

CPWF Project Report

Rice Landscape Management for Raising Water Productivity, Conserving Resources, and Improving Livelihoods in Upper Catchments of the Mekong and Red River Basins

Project Number 11

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Program Preface:

The Challenge Program on Water and Food (CPWF) contributes to efforts of the international community to ensure global diversions of water to agriculture are maintained at the level of the year 2000. It is a multi-institutional research initiative that aims to increase the resilience of social and ecological systems through better water management for food production. Through its broad partnerships, it conducts research that leads to impact on the poor and to policy change.

The CPWF conducts action-oriented research in nine river basins in Africa, Asia and Latin America, focusing on crop water productivity, fisheries and aquatic ecosystems, community arrangements for sharing water, integrated river basin management, and institutions and policies for successful implementation of developments in the water-food-environment nexus.

Project Preface:

Rice Landscape Management for Raising Water Productivity, Conserving Resources, and Improving Livelihoods in Upper Catchments of the Mekong and Red River Basins.

The project validated and disseminated a large number of improved rice-based cropping systems technologies suited to upland agro-ecologies. These improved technologies have good potentials to raise the productivity of water, land, and labor. The innovative strategies employed by the project including the paradigm of landscape management, multi-institutional partnership, multidisciplinary teamwork, farmer participatory approach to technology validation, and community-based seed production led to successful generation and dissemination of technologies. Initial monitoring to adoption of technologies showed good indications of spread and promising impacts on food security, poverty reduction, and environmental protection.

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RESEARCH HIGHLIGHTS

The ultimate goal of the project was to improve food security, reduce poverty, and protect the environment in upper catchments through sustainable management of natural resources. In this endeavor, the project produced and disseminated a wide range of outputs and outcomes related to rice varieties and component technologies. **"Research for development"** was the core principle of the project. **The project employed several innovative strategies for technology validation and dissemination, including the paradigm of landscape management approach, multi-institutional partnership, multidisciplinary teamwork, farmer participatory approach to technology evaluation, and community-based seed production.**

A complex subsistence-oriented smallholder farming system characterizes livelihoods in upper catchments. An average upland household is characterized as 3.0 ha of landholding, 6.0 members in the family, less than three years of schooling of the household head, slash-and-burn-based upland rice cultivation as the main occupation, chronic food insecurity, and high incidence of poverty. An upland rice-based extensive or semi-intensive farming system dominates in upper catchments of Lao PDR and Vietnam, while a cash crop-based intensive farming system is dominant in upper catchments of northern Thailand. Rice is the staple food crop. Rice production is characterized by subsistence-oriented traditional technology, low input use, and low yield. **Rice is crucial for household food security. Households with no or very small areas of upland paddies depend on the production of upland rice, which meets their rice requirements for 6.5 months, on average, in Lao PDR and Vietnam.**

Land and water are key livelihood assets of farm households that affect food security, poverty, and livelihood strategies. We classify land use in four primary domains: (a) permanent cropping, (b) shifting cultivation, (c) livestock grazing, and (d) forest. Permanent cropping and shifting cultivation area constitutes more than 80% of the upper catchments. **Population pressure, government policies, and market forces have resulted in a decrease in fallow periods over time.** The consequent effect of reduced fallow periods is increased problems such as insects and weeds, low soil fertility, soil erosion and sedimentation, more intensive cultivation of fragile lands, loss of biodiversity, and low yield of upland rice.

Small streams are the main sources of water supply. Farmers use water primarily for rice production in paddies, but water is also used to produce high-value crops where market access is good. **Water shortage is a major constraint to rice production in upland paddies in the dry season.** The competition and scarcity of water lead to water-use conflicts and the evolution of water institutions. **Rice yield is about 10% higher in the head end vis-à-vis the tail end of a canal because of reliability and timely availability of irrigation.**

Access to water is crucial to reduce poverty and food insecurity. Improved access to water enhances the productivity of livelihood assets and affects poverty directly and indirectly. The direct pathway includes higher income from increased rice production arising from an increase in area, yield, and cropping intensity. Higher income also gains from the production of high-value crops for market, if market access is good. Indirect pathways include easing out upland rice area to cash crops, promotion of crop diversification to high-value crops such as aquaculture, capital formation to invest in capital-intensive enterprises such as livestock and nonfarm activities, and employment opportunities. Improved access to water improves food security, farm income, and income diversification. **Access to lowland, access to a market, access to technology, access to credit, and population pressure are the main mediating factors through which water affects poverty. The water-poverty relationship was found to be stronger in a market-oriented agricultural production system and weaker in a subsistence-oriented agricultural production system.**

The upstream and downstream communities in upper catchments are linked in terms of stock, flow, and use of biophysical and socioeconomic resources. A change in the productivity of resources in one part of the catchment hence generates some effects (positive or negative) in other parts of the catchment. **Results of the hydrology model showed that a conversion of upland shifting cultivation area to forest results in an increase in total stream outflow on an annual basis, translating into an increase in overall water availability for upland paddy irrigation.** However, the amount of water available for paddy rice production in the dry season is rather small. **Results of economic trade-off analysis showed that the conversion of upland crop rotation area to forest is not economically viable when we consider the economic value of the incremental water supply in the dry season only.**

The project produced a large number of validated technologies suited to different agroecologies of uplands (long fallow slash-and-burn in sloping uplands, short fallow slash-and-burn in sloping uplands, and rice paddies in lowlands) and farmers' socioeconomic conditions. We classify technologies into two groups on a land type basis: (a) sloping upland and (b) upland paddies (valley bottoms and terraces). Similarly, we classify technologies into four groups on a technology type basis: (a) rice variety, (b) rice-based crop management, (c) rice-based cropping systems, and (d) water management. **The project identified, validated, and disseminated 44 upland rice system-based technologies inclusive of 29 rice varieties, 8 crop and field management practices, and 7 upland rice-based cropping systems. Similarly, the project identified, validated, and disseminated 50 upland paddy rice system-based technologies inclusive of 28 rice varieties, 11 crop management practices, 5 water management practices, and 6 cropping systems.**

The project took on major initiatives from its early stage to translate these technology products into "outcomes" by promoting the dissemination of validated technologies. **The project distributed approximately 67 tons of seeds of 49 different improved rice varieties to more than 6,000 farmers.** The distribution was done directly or indirectly through extension agencies and NGOs for self-testing and for potential farmer-to-farmer dissemination for a multiplicative effect. Nearly half of the distributed rice varieties are spreading and becoming popular among farmers at research sites. **The yield advantage of these improved rice varieties ranged from 200 to 1,500 kg/ha over the popular traditional varieties.**

The technologies validated have the potential to reduce the number of hungry months in the uplands where farmers are not able to meet food needs throughout the year. **The additional production generated from improved technologies can reduce the number of hungry months by 1–5 for an average household and contribute substantially to food security.** This also has potential for contributing to farm income by inducing the production of cash crops as family food needs can be met from increased production. **The farm household model results showed that the validated technologies have the potential to increase the income of an average upland household by 15–20% and contribute substantially to poverty reduction.**

The project trained more than 300 NARES staff members on agricultural research and development. Some 700 farmers learned improved agricultural technologies through participation in various training activities and field visits. In addition, the project prepared and distributed more than 6,000 fact sheets about improved technologies. The enhanced capacity of NARES and farmers will have a long-term impact on national agricultural development and farmers' livelihoods.

The project has established a multi-institutional platform for the exchange of technologies and information within and across borders. This platform serves as a foundation for impact not only from the technologies validated currently but also from development, exchange, and dissemination of technologies in the future. **The innovative approaches employed by the project led to the successful generation and dissemination of technologies.** Initial monitoring of adoption showed a good indication of spread and promising impacts on livelihoods of farmers.

EXECUTIVE SUMMARY

Background

More than 20 million people depend directly on growing rice, the staple food crop, for food security in the agriculturally marginal upper catchments of mainland Southeast Asia. The inhabitants of upper catchments suffer from severe poverty and food insecurity. Most poor people belong to economically and socially marginalized minority ethnic groups and they are truly the poorest of the poor. Rising population pressure and the consequent intensification of marginal areas for food production have contributed to soil erosion, water losses, and declining area of watershed forest. The incidence of poverty is highly correlated with the degree of rice self-sufficiency in these areas. Raising the productivity of rice is a key entry point for breaking the vicious circle of food insecurity, poverty, and environmental degradation that characterizes these upper catchments. Land and water are critical inputs to rice production and their efficient use will benefit the poor directly by improving food security and income. The overall goal of the project was to improve food security, reduce poverty, and protect the environment in upper catchments by developing innovative ways for managing land and water resources of the catchments in a sustainable manner. The project contributed to this objective directly by developing, validating, and disseminating improved technologies for rice-based cropping systems. The development and validation of technologies to raise the productivity of water, land, and labor were conducted in the context of the overall farming systems and the diversity of livelihood strategies. The project bridged the knowledge gap on the relationship between water use, resource productivity, and the trade-offs involved in water and other resource use across the landscape.

Methodology

The project is an IRRI-led CPWF-funded grant project implemented in the northern mountainous regions of Lao PDR, Thailand, and Vietnam. The project employed several innovative technological, managerial, and institutional strategies for technology validation and dissemination. These included the paradigm of landscape management approach, multi-institutional partnership, multidisciplinary teamwork, farmer participatory technology evaluation, and community-based seed production. The project operated a network of eight village-based field research sites and two experimental station-based research sites in three countries to carry out its research activities in collaboration with national agricultural research institutions. The project research activities focused on three broad components relevant to the sloping uplands and upland paddies (valley bottoms and terraces):

- ♣ Land use and hydrology—this covered three major aspects: (a) resource mapping, (b) land-use planning, and (c) a hydrology model.
- ♣ Socioeconomics—this covered four major aspects: (a) food security and poverty situation; (b) relationship between access to water, poverty, and livelihoods; (c) irrigation water institutions; and (d) trade-offs in resource use in the watershed.
- ♣ Technology development and dissemination—this covered four major aspects of rice-based farming technologies: (a) rice varieties, (b) rice-based crop management, (c) rice-based cropping systems, and (d) agricultural water management.

The project development activities are broadly categorized into three groups. The first group consists of capacity building of national programs through training of national collaborators on biophysical and socioeconomic research design and implementation. The second group involves influencing the attitudes, perceptions, and behaviors of farmers through the provision of knowledge on improved technologies by means of farmers' training, farmer field days, farmer visits to experiment sites, and technology fact sheets. The third group is concerned about providing better access to improved technologies by promoting community-based seed production and directly disseminating improved technologies through different means.

We used both secondary and primary data. Secondary time-series data on rice and other important crops, climate, irrigated area, irrigation schemes, land use, the economy, and provincial profiles were collected from various sources. Primary data were collected using four methods: field measurement, crop experiment, farm household survey, and stakeholder participatory assessment. Climate and field hydrology data were collected through direct field measurement and analyzed using a hydrology model. The model was constructed using MIKE SHE, an integrated, fully distributed, physically based watershed hydrology-modeling software package. Crop experimental data were collected using scientifically designed experiments with enough treatments and replications. The data were analyzed using Excel, IRRISTAT, and CROPSTAT software

packages as appropriate. Farm household survey data were collected using semi-structured questionnaires and analyzed using cross-tabular, regression analysis, mathematical modeling, and scenario analysis methods. The data were analyzed using Excel, Excel Solver, LINGO, GAMS, and SPSS software packages as appropriate. The participatory assessment data were collected using participatory tools such as focus group discussion, resource mapping, transect walk, seasonal calendars, resource flow matrix, and variety selection. The participatory data were analyzed using cross-tabular, graphical, and case study methods. Baseline socioeconomic data were collected from more than 500 households. In addition, several focus group discussions, participatory assessments, field measurements, and crop experiments were conducted to collect other necessary data. All data were stored and managed in Microsoft Excel.

Results and discussions

A complex subsistence-oriented smallholder farming system characterizes livelihoods in upper catchments of Southeast Asia. We characterize a representative upland household as 3.0 ha of landholding, six members in the family, less than three years of schooling of the household head, upland rice cultivation using slash-and-burn practice as the main occupation, chronic food insecurity, and high incidence of poverty. The upland rice-based extensive or semi-intensive farming system is dominant in upper catchments of Lao PDR and Vietnam, while the cash crop-based intensive farming system is dominant in upper catchments of northern Thailand. Rice is the staple food crop. Rice production is characterized by subsistence-oriented traditional technology, low input use, and low yield. Rice is crucial for household food security. Households with no or very small areas of upland paddies depend on the production of upland rice, which meets their rice requirements for 6.5 months, on average, in Lao PDR and Vietnam.

We inventoried, characterized, and mapped land and water resources in the upper catchments of Lao PDR, Thailand, and Vietnam. Land, water, and livestock are important livelihood assets of farm households that affect food security, poverty, and livelihood strategies. We classify agricultural land into two types: sloping uplands and upland paddies (valley bottoms and terraces). We further classify sloping uplands into two types: fertile and infertile uplands. Broadly, we can classify land use into four primary domains: (a) permanent cropping, (b) shifting cultivation, (c) livestock grazing, and (d) forest. Permanent cropping is practiced mainly in upland paddies, while shifting cultivation is practiced in sloping uplands that are relatively fertile. Livestock grazing and forest exist in relatively less fertile sloping uplands. Permanent cropping and shifting cultivation area constitute the lion's share of upper catchments. Upland rice, maize, sesame, Job's tear, cassava, legumes, and vegetables are important crops in sloping uplands. Rice is the dominant crop in upland paddies. In sloping uplands, farmers grow rice using slash-and-burn shifting cultivation practices.

The upland paddy endowment—an indicator of wealth—is vital for food security and income generation. Land rights are usufruct and hence early settlers have more paddy area than late settlers do although the overall paddy endowment is quite small (less than 0.25 ha per household on average). Households with a small valley bottom area construct terraces in sloping uplands. The major factors leading to terrace construction are small area of valley bottoms, rice deficiency, access to water, low upland rice yield due to degradation of sloping lands, restriction to use forest, and subsidy to construct terraces. Terrace construction is gradually increasing with population pressure. We observed a positive correlation between paddy area and upland cash crop area.

Streams and rivers are the main sources of irrigation water in upper catchments. Water is used primarily for rice production in paddies. Water is also used for vegetable production where market access is good. The water supply in the wet season is sufficient for rice production in paddies, though the early wet-season water supply is a constraint. The water supply in the dry season is a major constraint to rice production. The scarcity of water led to a water-use conflict and evolution of various water institutions. Farmers establish rules for water sharing and allocation when a scarcity arises. Farmers at the tail end of the canal plant 2–3 weeks later vis-à-vis those at the head end of the canal. Rice yield at the tail end is about 10% lower than at the head end.

We observed two modes of access to water; first, direct access to water without any cooperation of neighbors; second, access to water in agreement with neighbors. Neighbors' cooperation is required to share water from the sources, to allocate water from the main canal to a branch canal, sometimes to channel water through plots of peers, and for investment in irrigation infrastructure. We observed two types of water conveyance system; first, direct channeling of water from sources

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to fields using a private or public canal; second, storing water from multiple sources near the field, and sharing among clans or neighbors using mutually agreed upon rules.

Farmers share water on the basis of “first come, first served.” Newcomers can use surplus water downstream, but not upstream, which affects the water intake of current users. Water use upstream is possible, but it requires a consensus of downstream users who will be affected. The rules, however, break down when competition for water increases due to the high marginal value of water.

Land-use activities upstream affect livelihood downstream through several pathways because (a) slash-and-burn cultivation and deforestation reduce stream flow, (b) new terrace construction reduces water availability, (c) slash-and-burn increases flashfloods and siltation, and (d) vegetable production increases water pollution. Access to land and water, access to a market, and population density are the major driving forces that affect land and water use in the upper catchments. The major determinants of access to water are distance from the field to water sources, location of the field in the watershed (upstream and downstream), time of settlement in the village, and financial status for investment in irrigation infrastructure.

We conducted a detailed quantitative characterization of land and water resources and a hydrology-modeling exercise in the Hom watershed in Fai Village, Lao PDR, using two years of field hydrology data. Water availability is a significant constraint to increasing rice production in paddies. The purpose of the hydrologic scenario analysis was therefore to gain an understanding of the effects of sloping land use conversion on water availability for paddy intensification. Subsequent economic analysis could then determine the resulting economic viability of the conversion. We modeled the conversion of the upland shifting cultivation area (cropped and fallow areas) to forest progressively and estimated the resultant increase in water flow in the watershed. We used five different scenarios—base case and four different proportions of forest area in the watershed (25%, 50%, 75%, and 100%)—to estimate the effect of land-use changes on water supply in the watershed. We then assessed the total increase in paddy rice production by using this extra water flow.

Results of the hydrology model that compares land use and water flow in the upper catchments provide some conclusions. First, the conversion of upland shifting cultivation area to forest results in an increase in total stream outflow on an annual basis, translating into an increase in overall water availability for paddy irrigation. Improvement in water availability is predominantly evident in the early wet season. The amount of water available for paddy production in the dry season is rather small. Second, conversion of upland rotation to forest translates into insignificant expansion of dry-season paddy rice. Strategies to increase dry-season paddy cultivation would likely require an assessment of surface-water storage, potentially in tandem with water-saving rice technologies such as aerobic rice or alternate wet-and-dry irrigation practices. The water storage facilities, however, require storage infrastructure and could be costly. Thus, paddy intensification in the wet season appears to be a more viable option than the expansion of dry-season rice production. Third, the most significant change in the stream water availability under forest conversion scenarios is in the early wet season. Participatory assessment revealed that farmers normally plant rice in July due to early-season water constraint. A delayed onset of rains affects planting and hence rice yield. An increased water supply in the early wet season enables farmers either to continue transplanting at the same time but in more area, thereby increasing production, or to plant earlier but in the same area with a corresponding yield increase due to timely planting and good plant growth. Fourth, modeling results here consider only scenarios where shifting cultivation area is converted to forest. Many other potential land-use and water management options are yet to be explored, including sustainable (long fallow) shifting cultivation, alternative land-use mosaics, and surface storage and alternative water conveyance technologies that could dramatically increase water availability for alternative uses through more efficient use of available water. Finally, the project has afforded valuable lessons in research areas that have been underexplored, including hydrologic modeling in the data-scarce environment of the upper catchments of Southeast Asia.

We assessed the water-poverty relationship in upper catchments based on farm household survey data. Results indicated that access to water is very important for overcoming poverty and food insecurity. Improved access to water enhances the productivity of livelihood assets and affects poverty directly and indirectly. The direct pathway includes higher income from increased rice production arising from an increase in area, yield, and cropping intensity. Higher income also results from the production of high-value crops for the market, if market access is also good.

Indirect pathways include easing out upland rice area to cash crops, promoting crop diversification to high-value crops such as aquaculture, capital formation to invest in capital-intensive enterprises such as livestock and nonfarm activities, and employment opportunities. Overall, the water-poverty relationship was found to be strong in a market-oriented agricultural production system and weak in a subsistence-oriented agricultural production system.

