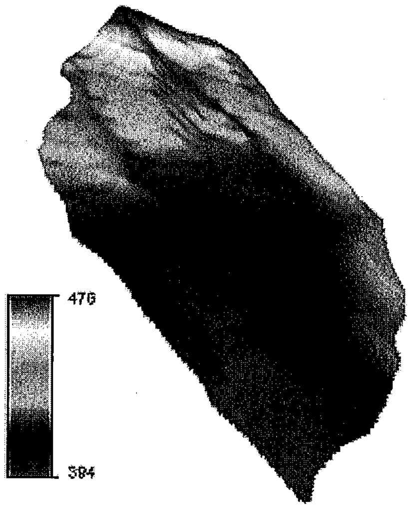

Figure 4. DEM of Weir 1 of Huai Ma Nai Catchment in Thailand

Table 1. Soil and land use parameters used in running the PLER model

	Manning's n	Cover	Cont cover
Forest	0.200	0.700	0.700
Abandoned trees	0.150	0.680	0.680
Bamboo/bananas	0.100	0.650	0.650
Fallow/grass	0.040	0.500	0.500
Orchard	0.700	0.600	0.600
Maize	0.090	0.350	0.350
Soybean	0.010	0.200	0.200

Figure 5 shows that the predicted and observed flow discharge started at the same time, but the decrease in the hydrograph was faster for the observed discharge. This implies that the model underestimates the rapid decrease in the soil humidity. However, the total volume of the runoff was similar. The observed runoff was 3,132 m^3 as compared to the simulated runoff of 3,018 m^3.

The second calibration was done for the whole Huai Ma Nai Catchment to also evaluate the capability of the model to work at a larger scale without introducing any changes. The whole Huai Ma Nai Watershed has an area of 93.2 ha. The DEM was built with a 5x5 m grid (Figure 6). The input tables were similar to the previous run.

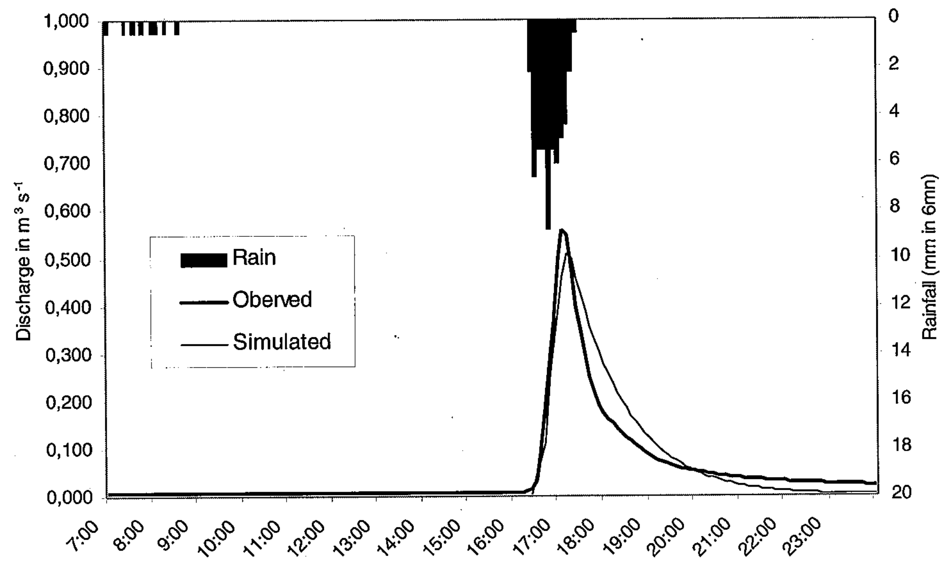

Figure 5. Comparison between the predicted and observed discharge ($m^3 s^{-1}$) at Weir 1 using the PLER model after calibration of a rainfall event (September 10, 2002) of 52 mm and intensity of 80 mm h^{-1}

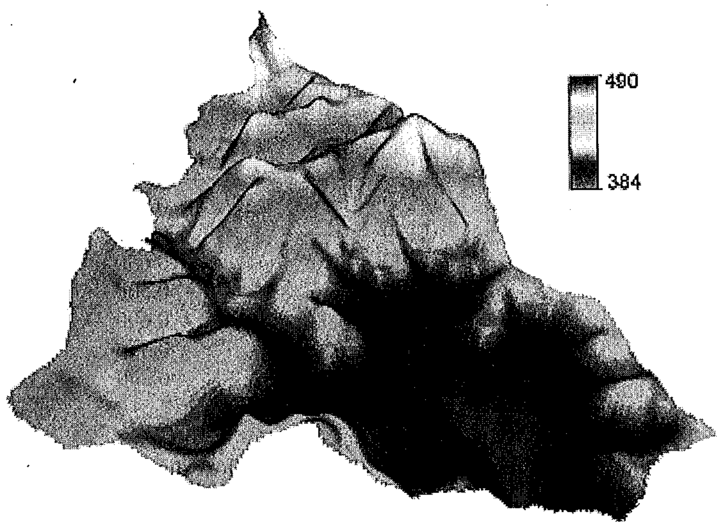

Figure 6. DEM of the whole Huai Ma Nai Catchment in Thailand

Figure 7 shows the result of the calibration of the PLER model for the whole catchment. Both the predicted and observed discharge started at the same time and reached almost the same maximum values (close to 2.5 $m^3 s^{-1}$). However, the predicted hydrograph increased and then decreased relatively slower than the observed hydrograph. Again, the total observed volume of 20,761 m^3 was close to the simulated volume of 19,240 m^3.