The project produced a large number of validated technologies suited to different upland agroecologies (long fallow slash-and-burn in sloping uplands, short fallow slash-and-burn in sloping uplands, and rice paddies in lowlands) and farmers' socioeconomic conditions. We classify technologies into two groups on a land type basis: (a) sloping upland and (b) upland paddies (valley bottoms and terraces). Similarly, we classify technologies into four groups on a technology type basis: (a) rice variety, (b) rice-based crop management, (c) rice-based cropping systems, and (d) water management. The project identified, validated, and disseminated 44 upland rice system-based technologies inclusive of 29 rice varieties, 8 crop and field management practices, and 7 upland rice-based cropping systems. Similarly, the project identified, validated, and disseminated 50 upland paddy rice system-based technologies inclusive of 28 rice varieties, 11 crop management practices, 5 water management practices, and 6 cropping systems. The yield advantage of validated improved rice varieties over the local check ranged from 200 to 1,500 kg/ha for upland rice and from 200 to 1,300 kg/ha for paddy rice.

The project took major initiatives from its early stage to translate these technology products into "outcomes" by promoting the dissemination of validated technologies. The project employed multiple methods for wider distribution and dissemination of validated technologies. Given the nonavailability of quality rice seeds, rice seed production and distribution were a key initiative of the project. In addition, the project organized farmer training, farmer field days, and farmer exposure visits; produced and distributed informational materials on validated technologies and improved agriculture; and established linkages with extension agencies, nongovernmental organizations, and other projects for wider dissemination of validated technologies.

One of the key features of the project was the farmer participatory rice seed production initiative. The seeds were produced in farmers' fields with farmer participation under the technical supervision of national collaborators. Participating farmers were given training on scientific aspects of quality rice seed production. The project produced 73 tons of seeds of 72 rice varieties. Of the total, upland rice accounted for 53 varieties and 17 tons of seed, and lowland rice accounted for 19 varieties and 56 tons of seeds. While part of the produced seeds was procured by the project for distribution, extension agencies, NGOs, and farmers bought the remaining seeds.

The project distributed 15 tons of 28 upland rice variety seeds to about 800 farmers, and 52 tons of 21 paddy rice variety seeds to more than 4,100 farmers. Nearly half of the distributed rice varieties are spreading and becoming popular among farmers at research sites.

The project changed perceptions, attitudes, and behaviors of farmers through knowledge enhancement by organizing farmer training, field days, and exposure visits. The project organized seven farmers' training events to train farmers on validated technologies and improved agricultural practices. Farmers from field research sites and adjoining villages participated in the training. Of the 174 farmers who participated in the training events organized by the project, 53% were females.

The project organized 26 farmer field day events at its field and station research sites to expose farmers to the research activities carried out by the project and simultaneously involve farmers in evaluating the technologies being tested at the research sites. Of the 507 farmers who participated in the field day events, 45% were females.

For wider dissemination of validated technologies to farmers and extension agencies and sharing of research findings and activities among collaborating researchers and stakeholders, the project produced and distributed a large number of information materials. The project produced about 6,000 copies of informational materials such as fact sheets, booklets, leaflets or fliers, and posters, among others, in 31 topical areas in local vernacular and English language for distribution to farmers and extension agents.

The project strongly emphasized capacity building of national programs. The project trained 321 NARES staff members to build their research capacity through human capital development. While 101 staff members were trained on socioeconomic research and participatory methods, 131 were

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trained on crop experimentation, breeding, production, and management, and 14 were trained on English language and writing skills. In addition, 62 NARES staff members participated in within-country and cross-country study tours as a part of enhancing knowledge and research capabilities from cross learning. The project also supported thesis research work of 13 university students.

The project established a multi-institutional platform for the exchange of technologies and information within and across borders. The platform thus established a strong foundation for impact not only from the technologies validated currently but also from development, exchange, and dissemination of technologies in the future. In addition, this platform has helped foster "south-south" collaboration among partner countries in the region.

We calibrated a farm-household economic model to examine household land-use and resource allocation patterns between sloping uplands and paddies. The results showed that income from sloping uplands accounts for more than two-thirds of household income. We found that farmers' current cropping practices are not optimal. Alternative cropping options can generate higher income but the success depends on many factors, including the efficiency and reliability of marketing systems. Results of scenario analysis showed that an increase in rice production in upland paddies facilitates cash crop production in uplands by relaxing the food insecurity constraint.

We examined trade-offs in resource use and resultant outcomes in the watershed quantitatively and qualitatively. We analyzed trade-offs quantitatively by combining the hydrology model and the economic model, and qualitatively by soliciting farmers' perceptions on the effect of land-use changes on household income and the environment. The hydrology model simulated the effect of conversion of upland shifting cultivation area to forest on total stream outflow in the watershed. The economic model examined the economic viability of such conversions by estimating the cost of converting upland area to forest and the benefit derived from the use of incremental water flow.

The hydrology model results showed that conversion of upland shifting cultivation area to forest results in an increase in total stream outflow on an annual basis, translating into an increase in overall water availability for upland paddies. The amount of extra water available for paddy rice production in the dry season, however, is rather small. Results of trade-off analysis showed that conversion of upland crop rotation area to forest is not economically viable when we consider the economic value of incremental water supply in the dry season only. The total economic gain increases when we consider the economic value of forest as well as other environmental services that forest generates. However, some of these benefits are externalities that do not accrue to farmers but to society at large. Policy that promotes the conversion of upland cropped area to forest will have negative equity consequences. Many upstream households that are poor and food-insecure do not own paddies. They will lose their income and livelihoods from such conversion unless alternative opportunities are provided to them.

The qualitative assessment of trade-off in a commercialized agricultural production system in northern Thailand showed that a shift from a subsistence-oriented to market-oriented production system increased farm income and food security, but it also adversely affected the environment, human health, and even social relationships in some cases. This implies a strong trade-off between income growth and environmental effects. These trade-offs should be considered and options to minimize them are needed for promoting upland development while protecting the environment.

Potential impact

The project validated a large number of rice-based technologies suited to poor farmers with low purchasing power. The yield advantage of improved rice varieties validated by the project ranged from 200 to 1,500 kg/ha over traditional ones under farmers' growing conditions. The technologies validated have the potential to reduce the number of hungry months in uplands where farmers are not able to meet food needs throughout the year. The additional production generated from improved technologies can reduce the number of hungry months by 1–5 for an average household. Thus, the project has the potential to contribute to a substantial improvement in food security. These technologies also have the potential to contribute to farm income by inducing the production of cash crops as food needs can be met from increased rice production. The farm household model results showed that the validated technologies could increase the income of an average upland household by 15–20% and thereby contribute substantially to poverty reduction.

The validated technologies have the potential to benefit the environment by reducing the pressure on fragile uplands, releasing upland rice area to forest, reducing soil erosion, improving soil fertility, and increasing stream outflow in the watershed, among others.

Other dimensions in which the project made a substantial impact are national capacity building and institutionalization of the participatory approach. In addition, the project established a multi-institutional platform for the exchange of technologies and information within and across borders. The platform thus established provides a strong foundation for impact not only from the technologies validated currently but also from the development, exchange, and dissemination of technologies in the future. The innovative approaches employed by the project led to the successful generation and dissemination of technologies. Initial monitoring to adoption showed a good indication of the spread and promising impact on farmers' livelihoods and the environment.

The agricultural production system in northern Thailand transformed itself from subsistence orientation to commercial orientation in the past two decades in response to economic development, government policies, markets, and socio-cultural factors. This has generated both positive and negative economic, social, and environmental impacts. This provides valuable lessons for Lao PDR and Vietnam to take a proactive approach to design and implement technological, policy, and institutional options to promote positive impacts and to curtail negative impacts.

INTRODUCTION

More than 20 million people depend directly on growing rice, the staple food crop, for food security in the agriculturally marginal upper catchments of mainland Southeast Asia. Such rice-based farming systems occupy more than 5 million hectares in the upper catchments of Lao PDR, Myanmar, Thailand, and Vietnam. Although these countries have made important gains in rice productivity in their fertile deltas, farmers in the upper catchments have not directly benefited.

The inhabitants of upper catchments suffer from severe poverty and food insecurity (ADB 2001, Glewwe et al 2002, Pandey et al 2006). The incidence of poverty in the upper catchments of Laos and Vietnam is the highest within these countries, with the number of poor exceeding 75% of the population in some regions of upper catchments. Most poor people belong to economically and socially marginalized minority ethnic groups and they are truly the poorest of the poor. They tend to devote their limited resources of land, labor, and water to rice production until household rice needs are met, leaving little or no resources for producing cash income (Pandey et al 2006). Rising population pressure and the consequent intensification of marginal areas for food production have contributed to soil erosion, water losses, and declining area of watershed forest. The incidence of poverty is highly correlated with the degree of rice self-sufficiency in these areas (ADB 2001, WFP 2007). Therefore, raising the productivity of rice is a key entry point for breaking the vicious circle of food insecurity, poverty, and environmental degradation that characterizes these upper catchments. Water is a critical input to rice production and its efficient use will benefit the poor directly by improving food security.

Upper catchment areas are typically composed of sloping uplands and valley floors. The valley floors, gentle slopes, and terraced fields provide more favorable environments for growing rice in banded fields under wetland conditions (or paddies). These paddies have greater potential for increased rice production, especially where possibilities exist for large-scale irrigation. On the steeper slopes, farmers typically grow upland rice in unbanded fields in shifting/rotational cultivation systems.

These environments present the opportunity for a two-pronged approach in R&D efforts to increase rice production and manage the rice landscape better. From the perspective of the watershed and communities, increasing rice production in paddies will relieve the pressure for intensification of upland areas. For households having access to both paddies and sloping land, increasing rice productivity in their paddies also means releasing more resources, including labor, for them to engage in more diverse and profitable cropping, livestock, and agro-forestry activities on sloping lands to improve their livelihoods.

Households without access to paddies will remain dependent on the sloping uplands, primarily to grow rice for domestic consumption. Higher productivity of upland rice enables households to meet their food needs from a smaller area. This, in turn, reduces both extensive and intensive cultivation of sloping lands for food. Households have more land and other resources for cash crop production. Furthermore, there is scope for developing ways to manage the land to prevent soil erosion, conserve moisture, and enhance the native soil productivity, while at the same time providing additional income for farmers outside the main rice-growing season. As both the biophysical and socioeconomic conditions of highland farmers improve, possibilities are greater of introducing more permanent cultivation systems that are ecologically sound and socially acceptable on sloping lands. This requires concerted efforts not only in the component crop sciences (rice, maize, food and pasture legumes, etc.) but also in farming systems and integrative analysis of interactions among technology, livelihood strategies, and the fragile ecosystem.

Water is an important livelihood asset of rural households and improving access to water is an important way of helping to diversify livelihoods and reduce the vulnerability of poor farmers. A more efficient use of water for food production means sparing valuable water to meet other livelihood needs. Raising the productivity of water in upper catchments is seen in this project as one of the key interventions that will also improve overall landscape management.

Water is a major factor that determines the potential area of paddies and their productivity. Various proven technologies for saving water and improving its productivity in irrigated plains developed collaboratively by IRRI and NARES partners could be adapted to the paddy conditions in upper catchments. In the sloping uplands, improved cropping systems could similarly raise the productivity of water. Collaborative research projects in Vietnam and Lao PDR have identified a range of interventions that improve the moisture retention capacity of soils, reduce runoff,

increase water productivity for crops and pastures, and increase the overall productivity of farming systems. However, there is a need to explore workable combinations of these interventions that suit farmers' needs and livelihood strategies.

Past studies indicate that potentially large gains can be made by using more integrative approaches that consider the flow of resources across the landscape and the ways these flows affect, and in turn are affected by, farmers' livelihood strategies (Castella and Quang 2002). It has been demonstrated that improvements in the productivity of wetland paddies in the valley bottoms and terraced fields in upper catchments can lead to major changes in the landscape (Suraswadi et al 2002, Pandey et al 2006). However, these land-use changes also result in important trade-offs and conflicts in the use of water and other resources across the landscape (ICRAF 2002). Sustainable management of various resources in upper catchments therefore requires innovative approaches that not only raise productivity and improve livelihoods but also prove to be a mechanism for resolving various conflicts in resource use that eventually arise.

The overall hypothesis is that landscape management of rice-based production systems in upper catchments (consisting of sloping uplands and paddies) in an integrative manner is the key to achieving higher water productivity, resource conservation, and food security. The flows of water and other resources across the landscape and the diversity of farmers' livelihood strategies that interact with these flows provide the basis for integration.

The major target groups of beneficiaries are men and women farmers who depend on the use of resources of the upper catchments for their livelihoods. Assured food security through higher productivity of rice will directly benefit the broad spectrum of people living in the upper catchments and indirectly benefit downstream users who are connected with the upper catchments through trade and resource flow.

Women, who provide most of the labor for intensive operations such as weeding, planting, and harvesting of rice, stand to gain more through technologies that reduce drudgery and improve their labor productivity. In addition, better access to water resulting from improved catchment management will benefit women who currently spend a lot of time fetching water for domestic and other livelihood needs.

Other main beneficiaries of the project are local government leaders, NGOs, and regional/national policymakers who are concerned about improving livelihoods in upper catchments in a sustainable manner so that the livelihood strategies adopted and institutional arrangements to support such strategies are in conformity with the national and regional goals of sustainable and balanced development.

Researchers and extension agents are other beneficiaries who will benefit through new scientific knowledge and tools so that they can be more effective in developing and disseminating the required interventions.

The project was implemented in the northern mountainous regions of Lao PDR, Thailand, and Vietnam. The project followed five basic tenets: landscape management, a multidisciplinary research team, a farmer participatory research approach, integration of farmer knowledge, and integrative research and development for implementing project activities.

PROJECT OBJECTIVES

The overall objective was to design land-use options that improve water productivity at different scales (household to catchment), improve access to water by the poor, and assure sustainable food security to farmers in the upper catchments of mainland Southeast Asia. The project aims to develop, test, and validate (1) improved technologies for producing rice and other food crops, and (2) innovative approaches for managing the major resources such as water, land, and labor across the landscape for achieving sustainable food security while protecting the environment in the upper catchments of the Mekong and Red River basins. The project had six specific objectives:

1. To assess the relationship between agricultural practices and the use of rainwater and stream flow across the toposequence in upper catchments.
2. To assess the nature of the relationship among poverty, access to water, and livelihood strategies and to identify the factors that condition this relationship.
3. To develop and test, with farmer participation, water-efficient rice technologies that improve the productivity of highland paddies and to make such technologies available for delivery and dissemination.
4. To validate, with farmer participation, water- and soil-conserving technologies for rice-based production systems on sloping uplands and to make such technologies available for delivery and dissemination.
5. To assess the trade-offs in the use of water, labor, and other resources across the landscape as they affect food security and the environment, and to develop community-based strategies for efficient water management.
6. To develop promising strategies that integrate both improved farming technologies and innovative institutional arrangements for the use of water at pilot test sites and to monitor their impacts.

Achievements under each of these objectives are briefly summarized below. More details are available in annual reports or in the Appendices.

1. Objective 1: to assess the relationship between agricultural practices and the use of rainwater and stream flow across the toposequence in upper catchments.

The purpose for Objective 1 was to characterize the land and water resource base of study sites in spatial and quantitative terms, and make this information available for use in other objectives of the project to quantify the impact of alternative landscape management on livelihoods and food security within the target areas. We structured research efforts into two primary activities. Activity 1 sought to gain a qualitative but comprehensive description of the various components of the biophysical base. The main focus here was to integrate researchers' and the communities' perceptions of resource availability, usage, and interactions by (a) developing a comprehensive qualitative description of the biophysical resource domain of the study sites, particularly focusing on land and water resources; (b) identifying perceived interactions between land use and water availability; and (c) eliciting perceived changes in land and water resource availability over time. Activity 2 aimed at a detailed quantitative characterization of land and water resources in the representative subcatchment, representation of those resources in an integrated hydrology model, and subsequent analysis of the effects of land-use changes on water flows and availability for paddy irrigation. We conducted Activity 1 in all three countries, but Activity 2 in Lao PDR and Vietnam only. We analyzed the land-use changes and water flow relationships in the watershed comprehensively in Lao PDR.

1.1 Develop an inventory of land and water resources

1.1.1 Methodology

We selected two villages in Lao PDR, two communes in Vietnam, and four villages in Thailand in consultation with local stakeholders as representative field research sites (Table 1.1). The research sites in each country represent both upland and lowland areas. We used both primary and secondary data to develop an inventory of land and water resources at the study sites. We first characterized study areas in terms of resource endowments, climate, water resources, forest resources, land-use patterns, cropping calendar, crop productivity, economic activities, and household livelihood activities using secondary data. We collected secondary data for the period 2000-08 from government records and analyzed these data using appropriate statistical tools.

Table 1.1. Field research sites in three countries.

Administrative region	Lao PDR		Vietnam		Thailand	
	Study area	Sample size (no.)	Study area	Sample size (no.)	Study area	Sample size (no.)
Province	Luang Prabang		Yen Bai		Chiang Mai	
District	Xieng Ngeun, Pak Ou	158	Van Chan	200	Mae Chaem	159
Largely upland village/commune	Silalek	101	Nam Bung	100	Mae Ngan Luang, Kong Bot Nua	79
Largely lowland village/commune	Fai	57	Suoi Giang	100	Mae Suk, Kong Kan	80

We used a two-pronged approach to collect primary data—field surveys and participatory assessment. Field surveys of the land and water resource base helped to define resource availability and quality in spatial terms. Field surveys provided context to frame a more effective participatory assessment of local resources. We collected spatial data on land, water, and other biophysical resources from field surveys. We took landscape photographs in several locations and scales in the catchments, enabling seasonal comparisons of water availability and vegetation. Spatial coordinates for important landscape features, and for accuracy checks for the ASTER and LANDSAT satellite imagery, were obtained from GPS field sites. We used three approaches for the participatory assessment of resources at the study sites and the catchments: (a) informal interviews, (b) focus group discussions, and (c) participatory land-use and resource mapping. The first step of the participatory mapping process was to develop a basic understanding of the geography of the area to be mapped and to establish rapport with local villagers. This involved walking around and collecting information on the geographical setting and discussing with people about their livelihood strategies. The second step was to map resources with participation of farmers. We used a mix of participatory tools such as resource mapping, transect walk, seasonal

calendars, and a resource flow matrix for this purpose. Local farmers and community leaders having great insights into land and resources participated in the mapping process. Both men and women resource users belonging to different wealth categories and ethnicity were included in the participatory analysis. We collected detailed information on land and water resources, particularly focusing on land use and crop management, trends in quantity and quality of water supply, trends in water use, major driving forces that affect water supply and use, and future availability of resources, and we delineated other aspects of the community's resource domain. A resource flow matrix was instrumental in identifying resource flow interactions between uplands and lowlands. This provided support for spatial and temporal considerations in subsequent hydrologic and economic modeling. Participants prepared a map of resources on locally available large paper sheets using different-color pens and markers. We changed these temporary maps into permanent maps using GIS techniques and computer software. We analyzed these collected data and maps using GIS and other appropriate techniques.

1.1.2 Results and discussion

1.1.2.1 Lao PDR

We conducted participatory land-use and resource mapping in Fai and Silalek villages through group discussions. The discussions led to a detailed characterization, mapping, and analysis of land and water resources in two contrasting villages. The resource maps prepared in participation with farmers and village leaders showed detailed characterization of two villages (Figs. 1.1 and 1.2). Silalek has two rivers, three main streams, and a few small streams that run through it. Farmers identified six land-use zones growing upland rice, lowland rice, and other crops. Fai has a river and three main streams. Farmers identified four land-use zones to grow upland rice, lowland rice, and other cash crops. The water supply in rivers is large in both seasons, the water supply in main streams is large in the wet season but small in the dry season, and the water supply in small streams is available in the wet season only. Rivers are used for transportation, fishing, and household water supply. A transect map of land use derived based on a transect walk showed that forests and grazing areas are located on top of the mountains, upland crops (rice and nonrice cash crops) including fallow land in the middle, and plantation garden and lowland rice toward the bottom (Figs. 1.3 and 1.4). Walking time from house to upland fields was 20–60 minutes in most cases but as much as 90 minutes for some farmers.