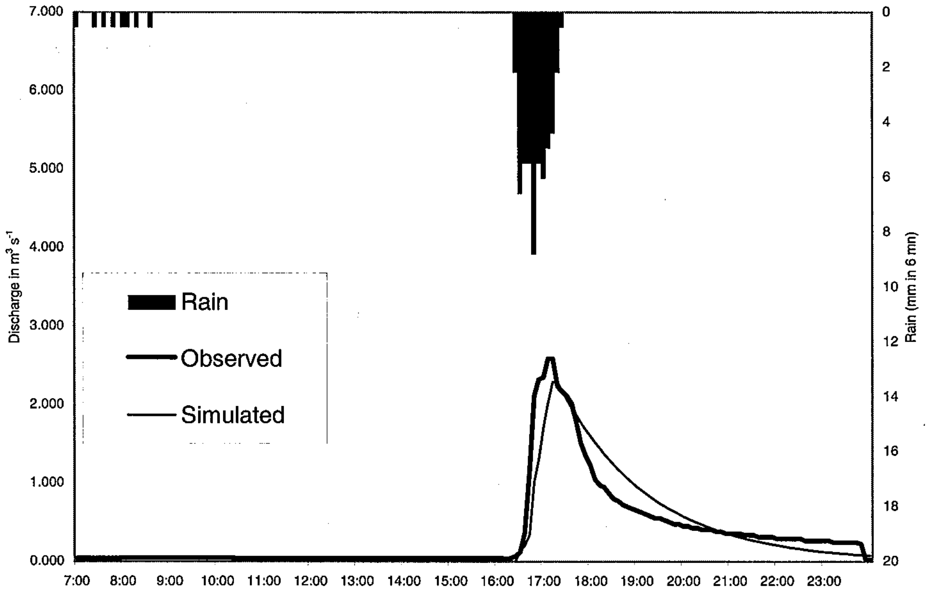

Figure 7. Comparison between the predicted and observed discharge (m^3 s^{-1}) at the flume (whole catchment) using the PLER model after calibration of a rainfall event (September 10, 2002) of 52 mm and intensity of 80 mm h^{-1}

Summary and Conclusion

The development and application of simple models for soil erosion is one major activity of the Management of Soil Erosion Consortium (MSEC). 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. This was later refined by the Asian Institute of Technology (AIT) in Bangkok and termed the MSEC-1 model for dynamic soil erosion. The limitation was that it treated the runoff coefficient as a constant even under varying conditions. The latest version, named PLER (Predict and Localize Erosion and Runoff) model combined the first two versions and has now addressed the problem of the fixed runoff coefficient by integrating soil infiltration capacity as one parameter in the model. 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 distribution and intensity of erosion, sediment storage, and flux.

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Economics and Soil Conservation on Sloping Lands: Nine Hypotheses for MSEC Project Implementation and Research

M. Giordano[1]

Abstract

While the basic physical processes behind land degradation are reasonably well understood and technologies for their arrest have been developed, the area of severely degraded land continues to expand. Part of the explanation for this unfortunate outcome may lie in the fact that the socio-economic factors which drive farmers' conservation decisions are often overlooked when degradation control measures are developed and implemented at the farm level. This paper attempts to highlight the role of socio-economic systems and institutions in producing and controlling land degradation. In the discussion, the concept of economically "optimal" degradation levels is introduced and a simple model of the farm level economics of land conservation is provided. The model is then utilized to develop nine hypotheses relating socio-economic conditions to farmers' decisions to adopt various land conservation strategies. These hypotheses are intended to serve as a departure point for the Management of Soil Erosion Consortium (MSEC) in its efforts to broaden the use of socio-economic analysis in its soil conservation research and implementation agenda.

Introduction

Land degradation has been defined as "the substantial decrease in either or both of an area's biological productivity or usefulness due to human interference" (Johnson and Lewis 1995, 2). While there is uncertainty as to the exact magnitude of the land degradation phenomena at the global scale (Swallow *et al.*, 2002), it is clear that degradation affects a significant portion of the earth's surface and that its costs can be substantial both to individual farmers and whole societies (Eswaran *et al.*, 2001). Furthermore, there is evidence that the social dimension of these costs may be especially high in certain tropical developing countries (Stocking, 1984; Lal, 1990; Barbier and Bishop, 1995; Bojö, 1996; Enters, 2000). While the basic physical processes behind land degradation are reasonably well understood and technologies for their arrest have been developed, the area of severely degraded land continues to expand (Oldeman *et al.*, 1990). Part of the explanation for this unfortunate outcome may lie in the fact that the socio-economic factors behind which individual farmers make land conservation decisions are often overlooked when land conservation measures are developed and implemented at the farm level.

The Management of Soil Erosion Consortium (MSEC) of the Consultative Group on International Agricultural Research has as a primary objective the development of community-

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based land management practices to arrest soil degradation. The consortium consists of six member countries including Indonesia, Laos, Malaysia, the Philippines, Thailand, and Vietnam. The first phases of MSEC work focused on the development of land conservation strategies for a variety of environmental and economic settings, but especially to areas with steep elevation. The next stage of the work will focus on the dissemination and uptake of the accumulated knowledge and understanding. Recognizing that socio-economic factors will play a significant role in this endeavor, MSEC is incorporating economic research into its work plan and strategies. This paper provides some concepts for using socio-economic theory and data to assist MSEC in its endeavor.

To do this, the paper first uses economic theory to provide insights into the costs and benefits of land conservation and presents the concept of "optimal" degradation. It then argues that current land conservation investment, whether from the perspective of individual farmers or society as a whole, is likely to be sub-optimal, in particular on the marginal lands of poor farmers in developing countries, the areas of most interest to MSEC members. A simple model of farmer investment in land conservation is then provided and employed to develop hypotheses which MSEC and others can use to create and target farm-scale land remediation strategies and which can serve as a basis for future research.