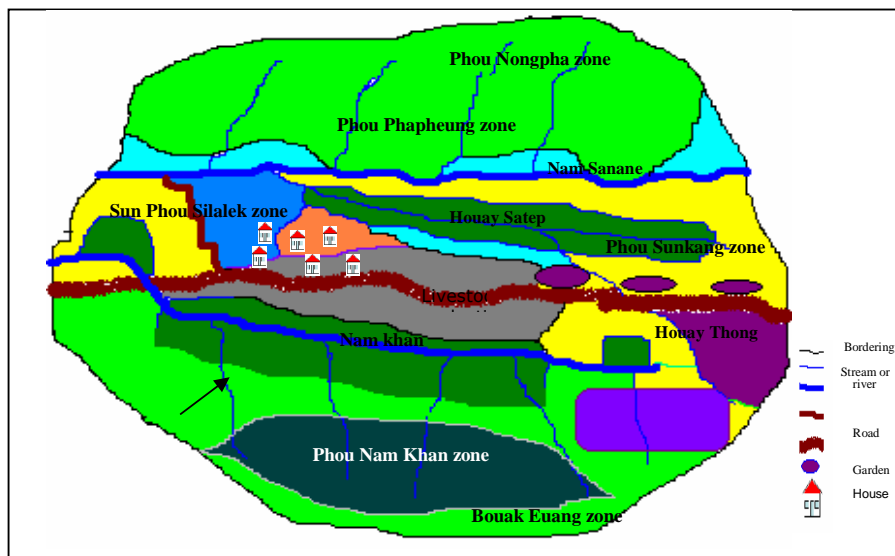


Figure 1.1. Resource map of Silalek Village.

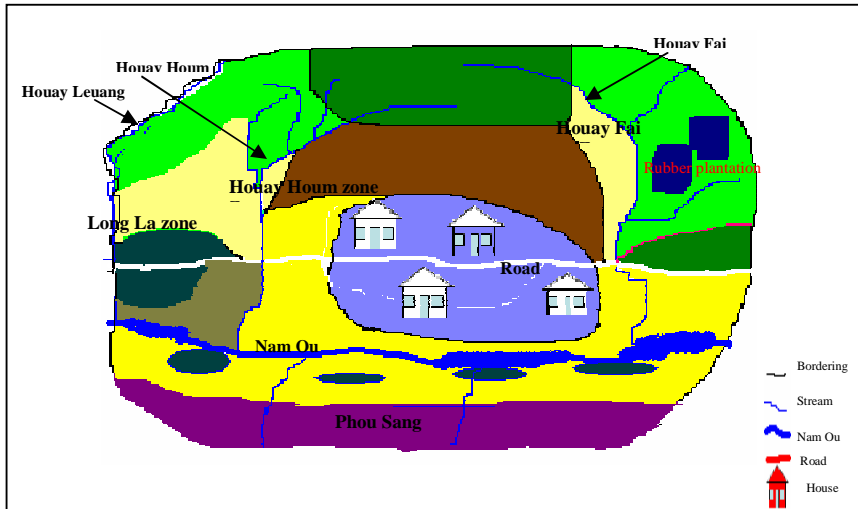


Figure 1.2. Resource map of Fai Village.

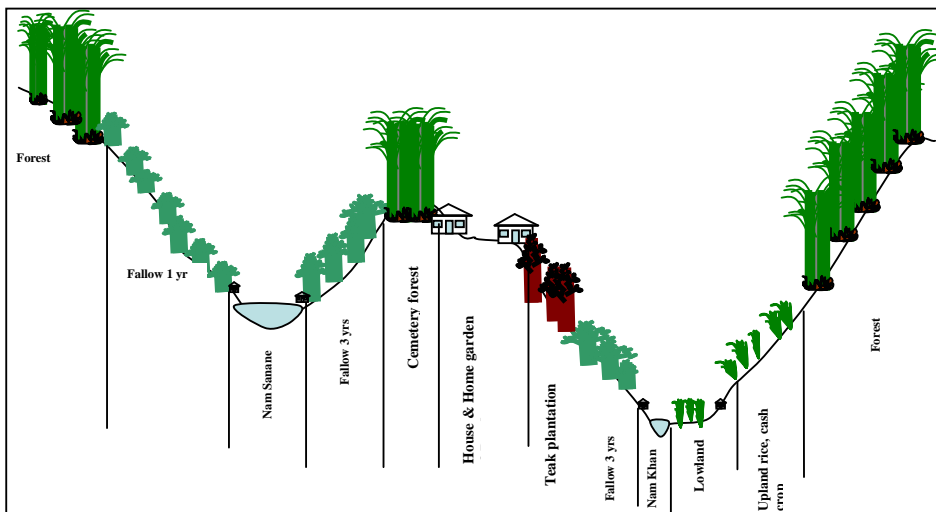


Figure 1.3. Transect walk mapping of resources in Silalek Village.

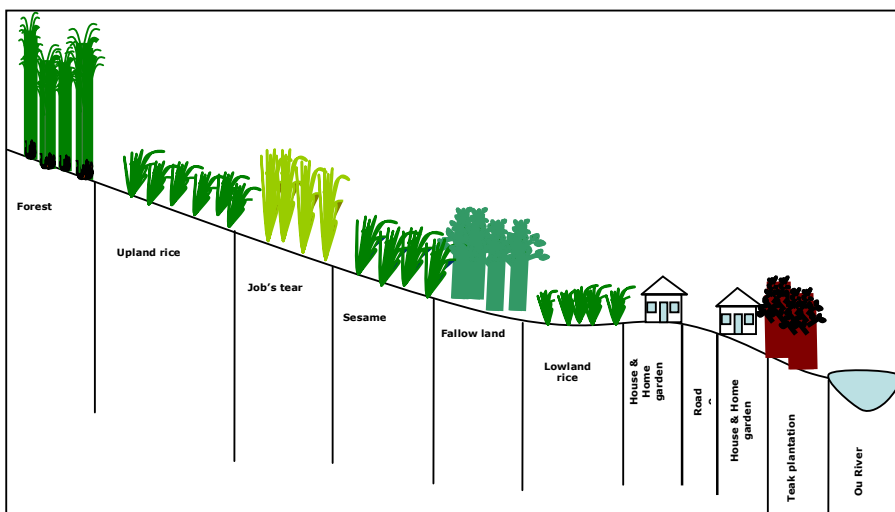


Figure 1.4. Transect walk mapping of resources in Fai Village.

Research efforts clarified that although the resource endowments and livelihood strategies differed between two target sites, broad biophysical resource bases comprise similar elements that reflect those found throughout the uplands of Lao PDR. We can describe these resource bases in three groups: components, products, and linkages. Figure 1.5 provides an overview of resource linkages in the target villages. Boxes denote hierarchical resource components, and component linkages denote interactions with all related subcomponents. Arrows indicate linkages or intercomponent influences, which we identified in field efforts rather than in hypothesized interactions, for example, nutrient fluxes from upland rotations to paddies via water flows. We further grouped components into three clusters for clarity: water, land, and livestock.

Components and products—We can classify land uses in various ways; here, we view land uses with a temporal perspective and therefore placed in one of the four primary domains: (a) forest and plantation, (b) permanent cropping, (c) upland shifting cultivation rotations, and (d) livestock grazing areas. The first category encompasses managed and unmanaged forest and plantation areas, with permanent or long-term durations. Permanent cropping types follow annual cycles and include wetland rice production, rice gardens, and home gardens. In farmers’ descriptions, upland rotation land follows 3 years to 6 years of cropping/fallow cycles. Lastly, grazing land includes area allocated for livestock open grazing. The grazing areas are an intermediate land-use type, which in one target village was a permanent land use and in another was an area omitted from the swidden cycle for a multiyear period.

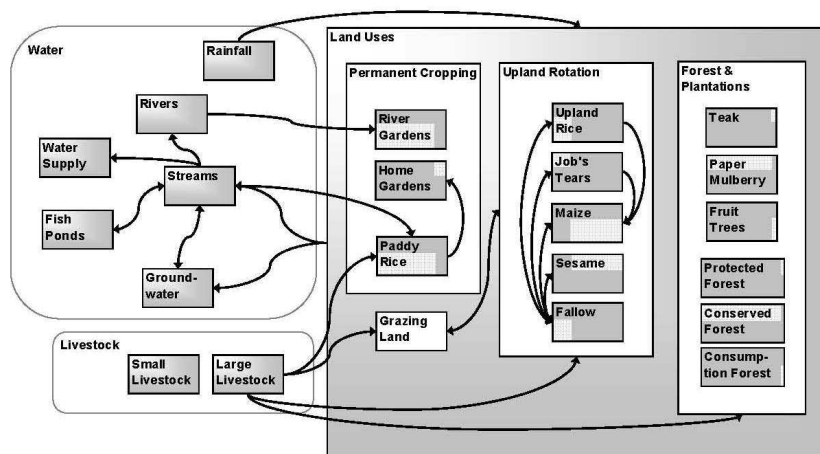


Figure 1.5. Biophysical resource linkages of target villages.

Government policy classifies forested areas into three groups: protected, conserved, and consumption forest. Participatory assessment, however, revealed that farmers considered two basic types of forest, considering protected and conserved forest virtually the same. Conserved forested areas are forests where the community cannot fell trees, but can collect nontimber forest products. These are meant to protect water sources, prevent soil erosion, and enhance biodiversity. Consumption forests are primarily for harvesting timber and therefore are not used for cropping.

Upland rotation area was the largest land-use category in both villages, with upland rice being the favored rotation crop. Job’s tear and sesame were the most prevalent alternative rotation crops planted, though others were also grown but to a much lesser degree. The most common rotation for a given upland plot is 2 initial years of consecutive cropping of alternate crops followed by 3 years of natural fallow since implementation of the upland land allocation program, though 2–6 years of rotation is occasionally used in some cases. In a few cases, farmers intercrop maize with rice about 45–60 days after rice planting, and harvest maize in the dry season.

Farmers use three criteria to make cropping decisions in uplands: (a) soil quality, (b) slope, and (c) distance from the village. Areas with higher soil quality are used for rice production, since Job’s tear, sesame, and maize can grow on poorer soils. Steeper slopes are typically planted to rice; sesame is reportedly difficult to harvest on steep slopes, and farmers avoid planting Job’s tear on steep slopes as they say that workers are more prone to injury from falling over the stiff stalks.

Areas close to the village are favored for Job's tear and sesame production, as these are more difficult to transport than rice. In addition sesame seed losses are high when transporting seeds long distances due to their small size.

Table 1.2 presents 2006 land-use estimates for two villages. Total land area under agricultural use was 67% in Ban Fai and 54% in Ban Silalek. Agricultural land under permanent cultivation was less than 20%. Overall, the lowland rice area is very small and farmers largely depend on upland areas for food security and income sources. Group discussions indicated that population pressure and government restrictions on shifting cultivation have reduced fallow periods from 8–10 years about two decades ago to 2–3 years now. This contributed to increased soil erosion, decreased soil fertility, increased pests and weeds, and reduced water flow in streams.

Table 1.2. Percentage area under different land-use types in two study villages, 2006.^a

Land-use type	Ban Fai	Ban Silalek
Forest	27	43
Forest re-growth (fallow)	35	23
Shifting cultivation	15	17
Permanent cultivation	17	14
Others	6	3
Total	100	100

^aTotal area is 792 ha in Ban Fai and 2,300 ha in Ban Silalek.

Data source: village record.

Water intracluster linkages—Land use primarily determines water flows. Streams feed into larger rivers along flatter terrain. Larger rivers supply water for riverside gardens and animal husbandry as well as fish for village consumption. Farmers are not using groundwater directly for domestic consumption or irrigation, but this is important to supply a dry-season base flow to streams.

Land intracluster linkages—Traditional land use has been heavily influenced by a combination of changing demographics, implementation of national land allocation policies, and, to a lesser extent, emerging market forces. Farmers in both villages reported little change in land use since the implementation of the land allocation program in 1997. In Ban Fai, farmers built new terraces in 2008 with assistance from a nongovernmental organization. Farmers with more paddy rice area allocate less area to upland rice and more to cash crops. Thus, there is a correlation between lowland endowment and upland rice area.

Land/water intercluster linkages—Though methods vary between the two sites, small streams draining the slopes are captured for irrigating paddies down slopes and for supplying the villages with clean water for domestic use. Irrigation for upland crop or vegetable production along the sloping area is not used in either village, a reflection of water management paradigms throughout the Lao uplands that contrast with those of the uplands of northern Thailand.

Both villages remarked how rainfall and climate patterns seem to have changed within the last 10 years. Villagers perceive delayed onsets of a shorter rainy season, pushing wetland rice planting dates back as far as 1 month with an accompanying drop in yields. Rainfall patterns are similarly more unpredictable, with dry periods during the rainy season affecting the viability of seedlings.

To gain an understanding of farmers' perceptions on how land use affects water yield of catchments, we asked farmers to characterize stream outlet flows for a hypothetical watershed under (a) upland rice cultivation, (b) fallow, and (c) forest. Farmers' perceptions were "more forest, more water," that is, forests are considered to be water reservoirs and, if forest is removed, less water flows out of the watershed. Land at the top of the toposequence is typically retained in forest, with upland cropping area cleared down-slope. When farmers were asked about the effects they would expect if forested areas were placed below cropping areas, their perceptions that water availability for downstream paddy irrigation would decrease were consistent. Farmers' perceptions of "more forest, more water" likely applied therefore to the overall volume of water produced at the stream outlet, rather than pertaining to changes in flow distribution throughout the year.

The conclusions drawn from the resource characterization exercise are useful to qualify the results of the watershed hydrology modeling exercise presented in the subsequent section. Research efforts also identified important areas for future studies. A central focus of the project is to improve the productivity of both upland and lowland rice agroecosystems and their interactions

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across the landscape. The two target villages exhibited significant contrasts in the structure of the lowland areas and the relationships between the lowland paddies and their water sources and surrounding slopes. Silalek converted riverbed areas into paddies, thereby eliminating the need to transport water from a remote source, but leaving the paddies susceptible to flood damage in significant storm events. Furthermore, paddy areas were located within subcatchments with forested slopes. Fai, on the other hand, has paddies either on slopes adjacent to a water course or in areas separated from surface-water supplies, requiring stream diversions and earthen canals to transport irrigation water.

Paddy locations protected lowland rice cultivation from flooding but were sometimes affected by insufficient water supply. Fai paddies were situated adjacent to rotation cropping area on the slopes as well, suggesting strong interactions between sloping land management and water availability for paddy irrigation. Variations in the relationship between lowland rice cultivation and the surrounding terrain indicate that improvements in rice productivity in the Lao uplands will not be attained through the application of a single technology "package." Rather, land and water management alternatives will need to be tailored to individual situations. This research identified two lowland rice environments within the Lao uplands, each with its own set of opportunities and challenges.

Though the project focused specifically on water availability and productivity of the rice ecosystems, this research has highlighted water control as an equally cogent issue in the Lao uplands. Though dry-season water availability for paddy irrigation differed between the two target villages, both sites exhibited excessive stream flows during wet-season storm events. Silalek paddies suffered regular damage and yield losses from these events because of their topographic position, a problem exacerbated by inadequately managed livestock, which damaged paddy structures. Although Fai paddies were undamaged by excess wet-season flows, high discharge rates at the watershed outlet indicated the inability to capture and use excessive runoff.

Results suggest that significant scope exists for systems improvement by moving beyond consideration of the trade-offs between different sloping land management alternatives and paddy productivity. Due to limited project resources, the scope of the project was necessarily limited to alternative arrangements of land uses already within the realm of experience of the target communities, and the ability to intensify or expand paddy production in light of these alternatives. Potential benefits gained through these upland/lowland trade-offs would be greatly enhanced by incorporating (a) improved water management and control technologies beyond land-use changes and (b) alternative land uses that currently lie outside the management paradigms of the target sites.

One possible intervention involves both aspects of irrigation of upland slopes. Since communities are highly rice-centric in their perspective, attempts to increase food security through increased rice production naturally favor intensification of paddies. Water management technologies, which capture excess wet-season flows and distribute them more effectively, could maximize wet-season benefits. Examples include simple surface storage options, which capture runoff and can be combined with aquaculture for additional benefits, and simple water-lifting technologies that increase irrigation water availability for terrain suitable for terracing.

1.1.2.2 Vietnam

We discuss an inventory of land and water resources first and the effect of land use on water flow in the watershed later. We discuss the resource inventory based on one catchment each in Nam Bung commune and Sai Luong commune. The Sai Luong commune is the user of the catchment area selected in Nam Bung commune. The catchment area of about 165 ha is divided into a sloping upper catchment area of 150 ha and irrigated bottom valley and terrace rice fields with paddies of 15 ha (Figure 1.6). The elevation of the catchment area ranged from 730 meters to 1,250 m above sea level, creating a large area of steep slopes. The upper part is less fertile due to soil erosion and degradation. Each household has 2 to 4 plots distributed along the toposequence. We identified well-separated subcatchments with specific land uses: (a) rice-maize-cassava rotation, (b) fallow land at varying stages, (c) garden near house, (d) protected forest near village, (e) and forest along streams and far away from villages.

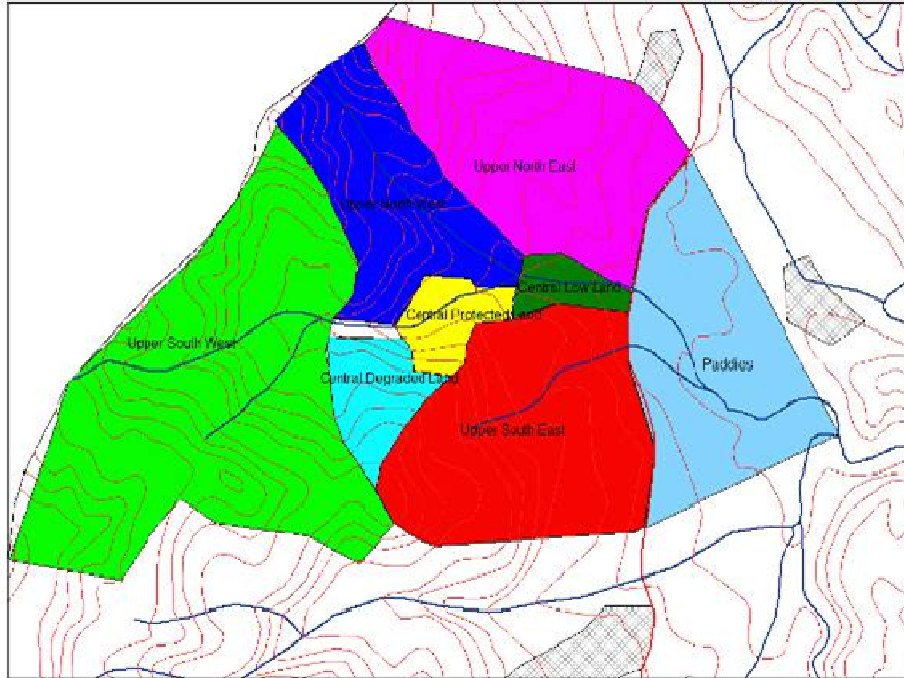


Figure 1.6. Land-use map of Nam Bung commune.