The Political Economy of Land Degradation

The term land degradation is typically considered to consist of soil erosion, the "physical loss of topsoil, reduction in rooting depth, removal of plant nutrients, and loss of water" (Lal 1990, 9), and loss of soil fertility. Soil erosion is the more easily quantifiable, and therefore more often studied, component of land degradation, but fertility decline may be as important, at least in developing countries (Drechsel and Gyiele, 1999; Eswaran *et al.*, 2000). At its most fundamental level, land degradation is caused when natural physical factors such as wind, rain, and gravity combine with human management practices to remove soil or its nutrients from a given site. While land degradation could be considered "natural" in some senses, it is human involvement which typically results in rates of decline of social concern at human time scales and drives the working definition given in the opening paragraph. Of the range of human actions associated with land degradation, the most important have been listed as deforestation and removal of natural vegetation, overgrazing, and poor agricultural practices (Oldeman *et al.*, 1991). The fundamental human role in land degradation is now relatively well understood, at least conceptually, and there is probably also near consensus that research to remedy land degradation must include a social component. This idea was exemplified by Miller who stated, "...curtailing soil and land degradation rests as much, if not more, in the realm of social sciences as in the natural or physical sciences" (1998, 15).

Unfortunately, an understanding of the interconnection between land degradation and land use practices has not always meant that social science has been effectively used to improve land conservation. Instead, many land conservation programs, especially in the developing world, have tended to emphasize technical solutions, such as terracing or ditch construction (Barbier, 1990; Lutz *et al.*, 1994; World Bank, 1994; Current *et al.*, 1995; Barbier 1999), rather than the economic factors, such as profitability, which drive farmers' decisions to employ degradation-reducing technologies and strategies. Even less emphasis has been put on the more fundamental factors such as poverty, legal institutions, and the national policy environment which can be seen, in some senses, as the ultimate causes of land degradation.

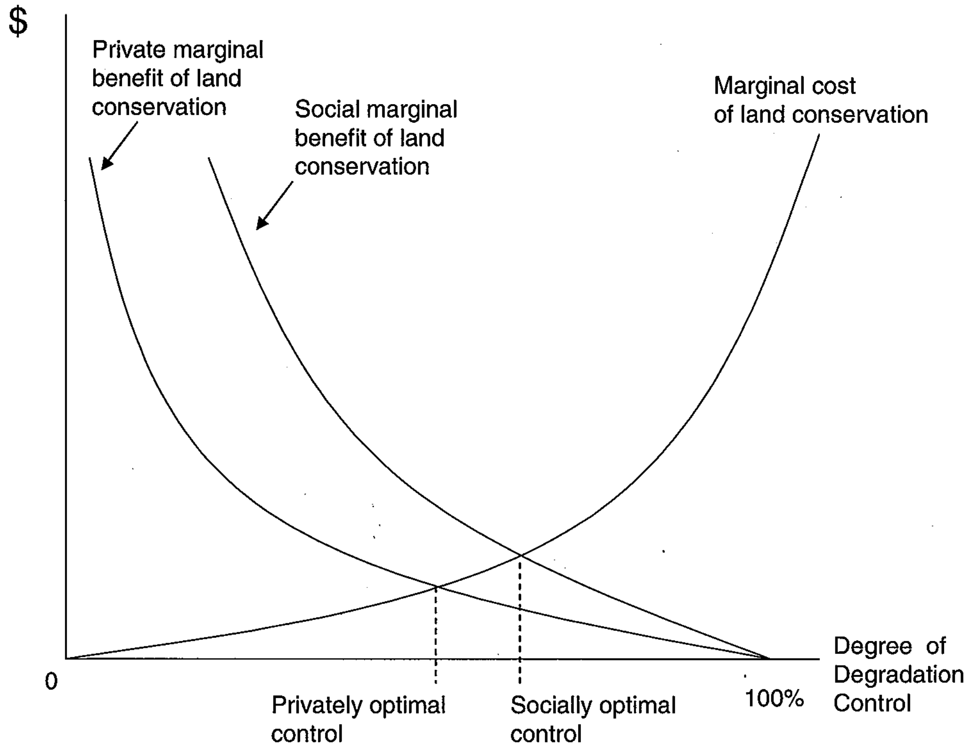
It is an understanding of these ultimate factors combined with the economics of farm level decision making, which together might be considered as "the political economy of land degradation," that is critical if the technical degradation control work of natural and physical scientists is to be successfully implemented in a manner which is sustainable in the long-term.

Economics, the Costs of Land Degradation, and "Optimal" Degradation Levels

Economics can add to an understanding of land degradation in part because it addresses costs. As highlighted above, land degradation can impose substantial costs on individuals and societies. These costs occur at two levels, typically referred to as on and off site. The on-site, or farm level costs of degradation are primarily related to reductions in future agricultural productivity but can also include increased risk, a factor disproportionately affecting marginal farmers (Barbier, 1996). Additional on-site costs may occur in terms of decreased forest cover and degraded water supplies which increase household labor requirements (e.g. in terms of fuelwood gathering) and contribute to lower health levels. The off-site impacts of land degradation can take myriad forms and may include reduced water quality, decreased reservoir storage, loss of navigational efficiency, disrupted irrigation supplies, and degraded fisheries. More broadly, off-site costs can include changed climatic conditions, decreased carbon sequestration, and reductions in perceived environmental amenities.

While any of these costs may be substantial, from an economic perspective, the question is not how land degradation and its damaging impacts can be stopped, but rather what the optimal rate of degradation is and how a society may move towards it. The concept of "optimal" land degradation can be perplexing to non-economists but is critical to grasp in formulating land conservation strategies with the highest chance of successful farmers' adoption. The idea of optimal degradation levels stems from the fact that degradation control generally requires the utilization of resources. Resources are by definition scarce (i.e. they have a cost and are not free), and so the use of a resource for one purpose, such as erosion control, generally means that the same resource, or the money equivalent used to purchase the resource, cannot be used for another purpose. With respect to land conservation, the problem then becomes one of determining the quantity of resources which should be devoted to avoidance of land degradation rather than some other investment or consumption option. From the farmer's perspective, the optimal level is that at which the benefit, in terms of on-farm productivity and other gains, from applying an additional unit of resources for land conservation is equal to the cost of applying that unit. In other words, a farmer should invest in land conservation until her/his marginal benefit from that investment is equal to her/his marginal cost (see Figure 1, "privately optimal control"). So long as there are positive costs to land conservation, the optimal investment level is likely to be one resulting in continued degradation.

From this analysis, we can see that in a perfectly functioning economy, land degradation would still exist. However, there would not be a land degradation "problem," because farmers, in attempting to maximize their own welfare, would reduce degradation to the optimal level given relative resource scarcity and existing technologies. Unfortunately, an "optimal" degradation level is unlikely to be achieved, especially in the case of poor farmers on marginal lands, for at least four reasons.



In general, we expect that farmers will devote resources to land conservation until the marginal costs of conservation equal the marginal benefits. However, the existence of externalities-the off-site costs of erosion- suggests that the private marginal benefits of conservation for the farmer are less than those for society as a whole, resulting in underinvestment in conservation from a societal perspective. Whether from the point of view of the individual farm or society, it is important to note that the "optimal" conservation is unlikely to be equated with no degradation.

Figure 1. "Optimal" land degradation and the marginal costs and benefits of land conservation

First, as stated, when farmers take measures to reduce degradation on their plots, benefits accrue both on and off site. However, the costs of controlling degradation, for example in terms of investment and possible removal of land from production, will generally fall entirely on site, i.e. to the farmer. This asymmetry in the benefits and costs of action causes what is known as an externality problem and will tend to result in an underinvestment in erosion control measures. Put another way, the marginal benefit to society of reduced degradation is greater than the marginal benefit to the farmer and, as shown in Figure 1, the farmer's investment in land conservation, from a societal point of view, is sub-optimal.

Second, property rights' regimes are frequently ill-defined in the marginal lands of developing countries, and land markets are likely to be imperfect or non-existent. When property rights are poorly defined, a farmer's expected return to erosion control is lower than would otherwise be the case, because she or he is not assured of reaping the long-term returns from her or his action in terms of increased crop output (Feder and Onchan, 1988). Even with well-defined property rights, land tenure arrangements may also influence the adoption of land conservation strategies. For example, there is evidence from the United

States that cash-renters are less likely to use conservation tillage than share-renters or owner-operators (Soule *et al.*, 2000), and in India land tenure laws discourage long-term leasing and, with it, incentives to invest in erosion control (Kerr, 1998). Similarly, if land cannot be sold (an illiquidity problem) or improvements in land are not fully capitalized in land values, farmers will be unable to recoup their investments through sale or legacy, again tending to result in underinvestment.

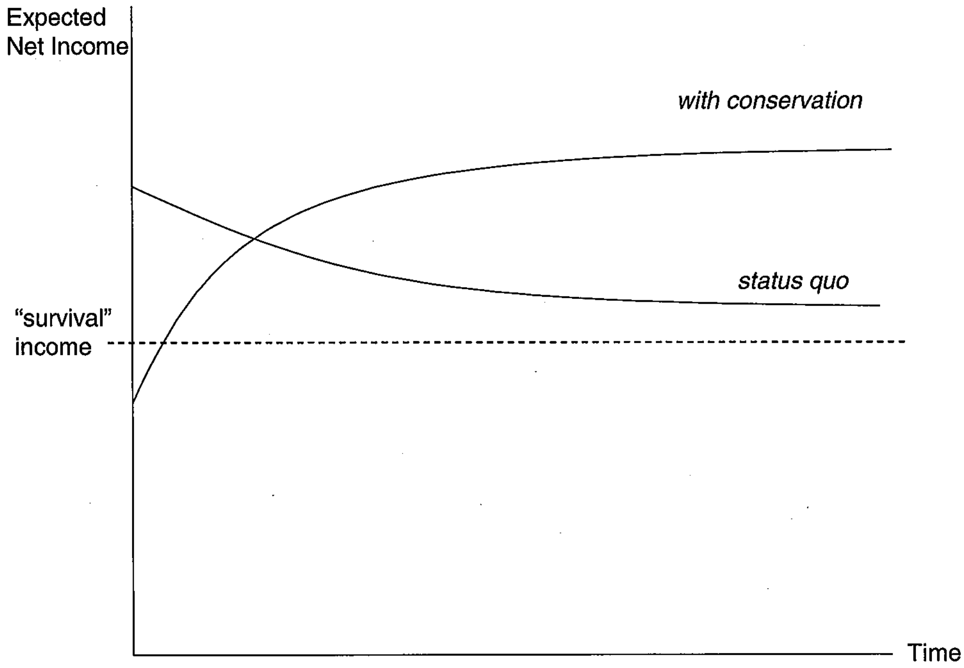
Third, capital markets are likely to be highly distorted in rural areas in developing countries and credit especially expensive for poor farmers. In part, this is related to the fact that many poor farmers, especially in marginal areas, do not have collateral in the form of land, a problem exacerbated by the property rights' problems just mentioned. As a result, farmers are unable to access formal credit channels and instead must borrow at high rates from local creditors, increasing the cost, and hence decreasing the quantity of investment in degradation control. In fact, Feder and Onchan (1988) showed that one of the principal reasons that land ownership in Thailand was correlated with conservation was that title to land allowed access to institutional credit. Furthermore, there is evidence that, even if rural credit markets did function properly, the discount rate that individual farmers apply to investment decisions may be lower than that which society applies, again resulting in sub-optimal investment (Barbier, 1996). This problem may also be worsened when property rights are not secure (Bishop, 1992).