In the last five years, farmers have built terraces especially in degraded and less fertile sloping areas. Terrace construction is low in upper parts of the catchment because of difficulties in capturing water; farmers build terraces mainly in lower parts of the catchment. Farmers opined that terrace construction would grow at a slow pace due to water unavailability. Limited access to valley bottom paddies and degradation of sloping land induced farmers to construct terraces.

The Sa Do stream is the main source of water in the catchment. The paddy area is divided into three subsectors corresponding to water use: one direct intake from the stream and two for each water access using a pipe. Around 15 ha of paddy area are irrigated in the wet season. In the past, the spring-season rice area was negligible despite water available to irrigate nearly two-thirds of the paddy area. Cold and drought constraints, low rice yield, and the high opportunity cost of labor caused a small rice area in the spring season. Following pressure to cultivate land and technological support from the local government, around 5 ha of area have been cultivated in the spring season since 2007. Paddy area is not distributed equitably among households.

There are two types of water access. First is direct water intake from sources. Farmers do not depend on other farmers to decide whether and when to irrigate their land (no water rotation or sharing rules established for water use in the field). Second is field-to-field water use. Farmers receive water from a plot situated above their own plot; water is served along the plots from upstream to downstream.

In normal weather years, the water supply in the wet season is sufficient to grow rice. Water sharing is not a problem between farmers owning paddy fields in the upper part and the lower part of the toposequence. However, problems arise in relatively dry years or years when early-season rainfall for rice planting is low. In abnormal climatic years, plots in the lower part are planted 2–3 weeks later than plots in the upper part. This delay in planting reduces rice yield of lower fields, although lower fields normally tend to have higher yield than upper fields. From a community point of view, inequity in water allocation penalizes productive land.

Pang, Cang Giang A, and Cang Giang B villages are the users of the study catchment in Suoi Giang commune. Farmers broadly compartmentalized the watershed area into three zones: the lower cone of the Suoi Giang River, the central part, and the upper cone of the watershed (Figure 1.7). Although farmers have built terraces to grow paddy rice, there is no clearly identified flat valley bottom with irrigated paddy rice.

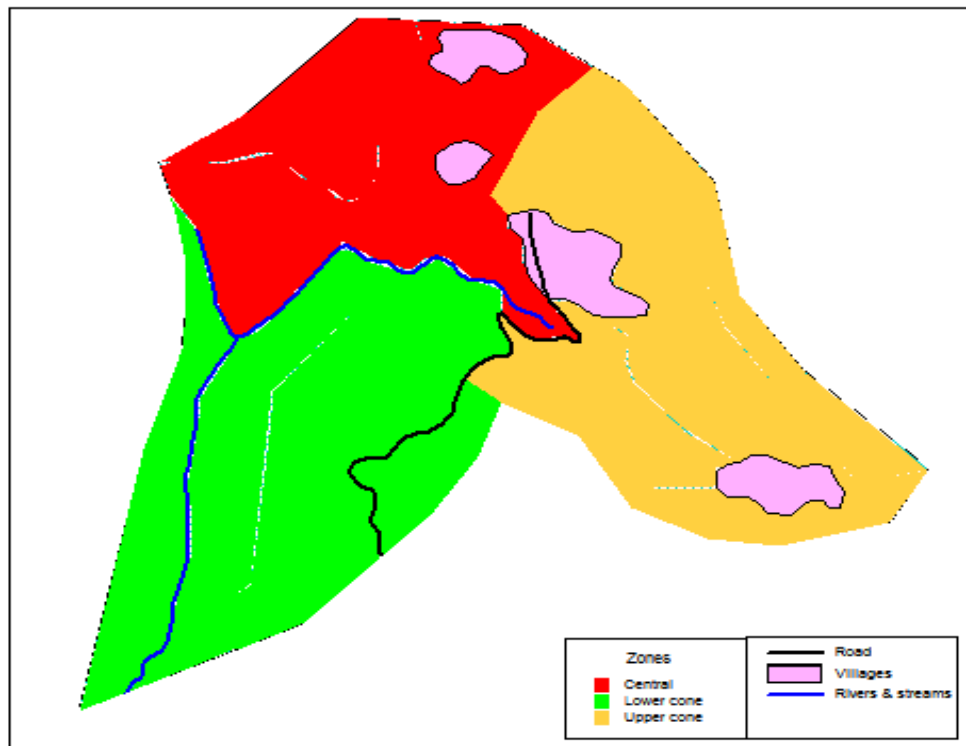


Figure 1.7. Land-use map of Sai Lung commune.

The lower cone of the Suoi Giang River corresponds to the bottom of the valley with an area of about 300 ha. We observe two main land-use patterns: (a) the valley with rainfed rice and degraded forest; farmers have not captured water for irrigation; (b) the right side of the cone where farmers grow cash crops such as maize and cassava. Good soil with high fertility explains the specialized use of this area. Landholding in this area is an indicator of wealth.

The central part of the catchment corresponds to one of the two rice-growing areas of the Pang Cang. We observe three main land-use patterns: (a) recent tea plantation—this is sloping land with rapid expansion of tea area each year. Upland rice fields are converted to a tea plantation in response to high demand for “Suoi Giang tea.” Farmers reported wandering buffaloes damaging tea trees in the dry season. (b) Rainfed rice fields and upper terraces—a large number of terraces were built in the last one decade. Construction of terraces is linked to (i) restriction on forest use enforced by the government, (ii) government subsidies to build terraces, and (iii) low economic yield due to high land degradation. (c) Economic forest zone—the local community has established a new forest zone by planting young trees with the help of the government.

The upper catchment of the Suoi Giang River is largely mountain with high slopes. Land use is mainly forest with small patches of Shan Tea (full-grown trees), upland rice, and gardens near houses. Due to the steep slope and upper catchment, there are no terraces and the area is mainly dominated by secondary forest zones. Households grow Shan Tea and collect nontimber forest products. Households with limited paddy rice depend on Shan Tea sales to buy rice. Remote and steep slopes led to less cultivation of annual crops, less land pressure, and minimal land degradation.

The mapping exercise of two contrasting catchments revealed some complex and contrasting land-use features. Biophysical, food security, and market access characteristics conditioned these land uses. The Nam Bung commune has large valley bottoms and paddy rice cultivation dominates livelihood activities. The Suoi Giang commune is situated in the upper part of the catchment and households have limited access to lowland. Cash crops dominate livelihood activities and households intensively use slopes by constructing terraces.

We also observe similarities between two communes. For both villages, households settled in the 1970s. During the de-collectivization period in the mid-1990s, the government distributed ancestral land to families (clans) based on historical cultivation, though farmers have no land title yet. Early settlers have access to better land than latecomers do. Land is managed privately; no “collectively managed” zones exist in the catchment. Itinerant buffaloes create two sets of problems for managing spring-season crops: (a) high losses of young tea trees to openly grazing buffaloes and (b) the cost of production increases due to the need to protect crops from animals.

Terrace construction is a recent phenomenon and farmers built many terraces in the last five years. While most terraces are rainfed, in a few cases farmers are channeling water from remote distances (up to 3 km) for spring-season irrigation. Since access to water is critical for the second rice crop, the community has established simple rules to construct terraces and access water. Access to water is on a “first-come, first-served” basis. Each farmer can open terraces in his field provided water intakes of other existing terraces are not disturbed. Negotiations on water sharing are done in agreement with current water users as they have the right to use water. Often through consensus, downstream new users get surplus water or upstream new users reach agreement with current users. However, with pressure to grow spring-season rice, some conflicts have started to emerge in the commune.

The output of the group discussion pertaining to land-use changes and water flow in the catchment includes mapping of resource distributions, identification of major resources and their uses, household livelihood strategies, and factors driving water flow in the catchment. The findings revealed that the upstream and downstream communities are tightly linked in terms of resource flow and livelihood strategies. Downstream communities perceived that agricultural activities upstream negatively affect the livelihoods of downstream communities through several mechanisms: (a) slash-and-burn and deforestation upstream reduced water available for irrigated rice paddies, (b) new terraces constructed by Hmong and Dao affected water supply downstream, and (c) rice paddies on river embankment were more damaged by floods in recent years. Flash floods are associated with deforestation upstream. On the other hand, upstream communities believed that some economic linkages existed with downstream communities. However, they perceived that their activities did not affect livelihoods downstream; they thought they were too distant from lowland communities.

1.1.2.3 Thailand

We conducted this study in the Mae Suk subwatershed of the Mae Chaem watershed in Chiang Mai Province, northern Thailand. It covers an area of 96 km². The hills with a height of 1,068 m surround the upper part of the subwatershed and the plain areas with paddy fields surround the lower part of the watershed. Three dominant ethnic groups inhabit the subwatershed across the toposequence. The Hmong ethnic group resides in the upstream of the watershed and practices intensive commercial vegetable cultivation. The Karen ethnic group resides in the mid-stream of the watershed and cultivates both upland and lowland fields. The lowland Thai ethnic group resides in the downstream of the watershed and cultivates lowland fields.

We selected two villages from the Karen upland communities and two villages from the Thai lowland communities as representative upland and lowland communities, respectively. We collected primary data from 158 sample households using a semi-structured questionnaire. We classified households into four groups according to upland and lowland communities, irrigated area, and income sources using two-step cluster analysis in the SPSS software package. The first group is lowland households with poor access to water (LL-BadAW) and the second group is lowland households with good access to water (LL-GoodAW). The third group is upland households with poor access to water (UL-BadAW) and the fourth group is upland households with better access to water (UL-GoodAW). Several livelihood indicators were developed and tested to characterize livelihood assets, livelihood strategies, vulnerabilities, and livelihood outcomes of each group with a focus on access to water.

Table 1.3 presents land-use changes for a three-period estimate based on aerial photographs. In 1976, forest covered 55% of the watershed area, while another 32% was young and old fallow. Field crops, consisting primarily of a mix of upland rice and poppy fields, covered a mere 5% of the landscape. From 1976 to 1984, field crops began to expand as an opium replacement program promoted other cash crops. The pressure on the fallow system began to mount, as some old fallow and forest were converted to cropping. Over time, field crops expanded significantly from 7% in 1984 to 20% in 1996 across the upper watershed area. As a result, forest, young fallow, and old

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fallow declined. The land-use maps reflect temporal changes in land-use patterns in Mae Suk subwatershed (Figure 1.8 and 1.9). The land-use changes support the growth of field crops as explained by farmers during the interview. Thus, expansion of field crops put strong pressure on land and water resources in the watershed.

Table 1.3. Percentage area under different land-use types in Mae Suk watershed, Chiang Mai, Thailand, 1976 to 1996.

Land-use class	1976	1984	1996
Forest	55	51	44
Disturbed forest	-	-	-
Old fallow	23	24	20
Young fallow	9	13	10
Forest and grassland	6	3	2
Field crops	5	7	20
Paddy fields	2	2	2
Settlement	0	0	1
All	100	100	100

Source: Badenoch (2006).

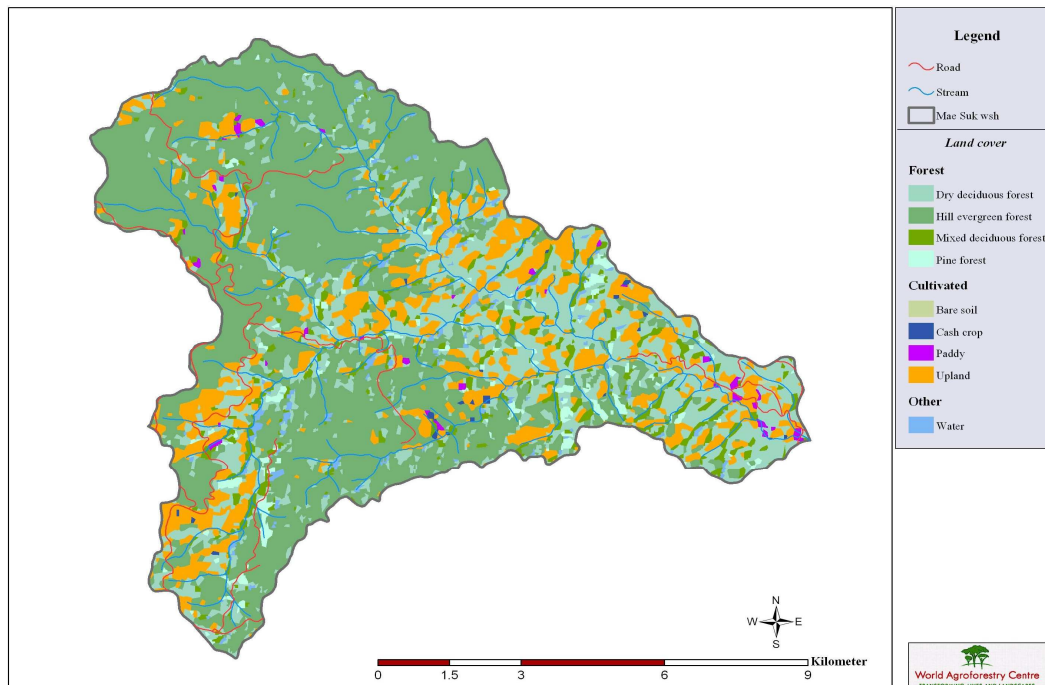


Figure 1.8. Land cover of Mae Suk subwatershed, 1989 (Source: ICRAF).

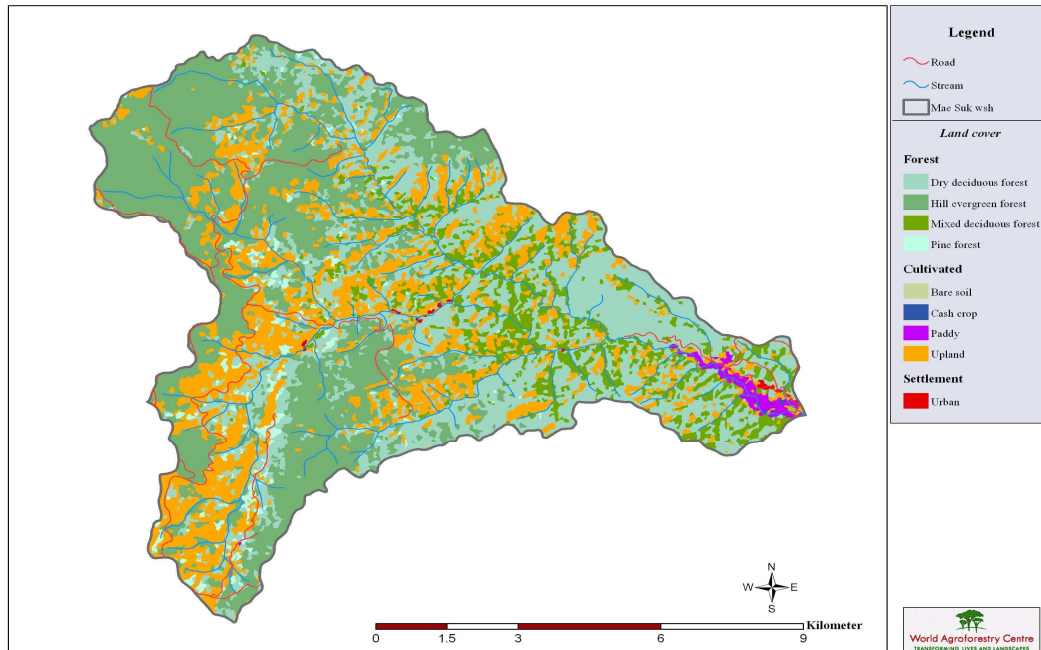


Figure 1.9. Land cover of Mae Suk subwatershed, 2000 (Source: ICRAF).

Table 1.4. Percentage area under different land use by ethnic groups, Mae Suk watershed, 2002.

Land-use class	Ethnic group			Total
	Hmong	Khon Muang	Karen	
Forest	1	70	20	26
Community-protected forest	15	2	31	23
Community rehabilitation forest	0	0	2	2
Forest plantation	4	0	0	1
Birth spirit forest	0	0	0	0
Fruit tree	3	1	0	1
Subsistence forest	13	7	5	7
Cemetery	1	0	1	1
Fallow field	0	0	29	18
Field crop	60	8	9	17
Paddy field	2	11	2	4
Settlement	1	1	1	1
Total (ha)	1,433	1,718	5,763	8,914

Source: Badenoch (2006).

Table 1.4 presents land-use patterns by ethnicity developed through a participatory land-use mapping exercise. Broadly, the Hmong, located at the top of the watershed, have a relatively large proportion of field crops; the Khon Muang, located at the bottom of the watershed, have a relatively large proportion of paddy fields; and the Karen, located at the middle of the watershed, have a mix of both field crops and paddy fields. The data show a concentration of field crops at the top of the watershed, paddy fields at the bottom of the watershed, and a broad area of forest in the middle. These zones correspond to three groups of ethnicity in the watershed, and represent different strategies for land management in terms of the forest-agriculture balance. The data do not support the popular belief of large-scale loss of forestland. The change associated with the expansion of field crops seems to have been balanced by re-growth of forest in fallow and grassland areas.

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Three main streams, namely, the Mae Suk, the Hngan, and the Sai Khow, with several creeks originated in the head watershed flow down the Mae Suk subwatershed and combine to form the Mae Suk stream. The Mae Suk stream flows through the lowland villages before feeding into the Mae Chaem River. Three ethnic groups, Hmong, Karen, and Northern Thai, inhabit the Mae Suk subwatershed. The land-use pattern varies with ethnic groups. The Hmong reside at the highest altitude, the Karen reside at middle altitude, and the Thai reside in the lowland. Water resources in the Mae Suk subwatershed are used for household consumption and agricultural purposes. Several sources of water are used for both household consumption and agriculture use in both upland and lowland communities (Tables 1.5 and 1.6).

Table 1.5. Number of households benefiting from different sources of domestic water in the study areas.

Item	Lowland community		Upland community	
	Mae Suk	Kong Kan	Mae Ngan Luang	Kong Bot Nua
Total household	117	98	120	110
Domestic water sources				
Shallow pond	8	-	-	86
Small reservoir	43	-	76	43
Creek/stream	117	98	120	70
Weir	80	-	120	28
Irrigation canal (Muang)	100	98	76	28
Tap water distributed by community	117	-	120	110
Private groundwater	-	8	-	-
River (Mae Chaem)	117	98	-	-

Source: Chiang Mai Statistic Office (2004).

Table 1.6. Number of households benefiting from different sources of irrigation water in the study areas.

Item	Lowland community		Upland community	
	Mae Suk	Kong Kan	Mae Ngan Luang	Kong Bot Nua
Total household	117	98	120	110
Agricultural water sources				
Shallow pond	8	-	-	110
Reservoir	-	-	60	-
Pond	3	-	74	-
Stream	117	88	120	80
Weir	80	88	120	110
Irrigation canal	100	88	-	-
Tap water	117	-	120	110
River (Mae Chaem)	-	88	-	-

Source: Chiang Mai Statistic Office (2004).