Finally, there may be overarching national policies that encourage underinvestment in erosion control. For example, Barbier (1990) found that subsidies encouraged Javan farmers to purchase fertilizers to enhance yields rather than invest in more environmentally sound soil conservation practices. Nelson (1990) came to a similar conclusion regarding the subsidization of tractors in Tanzania (cited in Kerr, 1998). Other policies which may impact farmers' willingness to invest in soil conservation include exchange rate distortions, agricultural price interventions (Barbier and Burgess, 1992 cited in Barbier, 1996), and tax policy, though the direction of these impacts on erosion control is dependent on circumstance.

A Conceptual Model of Farm Level Investment in Land Conservation

There are thus many factors which tend to cause farmers, especially poor farmers on marginal lands, to choose land conservation levels which are socially, and even privately, sub-optimal. In addition, each of the factors just cited was socio-economic, rather than physical, in nature. As a result, there is no reason to believe, *a priori*, that further dissemination of technology-based erosion control strategies will be, in and of themselves, likely to solve erosion problems. Rather than focusing predominately on technical solutions, researchers and extension agents should instead try to understand both the socio-economic and the physical environments in which farming decisions are made and which lead to sub-optimal erosion control and then tailor extension services to meet those specific circumstances. Only through such an approach are the many promising technical and engineering solutions to erosion control likely to be successful in the long term.

To help in understanding how land conservation investments are determined in a given physical and social environment, we can use the simple model, shown in Figure 2, of the farmer's decision-making process.[2] Most farmers appear to be aware that land degradation typically carries with it costs in terms of reduced soil productivity (Kerr, 1998). Thus, farmers anticipate that a continuation of status quo practices will result in a decline in net income from a given piece of land over time as degradation reduces soil productivity. In contrast, farmers expect that soil productivity will increase, or fall less rapidly, if productive investments in conservation are made. However, such investments involve initial costs as well as continued upkeep and so expected net income in early investment periods may actually be less than under the status quo scenario.



Land use practices which cause degradation tend to reduce expected net income over time as productivity decreases. Investment in conservation can reverse the fall but typically requires up-front and on-going costs. How farmers perceive the status quo degradation path, the costs of conservation and the rate at which the investment will provide returns all influence whether or not a particular conservation measure will be undertaken. However, particular socio-economic factors and constraints will also influence the adoption rates of particular farmers in particular places. For example, if an initial investment in a conservation strategy puts a farmer below "survival" income levels, the strategy is unlikely to be adopted even if it "pays" in the long term.

Figure 2. The farm-level economics of investment in land conservation

We would expect the farmer to engage in erosion control investment as long as the expected net income with conservation was more over the relevant time horizon of the investment than if no investment were made. Given a range of land conservation options, the farmer would be expected to invest in the technology resulting in the highest expected net income. However, as already discussed, there are many reasons that investment in land conservation will be less than optimal even as individual farmers attempt to maximize their own welfare. The

[2] This model is based on Barbier (1998). In Barbier's original work, present value is measured on the vertical axis. Since present value measures the value of an income stream at a point in time, it cannot be used to measure income across time. This is a minor mistake in the original work.

question for researchers and extension agents then is, given the socio-economic conditions in which farming takes place and a farmer's decision-making process, which technologies and bundles of extension services can be provided that have the highest possibility of being adopted over the long term and which will provide on-farm benefits and/or reduce off-site land degradation costs?

Implications for Extension and Further Research: Nine Hypotheses

With a better understanding of the role of socio-economics in land management decision making, insights can be developed to help address various aspects of the question just posed. For example, we can quickly see from Figure 2 that an investment in land conservation is unlikely to be made if that investment does not raise expected net income above the status quo levels. From insights such as this, working hypotheses can be developed to help extension agents and researchers target particular land conservation strategies that are consistent with the broader socio-economic environment in which they are working. Nine such hypotheses for targeting land conservation strategies are presented here.

Hypothesis 1: When property rights are insecure or land tenure has only a short-term guarantee, land conservation strategies with low initial costs are more likely to be adopted. As shown in Figure 2, an investment in erosion control causes an immediate decline in expected farm income. The larger the initial costs of that investment, the longer the time period which is required for the farmer to recoup her or his funds. Insecure land rights, short-term tenure arrangements, and certain rental arrangements, as discussed above, reduce the probability of farmers reaping the full benefit from the future productivity gains. Under such circumstances, land conservation strategies with low initial investments are more likely to be profitable from the farmer's perspective and are therefore more likely to be adopted. To a lesser degree, the same result holds for cases in which land markets are imperfect and investments in soil conservation are not capitalized in land values. As an addendum, we should remember that "property rights" does not necessarily imply private property, and that many communal rights' systems may also be effective in guaranteeing a farmer's investment in soil productivity. Furthermore, there may be strategic reasons that farmers without property rights or tenure may invest in conservation under certain circumstances (Neef and Sangkapitux, 1999)

***Hypothesis 2: When property rights are insecure or land tenure has only a short-term guarantee, land conservation strategies with short pay off periods are more likely to* be adopted.** As described in Hypothesis 1, farmers are unlikely to invest in land conservation strategies with high up-front costs. However, there are two factors which influence the break-even time for an investment in land improvement, the initial costs already described as well as the waiting time before the investment produces increased yields (or decreased declines in yield). Land conservation strategies which have high "waiting costs," for example agro-forestry schemes which may take many years before any returns are realized, are also less likely to be adopted when property rights or land tenure is insecure.