1.1.3 Conclusions

A combination of field surveys and participatory methods is important for detailed spatial and temporal characterization of land and water resources at different scales from farm to watershed. Agricultural land, water, and livestock are important livelihood assets of farm households. The land and water resource endowment significantly affects poverty, food security, and livelihood strategies. We can broadly map the upper catchments as forest, livestock grazing areas, shifting cultivation, permanent cultivation, or terraces and valley bottoms across the toposequence from the top to the bottom of the watershed. We can classify land use into four primary domains: (a) permanent cropping, (b) shifting cultivation, (c) livestock grazing, and (d) forest. Permanent cropping and shifting cultivation area constitutes more than 80% of the watershed area. Farmers grow paddy rice in valley bottoms and terraces, and upland rice on sloping land using slash-and-burn cultivation practices. Paddy rice yield is significantly higher than upland rice yield. Lowland rice holdings vary significantly among households. Early settlers have more lowland than late settlers although the overall lowland endowment is quite small. Households with more lowland are more food secure and earn higher income. Households with small lowland holdings construct terraces on sloping land. The major factors leading to terrace construction are low access to

paddies, rice deficiency, good access to water, low rice yield due to degradation of sloping land, restriction on forest use, and a subsidy to construct terraces. Terrace construction is gradually increasing with an increase in population pressure. We observed a positive correlation between paddy rice area and upland cash crop area. Traditional rice technologies, low rice yield, and high opportunity costs of labor discourage the intensification of rice production in the dry season. Population pressure, government policies, and market forces reduced the fallow period in sloping uplands from 6–8 years a decade ago to 3–4 years now. The reduced fallow period resulted in an increase in pests and weeds and an overall degradation of fragile upland areas.

Large and small streams flow across the watershed and feed into the large rivers at the lower part of the watershed. Farmers use water predominantly for paddy rice production. Where market access is good, farmers use water for both rice and vegetable production. Farmers usually channel water from streams to paddy rice fields through long earthen canals. The water supply in the wet season is sufficient for rice production in paddies, though the early wet-season water supply is a constraint. The water supply in the dry season is a major constraint for rice production. Farmers establish rules for water sharing and allocation when scarcity arises. Farmers at the tail of the canal plant rice 2–3 weeks later than those at the head of the canal. Late planting reduces rice yield.

We observed two modes of access to water in upper catchments: first, direct access to water sources without any community cooperation for water sharing and use; second, access to water in agreement with neighbors. Other farmers' cooperation is required to share water from the sources, and to allocate water from a main canal to a branch canal, and sometimes to channel water through plots of neighbors. We observed two types of water conveyance system: first, farmers directly channel water from sources to the field using private or public canals; second, farmers channel water from multiple sources, store it near the field in a water storage system, and share it among clans or neighbors using mutually agreed-upon rules.

Farmers share water sources on a "first-come, first-served" basis. Newcomers can use surplus water downstream, but not upstream, which affects the water intake of existing users. Water use upstream requires a consensus of downstream users who will be affected. The rules, however, break down when competition for water increases because of the high marginal value of water. The scarcity of water leads to conflicts over water use.

Resource flow and use are tightly linked between upstream and downstream communities. Land uses upstream affect water flow downstream. Downstream communities perceive that land-use activities upstream affect livelihoods downstream through several mechanisms, including (a) slash-and-burn cultivation and deforestation reduce stream flow, (b) new terrace construction reduces water availability in the dry season, and (c) slash-and-burn increases flashfloods and siltation. New terrace construction upstream has no significant effect on water availability downstream during the wet season, but it significantly reduces water availability in the dry season. Access to land and water, access to markets, and population density are major driving forces that affect land and water use in the uplands. Improved access to lowland and to water is vital to improve food security, overcome poverty, and protect the environment.

1.2 Estimating water use and water flow across the landscape

1.2.1 Methodology

We conducted a detailed quantitative characterization of land and water resources and a hydrology modeling exercise in the Houay Hom watershed in Fai Village, Lao PDR (Figure 1.10). Assessments of alternative land use and water flows in the catchment were then based on the modeling studies, which compared alternatives against a base scenario, reflecting conditions during the 2-year data collection period. The Houay Hom catchment covers approximately 3.5 km² and is one of the four small catchments located within the boundary of Fai Village. The Houay Hom watershed exemplifies the topographic and land-use characteristics found throughout the northern Lao uplands. A lack of quality secondary hydrological and remotely sensed elevation and land-use data for modeling and land-use analysis necessitate more time- and resource-intensive primary data collection.

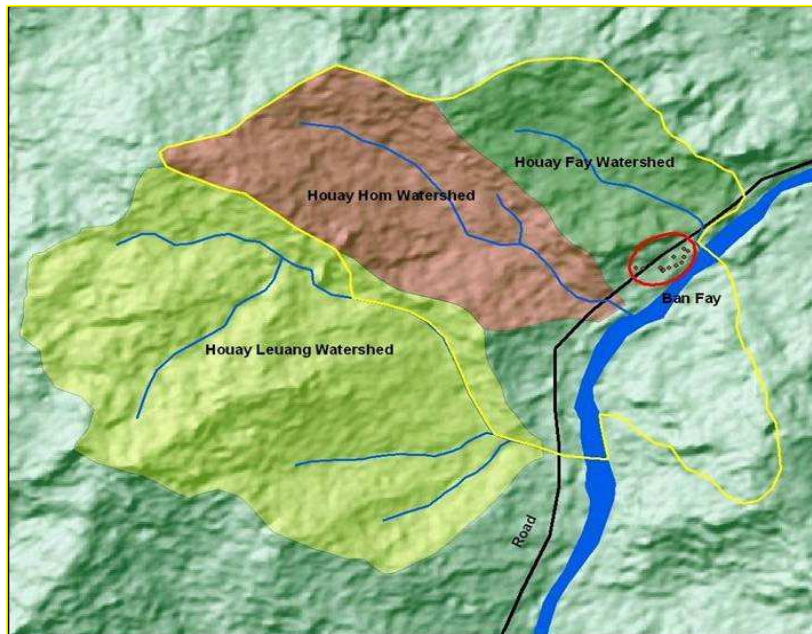


Figure 1.10. Houay Hom watershed, Ban Fai, Lao PDR (364 ha).

A combination of techniques, such as participatory mapping, field measurements, GPS-based field mapping surveys, and a remote field-mapping survey, was used to collect watershed-level biophysical, hydrological, and climate data. Biophysical data include topography (elevation, slope, and distance from base points) and land use (paddy, upland rotation, permanent cropping, forest or plantation, and fallow areas). Hydrological data include stream and conveyance networks and structures, dry-season springs, and seasonal water flows in the streams. Climate data include temperature, rainfall, and evapotranspiration. The two primary uses of diverted stream water were paddy irrigation and domestic water supply for the village. Collected field data were used for spatial analysis, such as mapping of land and water resources, developing land-use typology, and formulating a hydrological model. The prepared map reflects detailed land-use characteristics, stream networks and canals, topography, and contours.

Quantitative characterization of land and water resources in the Houay Hom watershed

Field research efforts centered on collecting detailed topographic, land-use, and hydrological data for a two-year period (March 2007 to March 2009). Field monitoring visits documented management decisions, seasonality, and discharge characteristics of water flows and land-use regimes, providing qualitative understanding to augment the two primary quantitative data collection methods: detailed field surveys and land-phase field hydrology. Table 1.7 lists the primary field methods employed. An automated weather station located on a sloping location in the catchment gathered Penman-Monteith evapotranspiration (ET) climate parameters and rainfall amounts every 2 minutes over a 2-year period, resulting in time-series high-quality ET, and rainfall amount and intensity.

Table 1.7. Field survey methods employed in hydrology modeling, Fai Village, Lao PDR.

Method	Data type	Key methodological elements
Remote field-mapping survey	Topography; land use	Augmented Activity 1 field research in Ban Fai. Used a Garmin 76 global positioning system (GPS) unit, an altimeter, a compass, and a Laser Technology TruPulse 200 laser rangefinder/hypsometer.
Climate monitoring (3 locations)	Evapotranspiration (potential); rainfall	Automated weather station (1 location); supplemental weather stations (2 locations); ET gauge (3 locations). Distributed across watershed to capture spatial and elevation effects. Manual and automated readings.
Stream flow monitoring (4 locations)	Stream flows	High-resolution (10-min) depth measurement at the watershed outlet during wet season; daily depth measurements in dry season. Used velocity-area method, volumetric measurement, S-M flume (Samani and Magallanez 2000), and rectangular culvert depth monitoring.
Paddy water level monitoring	Paddy water management	Daily manual depth measurements in two adjacent rice paddy areas, at multiple levels on the toposequence.

Volumetric dam measuring sites provided daily manual readings of feeder streams. High discharge variability at the watershed outlets required two flow monitoring techniques used in tandem. High flows at the outlet were estimated by logging flow depths through a 3 m × 3 m rectangular culvert, while low flows were measured using an S-M flume with a depth logger located just upstream of the culvert. We calculated high flow estimates using a hydraulic model of the culvert, under either uniform flow or gradually varying flow assumptions, and correlated to S-M flume results where measurement ranges overlapped.

In the field-mapping survey, paddy areas, stream and conveyance networks and structures, dry-season springs, and easily accessed areas were delineated and mapped. However, we used a Remote Field-Mapping Survey, a ground-based method for simultaneous and rapid collection of spatial land-use and topography data over several square kilometers, for detailed land-use characterization of the entire watershed. Survey base points, along with key land uses and topographic formations with easy access, were mapped using a GPS unit. A laser rangefinder and electronic compass acquired height, distance, and bearing data relative to the base points for land uses and terrain extremes in less accessible areas of the watershed. Base points and remote points were then translated to detailed land-use and high-resolution contour maps.

Watershed hydrology model

Results from detailed land and hydrology data collection served as inputs to a watershed hydrology simulation model of the Hom watershed. The model was constructed using MIKE SHE, an integrated, fully distributed, physically based watershed hydrology-modeling package. MIKE SHE simulates all aspects of the land-phase of the hydrological cycle, is capable of modeling water flows in complex terrain, incorporates both natural hydrological fluxes as well as managed-flow processes, and exhibits considerable flexibility and functionality for the user.

Input data requirements for distributed hydrology models are intensive, and, as is the case in many upland regions in the developing world, data on land uses, soil properties, and subsurface hydraulic properties are largely unavailable or of low quality or resolution. Modeling efforts therefore combined distributed representations based on high-quality primary data on land use, climate, topography, stream flows, and paddy water level monitoring with conceptual lumped approaches for processes undersupported with data, such as distributed soil depths and subsurface hydraulic properties. Figure 1.11 presents the configuration of the MIKE SHE hydrology model.

The climate in northern Lao PDR is monsoonal, with a pronounced wet season from May to October. Field hydrology results indicated that the dry-season base flows reach a minimum in April, despite some initial storm events during February-April, indicating that subsurface storage reaches an equilibrium value at the end of the dry season in late April, lessening the complicating effects of carryover surface or subsurface storage and allowing more precise water balance

estimation. A water year (WY) of May-April was consequently established as the temporal basis for analysis. The modeling period was from May 2007 to April 2009 or WY2007 and WY2008, with the results reported in terms of individual years.

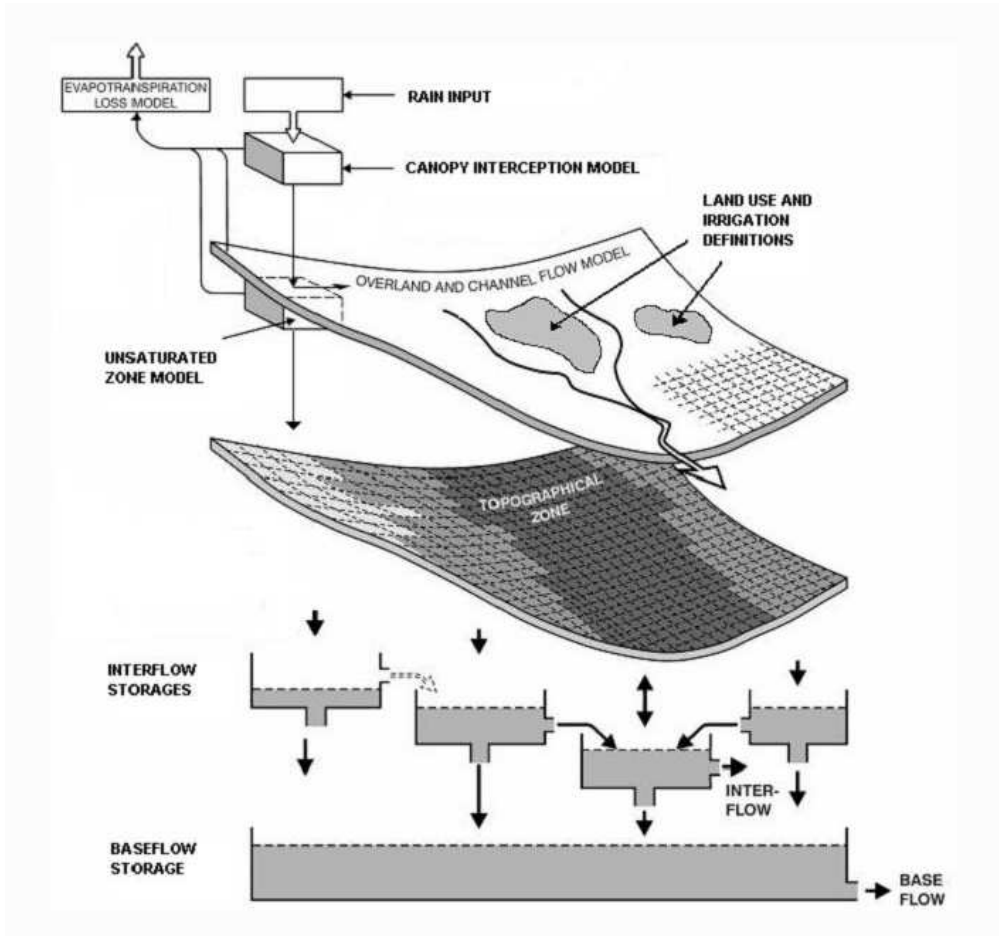


Figure 1.11. MIKE SHE hydrology model formulation for Houay Hom watershed (adapted from DHI 2009).

In Vietnam, unavailability of a hydrologist limited the quantitative modeling of land-use and water-flow relationship analysis. Instead, qualitative methods were mainly relied upon. First, we discussed the effect of land-use changes on water flow through group discussions. Second, we collected the water-flow data in the Sai Luong subcatchment for a six-month period in 2008. Eight inlets in the subcatchments measured water flow from July to December 2008. An automated weather station recorded the amount and intensity of rainfall, temperature, humidity, wind speed, and solar radiation intensity. We also installed a hydrometric station that measured the water level in the stream every 3 minutes. These data are useful for developing a watershed hydrology model to analyze the effect of land-use changes on water flow in the watershed. A lack of sufficient data, however, limited the development of a full hydrology model in this project.

1.2.2 Results and discussion

1.2.2.1 Lao PDR

Figure 1.12 depicts topographic and land uses for Houay Hom watershed derived from field data collection. We obtained highly accurate data from Remote Field-Mapping Survey efforts. Results reflect intensive land-use regimes: cropping and fallow areas constitute 80% of the area in the watershed. Results indicate an aggressive use of upland areas for shifting cultivation to meet household food needs. These results are congruent with farmers' interviews.

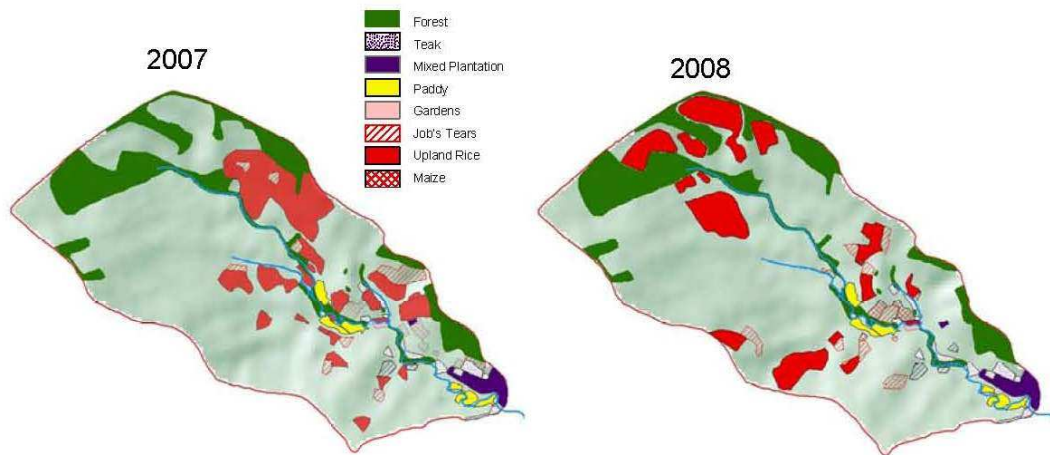


Figure 1.12. Land-use map, Houay Hom watershed, Fai Village (2007 and 2008).

Figure 1.13 presents rainfall and evapotranspiration data for Houay Hom watershed. Climate field efforts produced high-quality Penman-Monteith parameter data and rainfall data at 2-minute resolution for a 2-year period. Rainfall is predominantly monsoonal type with more than 85% of the rainfall occurring during May-October; dry-season rainfall is very small. Results from the three climate stations indicated negligible variance in reference evapotranspiration rates, despite spatial separation and elevation differences. Spatially uniform reference evapotranspiration time-series data were consequently used for the hydrology modeling.

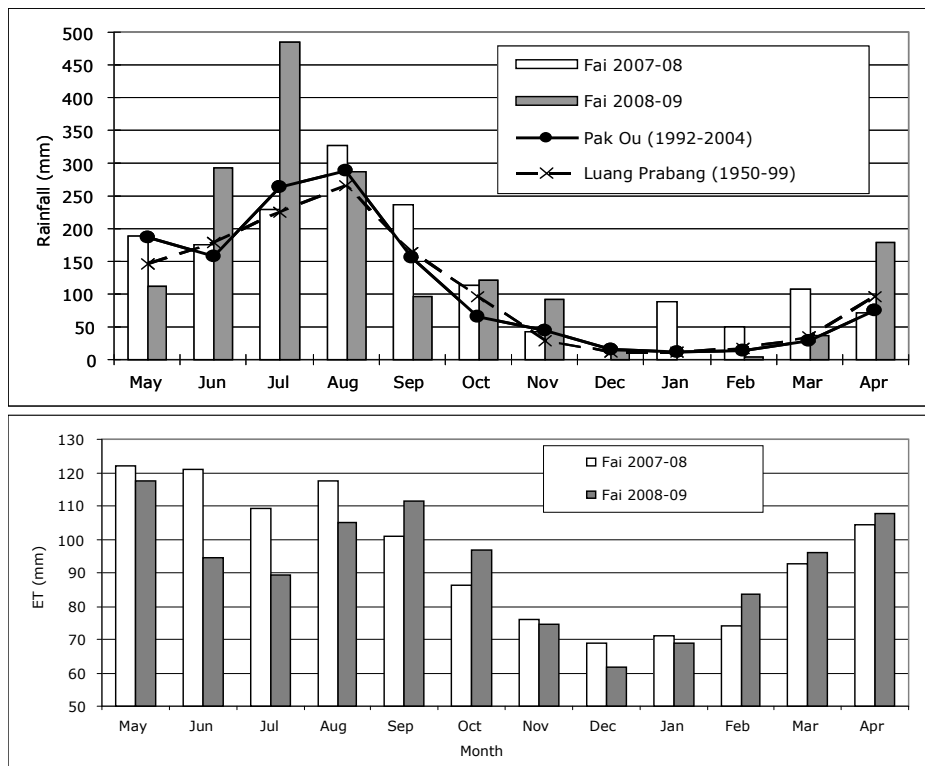


Figure 1.13. Monthly rainfall and reference evapotranspiration values for Hom watershed.