Hypothesis 3: When farmers are extremely poor, land conservation strategies with low initial costs and short pay off periods are more likely to be adopted. Even if land tenure is secure, poor farmers, in particular those with no off-farm income and small plots needed for subsistence, will be unlikely to invest in land conservation strategies with high up-front costs and/or long pay-off periods because of short-term survival concerns. Consider a farmer with an income at the "survival" level as depicted in Figure 2. If the land conservation strategy shown in the figure were implemented, income in year zero would fall below the level needed for mere survival. Unfortunately, it is not possible to invest for long-term gain when short-term survival is in question. Poor farmers may also be reluctant to make erosion control investments, even if such investments do not put them below the survival level, if the investments require a switch from subsistence to cash crops because of the added risk (see Hypothesis 7).

Hypothesis 4: Farmers who do not perceive a direct land degradation problem are least likely to adopt land conservation strategies. Educational level and perception of erosion as a problem have been shown to be related to willingness to invest in erosion control (Ervin and Ervin, 1982). While, as stated above, there is evidence that farmers in general understand that degradation can have direct, on-farm costs, this is not necessarily the case. Furthermore, the actual costs of degradation are likely to be as difficult for farmers as for researchers to grasp. For example Eswaran (2001) noted that even establishing cause-and-effect relationships between land degradation and productivity is difficult. In addition, the existence of particular land management problems, for example high levels of erosion, does not necessarily translate into reduced farm income (Barbier, 1990). If the farmer's perception of land degradation is underestimated or degradation does not result in direct income losses, but rather imposes costs only off site, the fall in expected income depicted in the status quo scenario of Figure 2 will be less than true levels, in turn reducing both the perceived gains from land conservation and the likelihood of conservation investment.

Hypothesis 5: New commodity technologies are more likely to be adopted in areas where access to markets is secure, improved natural resource practices are more likely to be adopted in areas where this is not the case. New commodity technologies generally require more purchased inputs than improved natural resource practices (Crosson and Anderson, 2002). In areas where institutions and policies give farmers reliable and easy access to inputs on favorable price and credit terms, for example where markets and governments function well, commodity technologies will be relatively more attractive to farmers than improved natural resource management practices. Where markets and governments are less likely to function, natural resource management practices are likely to be relatively more attractive. In terms of Figure 2, this implies that, for a given technology, the shape and slope of the *with conservation* expected income curve will vary based on the location of the farmer. Thus understanding the institutional and policy environment, *at the location of the farmer*, is important in understanding the land conservation strategies most likely to be profitable at the farm level. It should be noted, however, that even when market access is poor, it is still important to consider relative prices and demand. In India, for example, straw and manure, which could provide soil nutrients, have high value for feed and fuel and so are unlikely to be employed in soil fertility schemes whether or not farmers are integrated into the cash economy (Kerr, 1998).

Hypothesis 6: Land conservation strategies which use crops that are consistent with the overall policy environment are most likely to be adopted. The introduction of new erosion control practices often requires a change in cropping patterns. New practices which encourage plantings of policy disadvantaged crops, that is crops which face higher taxation or lower subsidization than other viable crop options, will be less likely to succeed in the long term. Conversely, practices which favor policy advantaged crops, when farmers perceive that the advantage will be sustained, are more likely to succeed. The impact of the policy environment on the relative attractiveness of land conservation schemes which require changes in cropping patterns can also be much deeper than relative pricing levels. For example, McMillan and Masters (2000) showed that, all *else* being equal, farmers in many tropical countries have a disincentive to investment in crops with high-fixed costs or long gestation periods, aside from the issues brought up under hypotheses 1 and 2, because farmers expect confiscatory tax rates to reduce returns after investments are made.[3] In terms of Figure 2, the income effects of changes in cropping patterns are reflected by changes in the slope and level of the *with investment* income stream.

***Hypothesis 7: Land conservation strategies which take into account the risks of erosion control, farmers' risk perceptions, and farmers' risk tolerance are more likely to be* adopted.** The adoption of land conservation measures, either in terms of new cropping patterns or new procedures, involves risk. For example, a change from subsistence to cash cropping adds risk in terms of exposure to unfamiliar price patterns as well as unfamiliar responses to climatic and other natural variability. Increases in risk are typically reflected in a perceived decrease in future benefits (reflected by a drop in the *with investment* income stream of Figure 2) and should not be underestimated as a disincentive to change. Furthermore, this disincentive to change may vary markedly across farmers and locations. For example, subsistence farmers with little or no savings, small plots, and no off-farm income may have a much lower tolerance for the price risk associated with a shift to commercial cropping, even if they are guaranteed higher average income over time, than a farmer in a better economic condition.

Hypothesis 8. The expected benefit from conservation can change over time, even holding output prices and technology constant. The relative benefits from investing in land conservation can change over time as society-scale transitions take place. For example, Kerr (1998) and Southgate (2001) have provided conceptual models to demonstrate the mechanism through which changes in population densities or the land/labor price ratio can cause farmers to shift from non-degrading practices, to degradation and finally back to conservation. Tiffen *et al.* (1994) described how such an outcome actually occurred in Kenya while Critchley *et al.* (2001) discussed the relationship for the specific case of terracing. This finding implies that the exact nature of the curves shown in Figure 2 will vary over time for a given farmer in a given location as the broader economic and demographic landscapes change. Thus a conservation practice deemed "good" at one time might become unadoptable later and vice versa.

Hypothesis 9: Second "best" is sometimes better than best. Because farmers do not take into account the off-site benefits of erosion control, erosion control strategies with the highest on-site benefits are most likely to be adopted. This suggests that it may be best to advocate "second best" strategies which, though they are not optimal at the catchment or broader scales, may be better than no action in that they have an improved likelihood of adoption. To highlight this point, consider two erosion control strategies. The first has a high yield-increasing component, contributing to farmers' willingness to adopt, as well as minor off-site benefits in terms of reduced sedimentation. A second technique provides no yield increase to the farmer but substantially reduces downstream sedimentation. In general, it may be better to advocate the first strategy, even if it is sub-optimal from a technical or societal point of view, because of higher likelihood of actual adoption out of farmers' self-interest. Kerr (1998) points out that the second best strategy may also be appropriate when, as is likely

[3] The study was actually designed to explain how production technologies may influence tax rates, R&D expenditures, and growth rates in tropical countries. However, the study results have clear implications for willingness to change cropping patterns as explained in the text.

to be the typical case, land conservation decisions are influenced by other social, economic, and environmental objectives and constraints. For example, he notes that on some Indian lands, technically superior contour-based erosion control measures are unlikely to be adopted over boundary-based measures because of the need to demarcate ownership boundaries.