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Stream flows exhibited significant variability, ranging from approximately 3 L/s at the end of the dry season to extreme storm event flows estimated to be in excess of 30,000 L/s. Extreme flow events, which frequently damaged field measuring equipment, resulted in poor-quality stream flow data for Houay Hom in 2007. Changes in field measuring techniques in 2008 rendered some periods of high-quality data that were subsequently used for calibration and validation exercises in the hydrology modeling.

Watershed hydrology model—scenario design

Water unavailability is a significant constraint to increasing paddy production through expansion of paddy area either in the wet season or in the dry season. The purpose of the hydrological scenario analysis was therefore to gain an understanding of the effects of sloping land-use conversion on water availability for paddy intensification. Subsequent economic analysis could then determine the resulting economic viability of the conversion. Table 1.8 presents current (base case) land use in the watershed.

Table 1.8. Land use (ha) in the Hom watershed, Fai Village, Lao PDR.

Land-use type	2007	2008
Forest	53.8	54.0
Plantation	9.4	9.4
Upland rice	37.7	38.8
Job's tear	6.4	5.8
Maize	2.9	2.1
Paddy	3.9	3.9
Fallow	249.0	249.1
Other	0.8	0.8
Total	363.9	363.9

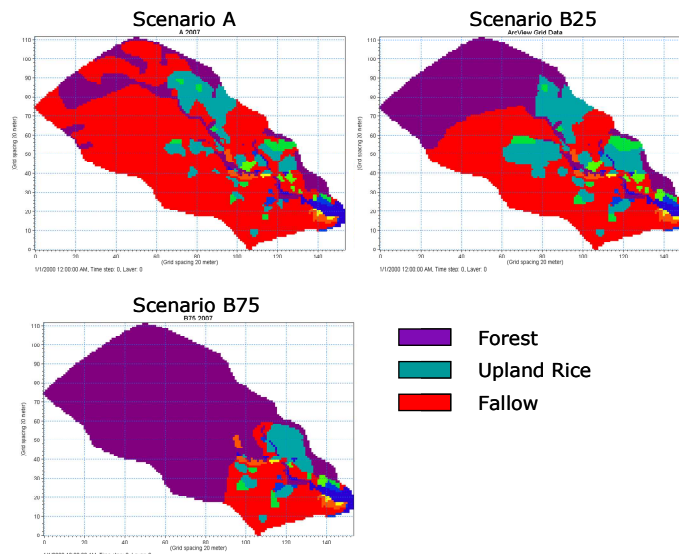


Figure 1.14. Land-use scenarios in Hom watershed in 2007.

We modeled the conversion of the upland shifting cultivation area (cropped and fallow areas) to forest progressively and estimated the resultant increase in water flow in the watershed. We used five different scenarios—base case and four different proportions of forest area in the watershed (25%, 50%, 75%, and 100%)—to estimate the effect of land-use changes on water supply in the watershed. We then assessed the total increase in paddy rice production by using this extra water flow. We present three of the five scenarios for brevity (Figure 1.14). As existing paddies and expansion areas are located in topographic lows, that is, the Hom stream, conversion to forests was incrementally done in the model from the top of the watershed toward the outlet to maximize change in paddy water availability. After conversion to forest, cropping areas for upland crops (upland rice, Job's tear, and maize) were modeled to expand from existing areas to meet (a) an

assumed cropping intensity of 30% of total swidden land area per year, reflecting current fallow periods of 3–4 years; while (b) maintaining appropriate area percentages between the three upland crops of 81%, 13%, and 6%, respectively. The scenarios thus reflect land-use regimes, which result from setting aside agricultural land for conversion to forest, while maintaining current cropping practices and intensities on the remaining slopes. Water availability was estimated using the discharge of the Hom stream at the watershed outlet.

Scenario A reflects land-use and hydrological conditions in the two-year data collection period (base case). Scenarios B25, B50, B75, and B100 assume that 25%, 50%, 75%, and 100% of shifting cultivation area is allocated to forest, respectively.

Watershed hydrology model results

Negligible surface-water and groundwater carryover storage across water years simplifies water balance determination. With the exception of a small amount of water captured for domestic water supply, virtually all precipitation water falling during the water year exits in the watershed in three ways: evapotranspiration, stream discharge at the watershed outlet through either direct runoff or base-flow processes, or subsurface percolation losses. Figure 1.15 depicts simulated normalized system outflow water balance terms averaged between WY2007 and WY2008 for Scenario A (reflecting current conditions) from an annual average rainfall of 1,645 mm. Some 57% of the rainfall evaporates or transpires, while only 14% exits in the watershed as stream flow. The remaining portion is lost through deep percolation of infiltrated water, a result consistent with expectations as springs were observed below the watershed outlet and the area is known for its karst geology.

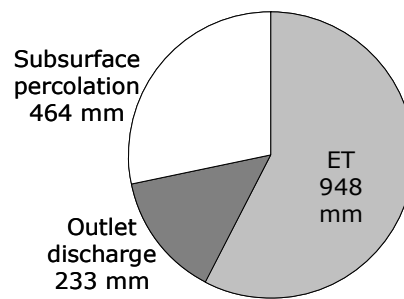


Figure 1.15. Annual average system outflows for Hom watershed (normalized).

Figure 1.16 identifies trends in stream-flow regime at the watershed outlet under forest conversion. Scenario A is contrasted with Scenario B100, the extreme case, where 100% of shifting cultivation area on slopes is converted to forest or other similar permanent cover. Results exhibit little change in September through April, which equates to the late wet and dry season. However, significant shifts are evident in the early dry season from May through August, with the greatest shift being a 47% increase in stream flows in July. The overall increase in stream flows was 35% during the wet season (June–November) and 20% during the dry season (December–May). It is worth noting that, despite a relatively large percentage increase in stream flow in the dry season, the absolute amount of water available for paddy production is still small due to the small amount of base flow.

While indicative of shifts in hydrological behavior, monthly averages of total watershed discharge are a poor reflection of water availability for paddy irrigation. Much of the discharge included in wet-season monthly values is high flows attributed to direct storm runoff, which cannot be captured and stored for later use. Furthermore, due to system inefficiencies such as percolation losses in irrigation canals and incomplete capture of stream water behind diversion weirs, not all stream water can be used for paddy irrigation. To mitigate these two factors, water availability estimations consider only simulated base flow (i.e., stream flow whose source is groundwater exfiltration), rather than high volumes associated with storm runoff, which are an unreliable source for irrigation. A small amount of water below an “accessibility threshold” is then removed from monthly base-flow estimates to account for inaccessible stream water. The resulting monthly water availability estimates are based on monthly base-flow volumes about an accessibility threshold of 8,500 cubic meters (Figure 1.17).

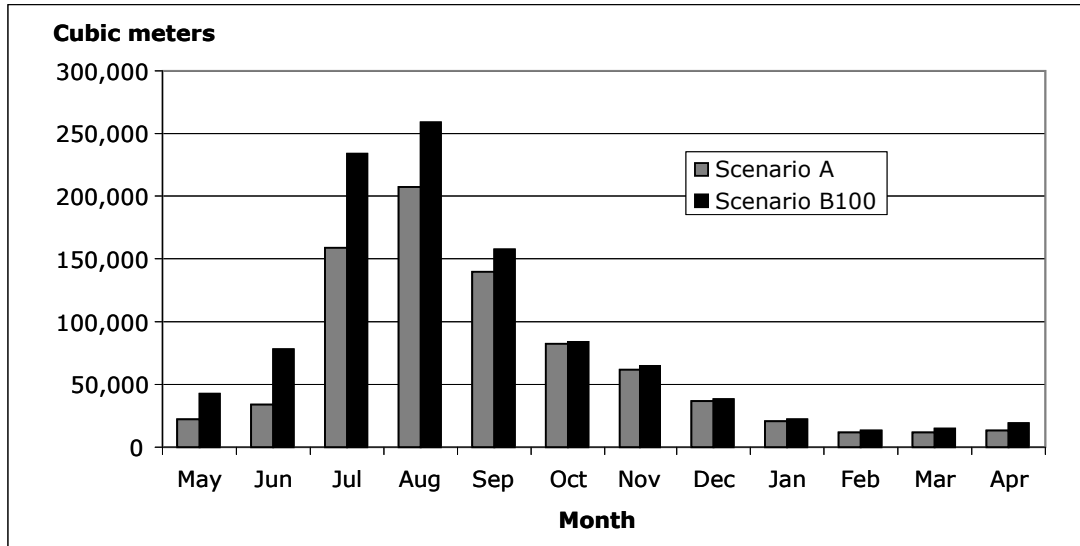


Figure 1.16. Monthly outlet discharge in Hom watershed (average of WY2007 and WY2008): Scenario A vs. Scenario B100.

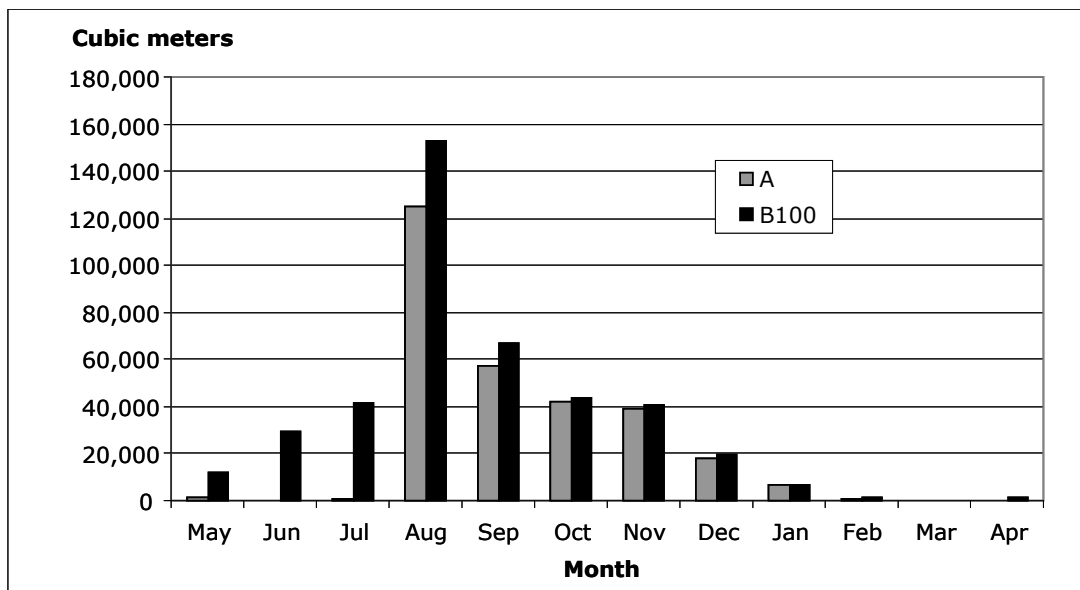


Figure 1.17. Available water volume in Hom watershed (average of WY2007 and WY2008): Scenario A vs. Scenario B100.

Though total volume differs, trends evident in total watershed discharge changes are readily apparent in available water volume between Scenarios A and B100. Under current conditions, almost no additional water is available in May through July for paddy irrigation beyond what is currently used (Scenario A). Since farmers must transplant wet-season paddy rice by late July to be able to harvest in November, farmers in the Hom watershed are currently water-constrained and would therefore likely be unable to expand current wet-season paddy area, despite high water availability in all scenarios from August through December. However, under the B100 scenario, additional water is not available in May through July, indicating a potential for expansion of wet-season paddy rice if slopes were converted from shifting cultivation land use to forest.

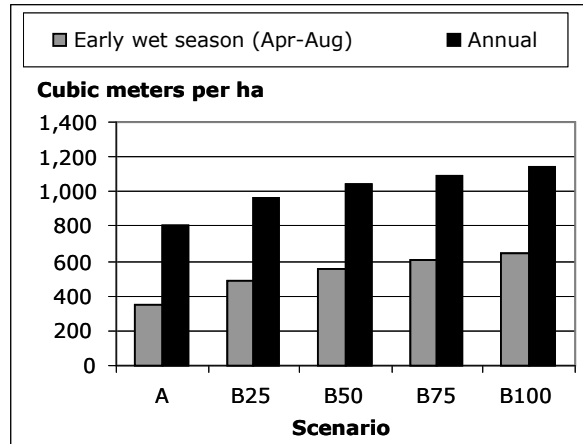


Figure 1.18. Simulated volume of water available in the Hom watershed.

Figure 1.18 illustrates water availability results in monthly flow volumes per unit watershed area for each of the forest conversion scenarios, for the purpose of potential extrapolation of results. Results suggest a nonlinear water availability response, with the greatest incremental gain in water availability evident in the transition from current conditions (Scenario A) to Scenario B25, which reflects a conversion of 25% of sloping swidden area to forest.

Results of the hydrology model that compares current land-use and hydrological conditions (Scenario A) to progressive conversion of swidden area to forest in the Hom watershed yield some preliminary conclusions. First, hydrological/landscape simulations suggest that conversion of upland swidden area to forest results in an increase in total stream outflow on an annual basis, translating into an increase in overall water availability for paddy irrigation. Nevertheless, the amount of water available for paddy production in the dry season is rather small. Improvements in water availability, predominantly evident in the early wet season, may primarily be a factor of the type of forest that replaces shifting cultivation area. A dipterocarp/deciduous forest indigenous to the Lao uplands and modeled in the hydrological simulations will exhibit lower ET during the dry season, thereby preserving soil moisture to be released in the early wet season. Altered ET dynamics, combined with higher runoff retention and greater infiltration under forest scenarios in the early wet season when swidden slopes would normally be cleared and bare due to burning, result in lower runoff rates and greater base-flow rates in the early wet season. Further analysis is needed to see whether a nondeciduous forest/plantation regime would significantly affect early wet-season water availability.

Second, conversion of upland rotation to forest translates into insignificant expansion of dry-season paddy rice. Limited soil depth and soil storage capacity do not allow sufficient groundwater carryover storage into the dry season in this watershed to benefit dry-season paddy irrigation. This conclusion concurs with soil surveys reported in the literature: upland soils in Laos are considered shallow, with low moisture storage capacity. Though increased forest cover leads to improved infiltration and less time to soil saturation conditions, it does not increase soil-moisture storage capacity (Figure 1.19 qualitatively illustrates base-flow dynamics). As late wet-season and dry-season stream discharge is dependent on base flow and thus soil-moisture storage, little change occurs during this period under various land-cover alternatives. As such, water availability for dry-season paddy irrigation appears to be insensitive to land-use alternatives, and any consideration of dry-season paddy cultivation would likely require assessment of surface-water storage, potentially in tandem with water-saving rice production technologies such as aerobic rice or alternate wetting-and-drying (AWD) irrigation schemes, to make dry-season paddy rice more viable.

This conclusion is significant to the project objectives. A preliminary line of inquiry of the project has been assessing whether losses in upland production incurred from conversion of sloping land to forest could be offset by increasing dry-season paddy rice cultivation, since no additional investment is needed for terrace construction, and so on. The viability of this option depends upon favorable changes in water availability in the dry season due to the land-use conversion. Our result indicates that this option is not viable. Thus, paddy intensification options appear to be most applicable to wet-season production.

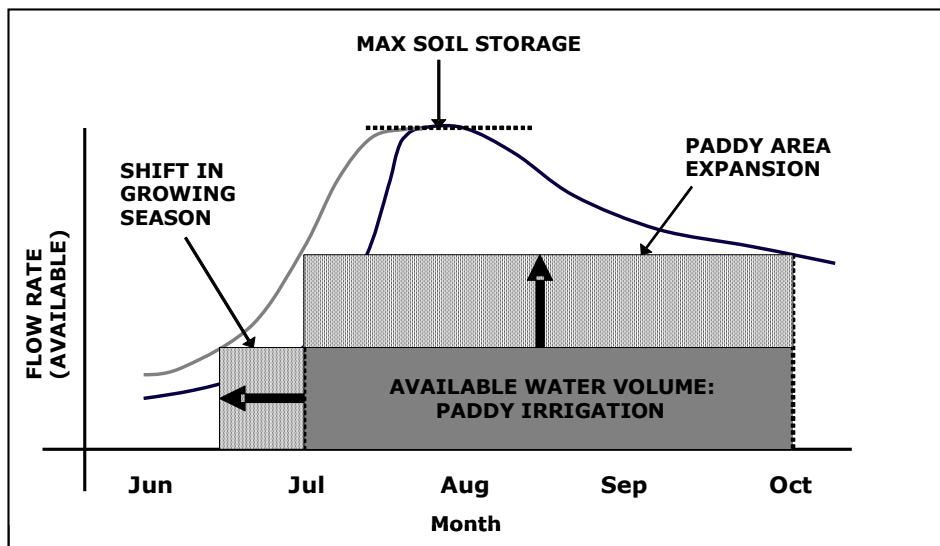


Figure 1.19. Available water-flow dynamics and options for paddy intensification.

Third, the most significant change in stream water availability under forest conversion scenarios is in the early wet season. Simulated results agree with participatory assessments in Ban Fai: farmers in the Hom watershed typically felt constrained by water availability when establishing their wet-season paddy rice in July, and delayed onset of rains sometimes affected production. Farmers usually plant rice late in the upper part of the watershed compared with the lower part of the watershed. Model results suggest, as indicated in Figure 1.19, that water availability within the various B scenarios (indicated by the flow-rate curve in gray) increases in May through July before leveling out in August, providing greater flexibility in two ways. Farmers can either continue to transplant in July and expand paddy area until water availability is again limiting or they may transplant up to a month earlier than under current conditions (Scenario A) with corresponding yield increases due to more beneficial synchronization with the wet season and between farmer transplanting dates.

Hydrological modeling results, which suggest a favorable shift in water availability from slope conversion, however, do not necessarily imply that the conversion is an economically viable option for farmers. Hydrological modeling results do not take into account farmers' decision-making processes, but are rather useful as an input into subsequent economic analysis, which we present later in this report.

Fourth, modeling results presented here represent only assessments from an initial modeling study, which considers only scenarios where land is removed from shifting cultivation and is allocated to forest or a similar permanent land cover. As such, this provides useful indications of how water availability changes under alternative policy and decision-making conditions. Many other potential land-use and water management alternatives have yet to be explored, including sustainable (long-fallow) shifting cultivation regimes, alternative land-use mosaics within the shifting cultivation system, and surface storage and alternative water conveyance technologies that could dramatically increase water availability for alternative uses through more efficient capture of precipitation. The hydrological platform developed within this project has the capability of easily incorporating alternative land-use and water management technologies to assess synergistic technologies for more productive use of water in upper catchments.

Finally, the project has afforded valuable lessons in research areas that have been underexplored, including hydrological modeling in the data-scarce environment of the Lao uplands, and assessment of various land-use and field-hydrology data collection techniques, which provide high-quality data in a challenging field environment. We hope that these lessons can be put to further use in characterizing and assessing land and water resource bases in upland areas throughout Southeast Asia.