In summary these hypotheses and the ideas behind them highlight the role of property rights, income, resource policies, and markets, along with perceptions of the costs and benefits of land degradation, in farmers' decisions to change land management practices. The use of economic analysis to develop such insights into the "political economy of land degradation" can serve to broaden our understanding of the causes of, and likely solutions to, land degradation within the socio-economic settings of particular farmers in particular places. In addition, such insights can serve to suggest the policy interventions which might be used to encourage adoption of particular land conservation technologies. For example, in extremely poor areas, credit subsidies may be necessary to entice the adoption of conservation strategies with high start up costs (Hypothesis 3) whereas changes in national agricultural policy may be required in other circumstances (Hypothesis 6).

Conclusion

As stated by Barbier, "Far from being a purely technical problem of soil science or plant breeding, the core of the land degradation problem is economic" (1997, 891). While physical scientists may differ with the exact wording of this statement, it is clear that economics and land degradation are integrally intertwined. This paper attempted to highlight the interconnection by applying the tools of economics to the analysis of land degradation and the adoption of conservation strategies. To do this, the concept of "optimal" land degradation was introduced, and it was suggested that current land conservation investment, especially for poor farmers in marginal lands, is likely to be sub-optimal. A model of farmers' behavior with respect to land conservation investment was then presented and used to generate hypotheses related to the adoption of land conservation strategies under various socio-economic circumstances. These hypotheses have four main functions. First, they can serve as a basis for targeting conservation intervention and suggest the data which should be collected to effectively carry out that targeting. Second, they suggest the policy interventions which might best be used to encourage the adoption of particular land conservation technologies in order to overcome externality or other market failures. Third, they can be taken as refutable statements to provide a basis for future research and empirical study to further improve our understanding of the factors which drive farmers' adoption of land conservation. Finally, and perhaps most importantly, they highlight the vital importance of economic, political, and geographic circumstances – the "Political Economy of Land Degradation" – in understanding why degradation takes place and how programs such as MSEC can best integrate their physical and social science work to lessen its negative impacts.

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Progam

2 December, Monday

Arrival of participants in Vientiane, Laos, check-in at Lane Xang hotel, registration

3 December, Tuesday

0800-0830	Registration, continued	
0830-1000	**Opening Session**	
	Messages	T. Bandaragoda, Director, IWMI-SEA G. Rambaldi, ADB
	Keynote address	B. Bouahom, Director General, NAFRI
	Introduction of participants, meeting rationale and guidelines	A.R. Maglinao, IWMI-SEA
	Master of Ceremonies:	P. Sophathirath, IUARP, NAFRI
1000-1030	Coffee break	
1030-1230	**Technical Session 1: Sharing Experiences**	
	Chair: Giacomo Rambaldi, ADB	
	Rapporteur: Amado Maglinao, IWMI	
	IWMI	A.R. Maglinao, IWMI-SEA
	IRRI	K. Goepert, IRRI, Lao PDR
	ASIALAND	A.B. Armada, PCARRD
	IUARP	P. Sophathirath, NAFRI
1230-1330	Lunch	
1330-1500	**Technical Session 2: Soil and Soil Erosion Research**	
	Chair: C. Valentin, IWMI-IRD, Lao PDR	
	Rapporteur: F. Agus, CSAR, Indonesia	
	Regional analysis of rainfall patterns in Asia	J.P. Bricquet, IWMI-SEA
	Soil infiltration, rainfall, runoff relationships	W. Soda, IWMI-SEA
	Tillage erosion in Lao PDR and Thailand	B. Dupin, IRD, Lao PDR
	Hydrological behavior and land use characteristics	M. Villano, the Philippines
1500-1530	Coffee break	

1530-1800	**Technical Session 3:**	**Managing Soil Erosion**
	Chair: J.P. Bricquet, IWMI-SEA, Thailand	
	Rapporteur: R.O. Ilao, thePhilippines	
	Soil erosion and land use change	A. Chanthavongsa, Lao PDR
	Effect of catchment size on soil erosion	F. Agus, Indonesia
	Nutrient yield and on-site cost of soil erosion	Sukristiyonubowo, Indonesia
	Agricultural practices, soil erosion and productivity	T.D. Toan, Vietnam
	Effect of land management practices on soil quality and productivity in Kaligarang watershed, Indonesia	B. Hermiyanto, Indonesia
1900-2100	Reception dinner (hosted by IWMI)	

4 December, Wednesday

0800-1000	**Technical Session 4: Assessing Impact**	
	Chair: D. Bosio, IWMI, Sri Lanka	
	Rapporteur: A.B. Armada, the Philippines	
	Off-site effect of erosion: the silting of reservoirs	A. Boonsaner, Thailand
	Impact assessment: Methodology and its application to the MSEC project	A.R. Maglinao, IMWI-SEA
	Modelling soil erosion: Scaling up and scaling out	J.P. Bricquet, IWMI-SEA
	Economics and soil conservation: Somehypotheses for the MSEC project implementation and future research	Mark Giordano, IWMI, Sri Lanka
1000-1030	Coffee break	
1030-1200	**Summary of Paper Presentation/ Briefing on Field Trip**	A.R. Maglinao C. Valentin
1200-1300	Lunch	
1340		Travel to Luang Prabang
1500-1800	Field visit and discussion	C. Valentin/A. Chanthavongsa
1900	Dinner	