1.2.2.2 Vietnam

We present the delineation of the hydrology model conducted in the Sai Luong subcatchment in Nam Bung commune (Figure 1.20). Table 1.9 presents the salient features of the catchment. Due to unavailability of a hydrologist to work on a long-term basis in Vietnam, model development was limited to evaluating the availability of water during the spring and summer season. We did not analyze the land-use changes and water-flow relationship.

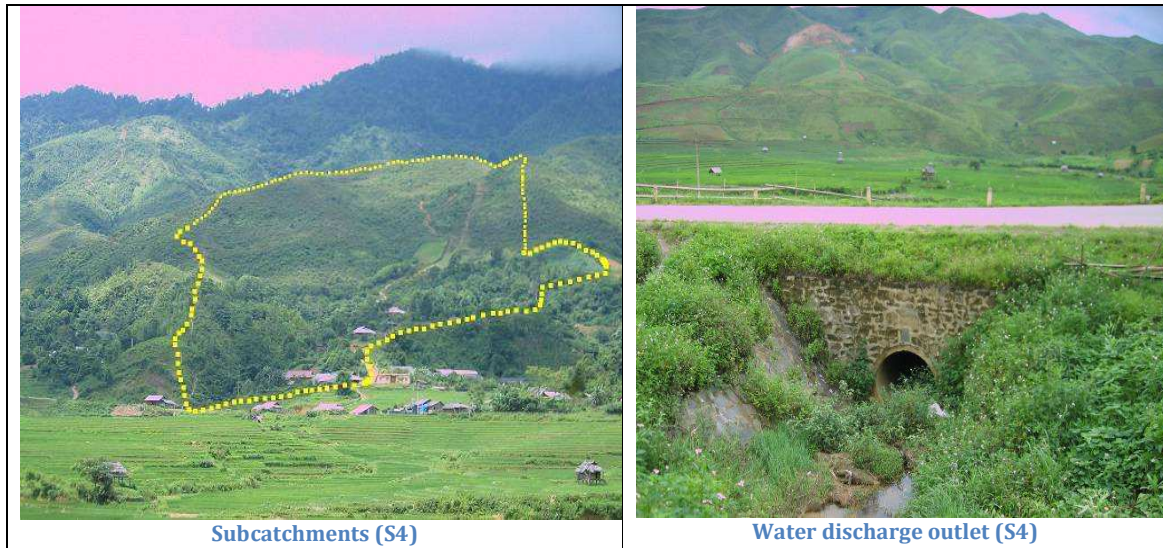


Figure 1.20. Sai Luong subcatchments, Nam Bung commune.

The water supply measured at the outlet in the wet season indicated that water flow in the subcatchment is sufficient to irrigate the 15-ha valley bottom situated downstream. These measurements showed that the water supply in the spring season is enough to irrigate all 15 ha of area of valley bottom in Sai Luong village. Nevertheless, the results are site-specific and cannot be generalized to all areas. In the same way, we attempted to evaluate the impact of new terrace cultivation on downstream flows. However, with only six months of data, we cannot draw conclusions about the impact of additional terraces. Discussions with farmers revealed that new terraces had no significant impact on water flows in the wet season. More data and further analyses are required to draw conclusions about the impact of new terraces on water flow in the watershed.

Table 1.9. Sai Luong subcatchment statistics.

Subcatchments	1	2	3	4	5	6
Drained by subcatchments	S1	S2	S3	S4	S5	S6
Area (km ²)	0.08	0.09	1.19	0.12	0.4	1.33
Perimeter (km)	1.5	1.5	5.2	1.8	2.7	6.9
Forest proportion (%)	20	20	20	45	55	10
Pasture proportion (%)	60	40	45	45	10	60
Paddy proportion (%)	10	30	15	5	30	15
Annual crops proportion (%)	10	10	20	5	5	15

1.2.3 Conclusions

Results of the hydrology model that compare land use and water flow in the upper catchments provide some conclusions. First, the conversion of upland shifting cultivation area to forest results in an increase in total stream outflow on an annual basis, translating into an increase in overall water availability for paddy irrigation. Improvement in water availability is predominantly evident in the early wet season. The amount of water available for paddy production in the dry season is

rather small. Second, conversion of upland rotation to forest translates into insignificant expansion of dry-season paddy rice. Strategies to increase dry-season paddy cultivation would likely require assessment of surface-water storage, potentially in tandem with water-saving rice technologies such as aerobic rice or alternate wetting-and-drying irrigation practices. The water-storage facilities, however, require storage infrastructure and could be costly. Thus, paddy intensification in the wet season appears to be a more viable option than the expansion of dry-season rice production. Third, the most significant change in stream-water availability under forest conversion scenarios is in the early wet season. Participatory assessment revealed that farmers normally plant rice in July due to early-season water constraint. Delayed onset of rains affects planting and hence rice yield. An increased water supply in the early wet season enables farmers either to continue transplanting at the same time but on more area, thereby increasing production, or to plant earlier but in the same area with a corresponding yield increase due to timely planting and good plant growth. In addition, early planting and harvesting of the crop enables farmers to grow a post-wet-season crop using residual soil moisture. Fourth, modeling results here consider only scenarios where shifting cultivation area is converted to forest. Many other potential land-use and water management options are yet to be explored, including sustainable (long-fallow) shifting cultivation, alternative land-use mosaics, and surface-storage and alternative water conveyance technologies that could dramatically increase water availability for alternative uses through more efficient use of available water. Finally, the project has afforded valuable lessons in research areas that have been underexplored, including hydrological modeling in the data-scarce environment of the upper catchments of Southeast Asia.

2. Objective 2: to assess the nature of relationships among poverty, access to water, and livelihood strategies.

Access to water is a crucial and necessary condition to improve agricultural production and thereby overcome poverty. However, the linkage among water, agriculture, and poverty is complex and nonlinear (Cook and Gichuki 2006). Several factors condition the poverty impact of irrigation, including access to land and its quality, access to complementary services (market, information, etc.), access to technology, irrigation infrastructure, water allocation policies and practices, agroecological conditions, and human capital development. This suggests that relationships are contextual, as conditioned by geo-physical, political, social, and economic factors.

2.1 Methodology

We purposively selected two villages in Lao PDR, two villages in Vietnam, and four villages in Thailand in consultation with stakeholders as representative study sites (Table 1.1). The research sites in each country represent areas with differential access to water and with farmers pursuing different livelihood strategies. We collected household and village-level data for this study. In the first stage, we collected primary data from 517 households in three countries during 2006-07 using pretested semi-structured questionnaires. The questionnaires covered several aspects of farm households, including demographic features, resource endowments, land-use and agricultural practices, water use and management, access to credit, income sources, and livelihood strategies, among others. In the second stage, we designed and implemented a detailed semi-structured questionnaire among selected rice farmers to gather additional information on water-poverty relationships. The questionnaire specifically focused on farm assets, land endowments, access to and use of water, technology adoption, and input use. We conducted key informant surveys, focus group discussions, and participatory analysis to collect additional qualitative information about households and communities. We conducted additional focused surveys of representative irrigation systems to study the dynamics of water institutions of upland irrigation systems. Both men and women farmers belonging to different wealth and ethnic categories were included in the targeted surveys, key informant surveys, focus group discussions, and participatory analysis. We stored data in Microsoft Excel and analyzed it using SPSS, STATA, and GAMS statistical and econometric software packages as appropriate. We used household typology and sustainable livelihood framework (SLF) as analytical approaches, and multiple regression probit regression, principal component, and cross-tabular analyses as analytical methods. We used multivariate techniques (i.e., principal component analysis) to develop household typologies. Main variables used to develop typologies are (a) asset endowments, (b) household labor supply, (c) household participation in goods and labor market, and (d) household access to water (e.g., irrigated area in the spring and summer season, and access to water sources directly or indirectly). This typology served as a basis for further analysis.

We used the SLF approach to examine the relationships among five livelihood assets of farmers (natural, human, social, financial, and physical), particularly focusing on water-poverty relationships (Figure 2.1). Five livelihood assets of farmers were measured using four indicators each: (a) *human assets*: age of household head, education of household head, labor availability in person-days, and health threats of household; (b) *natural assets*: agricultural area, irrigated area, fallow area, and number of animals; (c) *physical assets*: value of shelter and building, sufficiency of household water supply and sanitation, type and number of vehicles, and type and value of farm equipment; (d) *financial assets*: access to credit, pension, remittance, and value of household assets; and (5) *social assets*: membership in a water user group, leadership in existing groups, kinship network, and community network. We used a qualitative scoring system to value a household's asset base and to facilitate comparison among household groups according to access to water and income. We allocated a maximum of 5 points for each indicator. This means that each asset could garner a maximum score of 20 points. Each household got these scores separately. Scores of each indicator under each asset were summed to produce an average for that asset. The individual asset scores were aggregated to give an overall score for each group of households. The scores of each component of livelihood assets were evaluated and compared by testing for significant differences between groups.

We studied the water dimension of poverty and food security by considering upland and lowland holdings, wet-season and dry-season water availability, and the head and tail ends of irrigation systems. We studied livelihoods of farmers in terms of land use, rice security, income level, and income diversification.

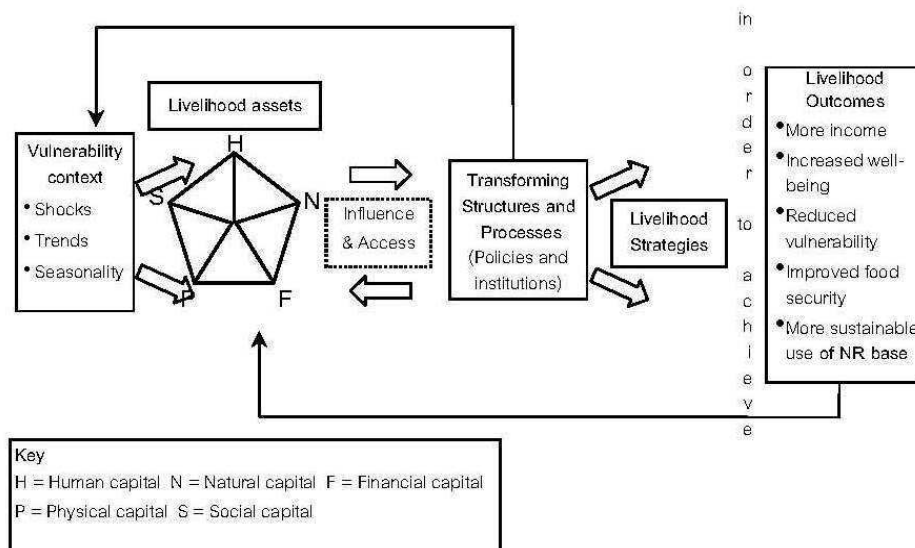


Figure 2.1. Sustainable livelihood framework.
Source: Ashley and Carney (1999).

2.2 Results and discussion

The upland landscapes of three countries have some similarities and some differences. The shared features include remoteness, geographic and socioeconomic isolation, fragile agroecosystem, high poverty incidence, chronic food insecurity, and environmental degradation. They differ in terms of population density, market access, agricultural production system, land-use activities, and livelihood strategies (Table 2.1). Low population density and low market access led to subsistence-oriented agricultural production in Lao PDR. Heavy investment in development activities and good market access led to highly commercial-oriented agricultural production in Thailand. Vietnam is in between those two countries and is gradually heading toward a market-oriented production system.

Table 2.1. Main characteristics of upland landscapes in three countries.

Characteristic	Lao PDR	Vietnam	Thailand
Economic development	Low	Medium	High
Population density	Low	High	Medium
Market access	Low	Medium	High
Agricultural production system	Less commercialized	commercialized	highly commercialized
Land-use activities	Extensive	Semi-intensive	Intensive
Main livelihood activities	Rice, livestock, and cash crops	Rice, livestock, nonfarm job, and cash crops	Rice, vegetables, off-farm/nonfarm job, and cash crops

2.2.1 Lao PDR

2.2.1.1 Baseline survey results and discussion

Lao PDR is one of the poorest countries in Southeast Asia, with 34% of the population living below the national poverty line. The country is divided into three regions (north, central, and south) geographically. The north is largely mountainous and subsistence farming is the dominant mode of production. Poverty, food insecurity, and environmental degradation are striking problems of the region. Poverty incidence is higher in the northern region and is highest in the northern uplands. The country is generally food-secure at the national level, but food security is precarious in the north. Rice is the staple crop; food security means rice security in Lao PDR. The rice self-

sufficiency ratio in the north is 0.71, meaning that the region is 29% rice-deficit. Within the region, many provinces, districts, and villages experience a rice shortage annually. Rice production is largely subsistence-oriented with minimal use of inputs. Upland rice accounts for 43% of the total rice area. Increasing population, government policies to stabilize shifting cultivation, and new market opportunities have reduced the fallow cycle from the usual 7–8 years earlier to 2–3 years now. As a result, rice yields have remained low.

Households that grow lowland rice in terraces and valley bottoms in the upper catchments use water primarily for rice production; other productive uses of water such as vegetable production in paddies and gardens (home, upland, and river), aquaculture, and livestock are very limited. Rice production in paddies is the main pathway, which links access to water and poverty. Therefore, we considered access to lowland as a surrogate of access to water for analyzing the water-poverty relationship. Fai Village, where average lowland holding and number of households with lowland are relatively large, represents villages with good access to water. Silalek Village, where average lowland holding and number of households with lowland are relatively small, represents villages with poor access to water.

Silalek and Fai differ in several aspects, including resource endowments and access to water (Table 2.2). Ethnic groups dominate both villages. Average farm size is around 4.1 ha/hh, of which lowland area is very small. Fai has a higher average lowland area than Silalek, which affords better food security for Fai. Fai is a more long-established village than Silalek. Land rights are usufruct and are distributed based on family size and available land. While early settlers have access to lowland and favorable uplands, late settlers have no or very limited area of lowland. The incidence of poverty and food insecurity is higher in relatively newly settled Silalek than in long-settled Fai.

Table 2.2. Basic characteristics of sample households, Lao PDR.

Characteristic	Fai	Silalek
Household size (no.)	4.8	6.6
Dependency ratio	0.7	1.5
Ethnicity	Lum	Thueng, Soung
Length of stay in the village (years)	33	15
Farm size (ha/hh)	4.1	4.4
Lowland area (% of farm size)	14	2
Lowland holding (% of hh)	56	17
Poverty incidence (%)		
Poor	9	14
Average	35	62
Well-off	56	24
Rice area (ha/hh)	1.16	1.1
Share of upland rice (%)	52	86
Households growing upland rice (%)	71	100
Rice yield		
Lowland rice (t/ha)	2.4	2.8
Upland rice (t/ha)	1.9	1.8
Per capita paddy rice production (kg/cap/year)	506	317
Rice self-sufficiency ratio (%)	1.45	0.90
Households with upland and lowland rice	1.73	1.59
Households with upland rice only	1.14	0.75
Households with lowland rice only	1.58	–
Households experiencing a rice shortage in past 10 years (%)	17	73

The two villages are overwhelmingly agricultural. Some 97% of the households depend on agriculture. Farmers grow rice in the lowlands and uplands for food. They grow nonrice crops such as Job's tear, maize, sesame, paper mulberry, peanut, soybean, and vegetables, primarily for cash. They also raise animals such as pigs, cattle, chickens, and ducks for meat, draft power, and cash. A few households also work for wages, weave, and collect forest products for cash. Rice is life and households are heavily rice-oriented. They borrow rice, work for rice, or purchase rice to overcome food-grain shortfall.

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Rice is the main crop in lowlands (or “upland paddies”). Irrigated rice area is approximately 6%. Thus, dry-season cultivation is very small and lowland cropping intensity is below 125%. Rice, maize, Job’s tear, sesame, and soybean are the main crops in the sloping uplands. In their lexicographic ordering of goals, upland farmers give top priority to satisfying their own food security. As a result, households allocate resources producing rice for own consumption. Households with large paddy area meet their rice requirement from paddies and allocate upland area to cash crops. In contrast, households with small (or no) paddy area rely on upland rice to meet their rice requirement and hence they have proportionately smaller area under cash crops in sloping uplands.

Average rice-farm size is about 1.1 ha, with upland rice area accounting for as high as 86% of the rice area. More than 70% of the households, particularly poor ones, rely on upland rice for their food security. Thus, upland rice is a very important component of their livelihoods. Labor use, the main input in rice production, is significantly higher for upland rice (257 days/ha) than for lowland rice (153 days/ha). Rice yield is relatively low for both upland and lowland, but yield is much lower for upland rice. Although a majority of farmers (54%) reported an increase or no change in lowland rice yield, a larger percentage of farmers (63%) reported a decrease in upland rice yield over the past five years. They attributed the yield decline to a reduction in fallow period, poor soil, labor shortages, drought, and a lack of improved upland rice technologies. Low yield but higher labor use in upland rice production have resulted in low labor productivity.

The rice sufficiency situation in Fai is better than in Silalek. Per capita rice production in Fai is 60% higher than in Silalek. The rice self-sufficiency ratio is 1.45 in Fai, but only 0.90 in Silalek. The number of households experiencing at least one rice-deficient year in the past 10 years was significantly smaller in Fai (17%) than in Silalek (73%). The average number of rice-deficient years for Fai and Silalek was 1.25 and 3.0, respectively. We observed a significant association between land endowment and rice self-sufficiency. The better rice security situation in Fai can be attributed to better lowland endowment, the inherent higher productivity of lowland rice (2.5 t/ha cf. 1.8 t/ha), and smaller family size. When we analyzed rice self-sufficiency and landholding, households with access to lowland are highly rice-sufficient but households with only sloping upland are largely rice-deficient. We can conclude that access to lowland, the inherent higher productivity of lowland rice, and smaller family size are the key factors of better food security in Fai.

Poverty incidence is high in the study villages (51%) relative to the national poverty rate (34%). Poverty incidence among sample households was substantially higher in Silalek (69%) than in Fai (17%). A chi-square test gave a significant association between the villages and poverty levels. This indicates that access to lowland (or water) is a crucial factor of poverty. A study of income sources reveals that Fai has higher and more diversified income than Silalek (Table 2.3). The higher income for Fai is primarily due to better lowland endowment and livestock farming. It is noteworthy that households with better lowland endowment are able to meet their rice requirement from lowland while they produce nonrice crops such as maize, Job’s tear, and sesame in uplands for cash purposes. Since Fai has better lowland endowment, this enables Fai farmers to grow nonrice crops in the uplands for cash. The income from cash crops is invested in other activities such as large animals, more area under cash crops, petty trade, agricultural products for marketing, transport pick-up, rice mills, and so on. This higher and more diversified income has contributed to their higher income levels.

Table 2.3. Percentage share of household income, by sources, Lao PDR.

Income source ^a	Fai	Silalek
Rice	29	49
Nonrice crop	16	6
Livestock	38	24
Forest products	2	8
Non-/off-farm job	15	13
Total income (US\$/hh)	1,441	722

^aCrop income refers to net income from crop production.
Data source: Farm household survey, 2006.