5 December, Thursday

0830-1230	Visit around Luang Prabang	
1440-1510	Travel to Vientiane	
1600-1700	Discussion of field visit	C. Valentin/A. Chanthavongsa
1700-1730	Preparation of project timeline	G. Rambaldi

6 December, Friday

0800-1000 **Technical Session 5:** **Action Plans, Panel Discussion**

Chair: F. Penning de Vries
Rapporteur: A.R. Maglinao

Financial situation and 2003 MSEC work plan
Institutional support for national development (country work plan)
Policy implications of the project

1000-1030 Coffee break

1030-1200 **MSEC SC Meeting/Other Special Meetings (Contd.)**
(*Materials for the SC meeting given to participating members)*
R.O. Ilao
A.R. Maglinao

1200-1300 Lunch

1300-1500 Continue meetings

1530-1600 Coffee break
1600-1730 **Final Plenary and Closing**

Chair: A.R. Maglinao/C. Valentin

Report of special group on work planSukristiyonubowo
M. Villano
Report on steering committee meeting R.O. Ilao
Remarks G. Rambaldi
F. Penning de Vries
B. Bouahom

7 December, Saturday

Departure of participants

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Acronyms Used in the Publication

ACIAR	Australian Center for International Agricultural Research
ADB	Asian Development Bank, Philippines
AFRS	Agriculture and Forestry Research Service, Lao PDR
AIAT	Assessment Institute for Agricultural Technology, Indonesia
AIT	Asian Institute of Technology, Thailand
ARI	Advanced research institutes
AWLR	Automatic water level recorder
CA	Comprehensive Assessment of Water for Agriculture
CFV	Conservation farming village
CGIAR	Consultative Group on International Agricultural Research
CIAT	International Center for Tropical Agriculture, Colombia
CIFOR	Center for International Forestry Research, Indonesia
CIRAD	Centre de CoopŒration Internationale en Recherche Agronomique pour le DŒveloppement, France
CMU	Central Mindanao University, Philippines
CRIDA	Central Research Institute for Dryland Agriculture, India
CSAR	Center for Soils and Agroclimate Research and Development, Indonesia
CP	Challenge program
DA	Department of Agriculture, Philippines
DAFO	District Agriculture and Forestry Office, Lao PDR
DEM	Digital elevation model
DENR	Department of Environment and Natural Resources, Philippines
DRO	Direct runoff
DSS	Decision support system
EA	Executing agency
FAO	Food and Agriculture Organization
FESLM	Framework for the Evaluation of Sustainable Land Management
FRC	Forestry Research Center, Lao PDR
GIS	Geographic information system
GPS	Global positioning system
GUESS	Griffith University Erosion Sedimentation System
IARC	International Agricultural Research Center
IBSRAM	International Board for Soil Research and Management, Thailand
ICIMOD	International Center for Integrated Mountain Development, Nepal
ICRAF	International Center for Research in Agroforestry, Kenya
ICRISAT	International Crop Research Institute for Semi-arid Tropics, India
IDRC	International Development Research Center, Canada
IFPRI	International Food Policy Research Institute, USA
IFRPD	Institute of Food Research and Product Development, Thailand
INRM	Integrated natural resource management
IRD	Institut de recherche pour le developpement, France
IRRI	International Rice Research Institute, Philippines
iSC	Interim Science Council of the CGIAR
ISRIC	International Soil Reference and Information Center, Netherlands
IWMI	International Water Management Institute, Sri Lanka

IWMI-SEA	International Water Management Institute, Southeast Asia, Thailand
IUARP	Integrated Upland Agriculture Research Project
LARReC	Living Aquatic Resources Research Center, Lao PDR
LDD	Land Development Department, Thailand
LDD	Land drainage direction
LRC	Livestock Research Center, Lao PDR
MAF	Ministry of Agriculture and Forestry, Lao PDR
MARD	Ministry of Agriculture and Rural Development, Vietnam
MDS	Minimum data set
MOU	Memorandum of understanding
MSEC	Management of Soil Erosion Consortium
NAFRC	Northern Agriculture and Forestry Research Center, Lao PDR
NAFRI	National Agriculture and Forestry Research Institute, Lao PDR
NARC	Nepal Agricultural Research Council
NARES	National Agricultural Research and Extension System
NARS	National Agricultural Research System
NGO	Non-government organization
NISF	National Institute for Soils and Fertilizers, Vietnam
NPWPCD	National Parks, Wildlife and Plant Conservation Department, Thailand
NSC	Network steering committee
NVS	Natural vegetative strips
PAFO	Provincial Agriculture and Forestry Office, Lao PDR
PCARES	Predicting Catchment Runoff and Soil Erosion for Sustainability
PCARRD	Philippine Council for Agriculture, Forestry and Natural Resources Research and Development
PLER	Predict and Localize Erosion and Runoff
PM&E	Participatory monitoring and evaluation
R&D	Research and development
RETA	Regional Technical Assistance
RFD	Royal Forestry Department, Thailand
RID	Royal Irrigation Department, Thailand
RMSE	Root mean square error
SALAD	Soil and land database
SANREM	Sustainable Agriculture and Natural Resources Management
SC	Steering committee
SDC	Swiss Agency for Development Cooperation, Switzerland
SEARCA	Southeast Asia Regional Center for Graduate Study in Agriculture, Philippines
SLM	Sustainable land management
SLWM	Sustainable land and water management
SSLCC	Soil Survey and Land Classification Center, Lao PDR
SSSA	Soil Science Society of America
SOC	Soil organic carbon
SQI	Soil quality index
SWNM	Soil, water and nutrient management
USLE	Universal soil loss equation
VASI	Vietnam Agricultural Science Institute
WMO	World Meteorological Organization