2.2.1.2 Economic analysis of terrace construction

We conducted cost-benefit analysis to examine the economic viability of terrace construction. The economics of terrace construction was assessed in terms of internal rate of return (IRR), net present value (NPV), and number of years required to recoup the cost of terracing (or break-even period). The IRR is the average return earned by the investment made. The NPV measures the total gain from investment made over the planning horizon. The estimated NPV measures the net gain in present value of switching the production of household rice needs from upland to lowland by constructing terraces. The estimated IRR indicates that the investment will yield an annual return of around 33%. The break-even period indicates that it takes approximately 6 years for farmers to recoup the cost of investment through higher rice yields and gains from savings in labor input. In summary, terrace construction is economically viable where water for irrigation is available or can be developed at low cost.

2.2.1.3 Upland irrigation systems

Irrigation systems in Lao PDR are classified into three groups: small (<100 ha), medium (100–500 ha), and large (>500 ha). In 2005, there were 25,000 irrigation systems including concrete weirs, pumps, reservoirs, gates and dikes, gabions, and temporary weirs. Of these, 92% are small systems. The dry-season irrigated area for the whole country is only 8% of cultivated area. In northern Lao PDR, over 95% of irrigation systems are small and dry-season irrigated area is only about 6%. Table 2.4 presents the major features of upland irrigation systems.

The upland irrigation systems are broadly characterized as small schemes that cover one to two villages and irrigate less than 100 ha or fewer than 100 households. The infrastructure is constructed and managed by the community, and institutional mechanisms for operation and management are relatively simple. Water is used for irrigation mostly in the wet season and dry-season irrigation is limited. Most systems lack a water users' association (WUA) and are managed informally. A simple gravity-flow system from the head end to the tail end, with field-to-field irrigation, is the main mechanism for sharing water among the villagers.

Table 2.4. Main characteristics of upland irrigation systems in northern Lao PDR.

Characteristics	Individual managed	Field-to-field	Community constructed and managed		Government constructed & community managed
			Small size (1 village)	Large size (>1 village)	
Irrigated area (ha)	<1	1–5	5–30	30–100	100–500
Beneficiary households (no.)	1	5–10	10–50	50–200	200–500
Max. canal length (km)	1.2	0.2	3	6	14
Canal/weir infrastructure	Temporary	Temporary	Temporary	Temp./concrete	Concrete
Irrigation facility	Wet season	Wet season	Wet season	Wet season	Wet/dry season
Need of collective action	Low	Low	Medium	High	High
Rules (O&M, allocation)	–	–	Informal	Semi-formal	Formal
Water allocation basis	–	–	Head/tail	Head/tail	Area
Irrigation service fee	–	–	No	No	Yes
Water use conflict	–	–	None	Low	Low
Conflict resolution mechanism	–	–	Discuss	Discuss/penalty	Varies
Conflict resolution authority	–	Village head	Village head	WUG	WUA

To sum up, irrigation helps to reduce poverty primarily through its use for growing rice in upland paddies. Since other productive uses of water are limited, the water-poverty relationship is weak to moderate and is mediated mainly through access to upland paddies. Technological improvement to increase rice yield, expansion in upland paddies through investment in terracing, increased rice area and cropping intensity through efficient use of available water and better management of irrigation systems, and good access to markets strengthened the water-poverty relationship.

2.2.2 Vietnam

2.2.2.1 Baseline survey results and discussion

We selected two villages in Nam Bung commune and two villages in Suoi Giang commune as study sites in the northern province of Yen Bai. Nam Bung and Suoi Giang communes are located in two separate watersheds where upland rice is dominant. Although the average lowland holding is

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almost equal at the two study sites, Nam Bung represents a village with relatively better access to water (spring and wet-season rice) than Suoi Giang. Suoi Giang Village is in the upper part of the toposequence and hence the catchment area is small. In addition, there is no valley bottom and terraces are constructed on low slopes to produce lowland rice. On the other hand, Nam Bung has valley bottoms and the catchment area is large. Therefore, Nam Bung has better water access than Suoi Giang. But, Suoi Giang has better market access than Nam Bung.

There are other major differences in the characteristics of these villages also (Table 2.5). Two separate ethnic groups that differ in terms of culture and livelihoods populate the villages. Nam Bung households are relatively older and have less education than Suoi Giang households. Agriculture is the main occupation for over 90% of the households in both villages.

Farmers classify landholding as (a) upland crop field, (b) lowland crop field, (c) garden fields near the house, (d) plantation area, and (e) fish ponds. Crop land and plantations constitute the major land endowments of farmers. Lowland fields consisting of valley bottoms and terraced paddies are more productive and are important assets for improved food security. The average farm size in Nam Bung (0.66 ha/hh) is about four times smaller than in Suoi Giang (2.62 ha/hh). The average lowland holding is almost equal (0.20 ha/hh) for both communes, but the upland holding is five times more in Suoi Giang than in Nam Bung. The proportion of lowland area is higher in Nam Bung (31%) than in Suoi Giang (8%). A higher average landholding puts Nam Bung households in a relatively better position in terms of food security.

Table 2.5. Basic characteristics of sample households, Vietnam.

Characteristics	Nam Bung	Suoi Giang
Household size (no.)	6.7	5.6
Dependency ratio	1.1	1.0
Age of household head (years)	46	39
Education of household head (years)	1.1	2.9
Ethnicity	Dzao	Hmong
Length of stay in the village (years)	44	36
Farm size (ha/hh)	0.66	2.62
Lowland area (% of farm size)	31	8
Lowland holding (% of hh)	89	76
Rice area (ha/hh)	0.49	0.92
Lowland rice (%)	38	21
Lowland dry-season rice (%)	16	5
Rice yield		
Lowland rice (t/ha)	4.1	3.0
Upland rice (t/ha)	1.4	0.7
Per capita paddy rice production (kg/cap/year)	171	203
Share of upland rice (%)	36	42
Households growing upland rice (%)	91	97
Rice self-sufficiency ratio (%)	0.67	0.80
Households with upland and lowland rice	0.7	0.9
Households with upland rice only	0.5	0.5
Households with lowland rice only	0.6	0.8
Households experienced rice shortage in past 10 years (%)	86	94

In sloping uplands, the major annual crops are upland rice, maize, and cassava. Farmers produce these crops for own consumption and for sale of any surplus. Farmers allocate sufficient area to rice for own consumption and allocate the remaining area to cash crops. Of the gross cropped area in uplands, upland rice accounts for 30% in Suoi Giang and 77% in Nam Bung. Upland rice area has remained almost constant in Suoi Giang but has increased substantially in Nam Bung. This is due to higher food needs arising from increasing population. In lowland, almost all area is cultivated to rice and farmers grow it mainly in the wet season. Dry-season rice area is very small—16% in Suoi Giang and 5% in Nam Bung. In Suoi Giang, the water supply limits dry-season rice production to 16% of lowland rice area. In Nam Bung, however, current dry-season rice area is only about 5% although farmers can irrigate a much larger area. The following factors lead to

underuse of irrigation capacity in the dry season: (a) difficulties in protecting crops from grazing animals; (b) high risk of cold weather damaging the crop; (c) farmers perceive that dry-season rice affects planting time and soil fertility, thereby reducing the yield of wet-season rice; (d) less water supply and drought risk; and (e) high opportunity cost of labor. This implies that technological improvement overcoming these problems can increase food security in Nam Bung.

The average rice landholding is much smaller in Nam Bung (0.49 ha/hh) than in Suoi Giang (0.92 ha/hh). Small rice landholdings, small dry-season rice area, and a large proportion of upland rice are factors that contribute to food insecurity in both communes. The average rice yield for lowlands (4.1 t/ha in Nam Bung and 3.0 t/ha in Suoi Giang) is significantly higher than the average rice yield for uplands (1.4 t/ha in Nam Bung and 0.7 t/ha in Suoi Giang). The yield of modern varieties is over 60% higher than that of traditional varieties. It is worth noting that, in Nam Bung, dry-season rice yield (2.6 t/ha) is nearly 60% lower than wet-season rice yield (4.1 t/ha). Short-cycle varieties, drought, and cold climate are the factors that contribute to this yield divergence. Both lowland and upland rice yields are significantly higher in Nam Bung than in Suoi Giang.

In lowland rice, labor and draft animals are the major inputs. Average per hectare labor use is 347 person-days, most of which is family labor. Farmers use a small amount of inorganic fertilizer (60 kg/ha) but a substantial quantity of organic fertilizers (mainly manure). It is important to note that a large number of households, particularly in Nam Bung, do not use fertilizers at all. Per hectare cash investment varied from \$110 to \$160, in which seeds and fertilizers account for the greatest proportion. In upland rice, labor is the main input. Labor use per hectare is 498 person-days, most of which is family labor. The use of external inputs and cash investment is almost negligible.

Farmers grow upland rice for subsistence; only 2% of production reaches the market. Most farmers grow improved varieties of upland rice because of higher yield. However, many farmers still grow a small area of traditional varieties such as sticky rice. These are used during New Year celebrations and other special days. Farmers grow lowland rice for self-consumption. Although there is a good market, production is not sufficient for sale. Only a few households sell some of their rice production. About 10% of lowland rice production reaches the market. Farmers usually store the newly harvested crop for the future and consume old stock.

Annual average rice production in both villages is about 1.1 tons per household or 185 kg per capita (in terms of rough rice). Upland rice accounts for 39% of the total rice production. Per capita paddy rice production is 171 kg in Nam Bung and 203 kg in Suoi Giang. This is much lower than the per capita paddy rice consumption of 255 kg. Some 18% of the households have no access to lowlands. Households without access to lowlands are much more numerous in Suoi Giang than in Nam Bung. Households with only upland holding produce rice at 119 kg/capita/year and households with both upland and lowland produce rice at 200 kg/capita/year. Thus, households without access to lowlands have more precarious food security.

Some 86% of the households in Nam Bung and 94% of the households in Suoi Giang experienced rice shortages at least once in the past 10 years. In 2005, some 71% of the households reported a rice shortage for own consumption. This implies that large numbers of households at the study sites are food-deficit. Households employ several strategies, including purchase and borrowing of rice and consumption of other nonrice food items, to manage the rice deficit.

Table 2.6. Percentage share of household income, by source, Vietnam.

Income source	Nam Bung	Suoi Giang
Rice	62	26
Nonrice	5	40
Livestock	23	14
Non-/off-farm job	10	20
Total income (US\$/hh)	247	541

Average income of households in Suoi Giang is more than two times the income in Nam Bung (Table 2.6). The higher income in Suoi Giang is attributed to larger farm size and good access to markets. Households in Suoi Giang get income from rice and nonrice crops, livestock, and nonfarm activities. Rice and nonrice crops account for 66% of household income. Good market access led to relatively higher income from nonfarm activities in Suoi Giang than in Nam Bung. Rice, particularly from lowland, is the main source of income in Nam Bung. Favorable lowland fields and good access

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to water produced higher rice yield. This contributed to a higher per hectare income from lowland in Nam Bung (\$101) than in Suoi Giang (\$76) despite both villages having almost equal lowland area.

To sum up, the land resource endowment is different between the two villages in terms of quantity and quality. In Suoi Giang, farm size is larger but its productivity is lower. Larger farm size and good access to markets led to a higher and more diversified income base in Suoi Giang. Rice self-sufficiency is a first priority in household decision-making and hence rice represents a major component of the land-use system. Nearly 90% of the households experience a rice deficit. Small rice area, poor access to water, and low rice yield are the major causes of a rice shortage. Low rice yield compels households to allocate most of their upland area to rice, cultivate available sloping land more intensively, and expand upland rice production to fragile areas to meet their daily food needs.

2.2.2.2 Household typology results and discussion

We classified sampled households into six typological groups based on three discriminating factors developed using the principal component analysis (Table 2.7). The first discriminating factor is access to irrigated land (or access to water in the spring season). The second discriminating factor is sloping landholding and its use. The third discriminating factor is the household labor supply. Family size and labor supply affect food security, choice of own cropping patterns, and off-farm activities. We present the general characteristics of sampled households for each watershed in Table 2.8. We present detailed characteristics of each typological group in Tables 2.9 and 2.10. We discuss structural typology and their characteristics below.

Table 2.7. Summary of typological groups, Vietnam.^a

Irrigable land per head		Sloping land per head		Labor available	
				WS-LS (G5)	OFFW (G6)
				WS-LR (G2)	
				PARI (G1)	TERLAB (G3)
				TERUPL (G4)	
Age color chart:	Old 55	Middle 40s	Young 30s		

^aWS-LS: water short and land short; WS-LR: water short but land rich; PARI: Paddy rice; TERUPL: terraces and uplanders; OFFW: off-farm-oriented; TERLAB: terraces and perennials.

Table 2.8. General characteristics of sample households, Vietnam.^a

Characteristics	Nam Bung	Suoi Giang	Significance
Household total landholdings (ha)	1.1	2.5	***
Area of irrigated paddies (ha)	0.1	0.06	**
Area of terraces (ha)	0.08	0.1	
Area of sloping land (ha)	0.9	2.3	***
Area of irrigated rice (summer)	0.2	0.15	**
Area of irrigated rice (spring)	0.03	0.03	
Household size (no.)	6.4	5.3	***
Adults finishing primary school (%)	28.1	30.5	
Level of significance: * $P < 0.1$; ** $P < 0.05$; *** $P < 0.01$			

^aThe sample households are different from base-line survey households.

a) *Water-short-land-short (G5/WS-LS)*

Small farm size, no irrigated land, low level of human capital development, and recent establishment characterize WS-LS households. They have small (0.6 ha/hh) sloping upland area, which is used to grow rice and other food crops. Due to small landholding, fallow periods are short. Off-farm activities are limited but still represent main sources of cash income. In addition, these households maintained a small area of fruit and plantation crops but their contribution to household income is small. The household food security situation is precarious and they consume maize and cassava to compensate for rice deficit. This category of households is the poorest and most food-insecure.

Table 2.9. Land and water access of different typological groups, Vietnam.

Areas (m ²)	G5: WS-LS	G2: WS-LR	G6: OFFW	G3: TERLAB	G4: TERUPL	G1: PARI
N	37	16	7	14	16	22
Proportion (%)	33	14	6	13	14	20
Total landholding	6,200 a	27,500 d	10,200 abc	24,100 cd	21,800 bcd	13,700 ab
Paddy land	270 a	370 a	1,560 c	230 a	360 a	2,630 b
Terraces	390 a	530 a	710 ab	1,760 b	3,360 c	90 a
Sloping land	5,600 a	26,660 c	7,940 ab	22,170 c	18,140 bc	11,040 ab
Irrigable land (spring)	30 a	140 ab	200 abc	650 abc	1,270 c	950 bc
Irrigable land (summer)	630 a	860 a	2,270 b	1,990 b	3,680 c	2,600 b
Tea	1,090 a	9,930 b	0 a	11,810 b	2,840 a	4,530 a
Flat irrigable land per year per head	142 a	235 a	238 a	317 a	926 c	611 b

Different letters indicate significant mean differences (Tukey's HSD at 95%)

Table 2.10: Household characteristics of different typological groups, Vietnam.

	G5: WSLS	G2: WS-LR	G6: OFFW	G3: TERLAB	G4: TERUPL	G1: PARI
HH size	4.9 b	4.1 ab	10 c	8.4 c	5.8 b	6 b
No. of adults	2.7 b	2.2 ab	6.5 c	6 c	3.8 b	3.5 b
Off-farm (person-years)	0.25 a	0.18 a	2.24 b	0.5 a	0.38 a	0.51 a
Education index	0.19 a	0.82 c	0.47 b	0.34 ab	0.46 b	0.27 ab
Established in	1996 b	1996 b	1972 a	1976 a	1992 b	1993 b
Head's age	35 a	32 a	54 b	53 b	42 ab	41 ab
Cultivated area per year per head	1,284 a	6,689 c	1,038 a	3,167 ab	4,490 b	2,526 ab
Spring irrigated rice area	16	137	98	432	875	439
Rainfed rice area	1,985 a	7,156 b	4,585 ab	3,935 ab	3,937 ab	2,873 ab
Cassava area	470 a	2,662 b	485 a	1,568 ab	1,175 ab	790 a
Perennial crop area	1,400 a	2,850 ab	485 a	290 a	7,587 b	1,600 a
Rice potential production (kg/head/year)	85 a	281 bc	97 a	159 a	367 c	270 b
% sloping land with upland rice	35.0 ab	29.6 ab	59.7 b	27.6 ab	20.7 a	24 a

Different letters indicate significant mean differences (Tukey's HSD at 95%)

b) *Water-short-land-rich (G2/WS-LR)*

Limited access to irrigated land, large area of sloping land suitable for food crops, large area of tea, good access to market, and high level of education characterize WS-LR households. These households, mostly in Suoi Giang, offset their lack of access to water by growing cash crops (tea, maize, cassava, etc.) for market. However, this is possible because of their large upland area. Off-farm activities are limited and they are not an important part of the livelihoods. These households are not rice-sufficient, but they are food-secure. They use income from cash crops to purchase rice for consumption.

c) *Off-farm-oriented (G6/OFFW)*

Large area of paddy land, long establishment, large family size and high proportion of labor, and off-farm-oriented livelihoods characterize OFFW households. Although they have a large paddy land, per capita paddy land is small and it is not irrigable in the dry season. Therefore, rice production is low and households are food-insecure. With a large work force and small land per head, these households resort to off-farm activities as the main livelihood strategy. To a lesser extent, they have constructed terraces on the slopes.

d) *Terraces and perennials (G3/TERLAB)*

Long establishment, large family size, and large area of terraces on sloping land characterize TERLAB households. These households have constructed a large area of terraces. Large family size, however, resulted in small paddy area per head. About one-third of their terraces receive

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water during the spring season. These households have relatively better food security. Contrary to OFF households, they have few off-farm activities, but a large tea area.

e) *Terraces and uplanders (G4/TERUPL)*

Large holding of upper terraces, recent establishment, and less work force characterize TERUPL households. More than one-third of terrace area is irrigable in the spring season but farmers have not fully used it. Farmers use sloping areas for food (rice, maize, cassava) and tea crops. Lowland is the main source of rice and the farmers are mostly food-secure. Therefore, farmers allocate a small area to upland rice and diversify agriculture to cash crops.

f) *Paddy-rich (G1/PARI)*

Large area of paddies and good access to water in the spring season characterize PARI households. Households underuse water, as only 50% of irrigable land is cultivated in the spring season. Low rice yield, climate risk (cold and drought), and high opportunity costs of labor explain this. Lowland produces a large quantity of rice and farmers are food-secure. Therefore, they allocate a small area to upland rice and diversify agriculture to cash crops (maize, cassava, and tea).

We found six types of households strongly contrasting in terms of landholding, access to water, production characteristics, and livelihood strategies. About 50% of the sample households (G1, G3, and G4) have good access to water, while the remaining 50% (G2, G5, and G6) have poor access to water.

Recently established households (young couples) usually have low access to irrigated land. Having split from the parent's household, they have only a small fraction of irrigated land. It is more difficult for new households to increase/maintain their food production over time as the land frontier is closed. The only remaining alternative is to construct new terraces. However, the construction of terraces can be limited by time availability (new households have a limited labor force) and by the availability of water: they have to find new sources of water for irrigation that are farther away from the existing ones, thus increasing their construction and maintenance costs.

Access to water (or irrigated land) in the spring season was uneven among households. This unequal access to water has several adverse effects on the society. Households with good access to water do not always fully use it; only 60% of the irrigable area is cultivated in the spring season among rice-sufficient households. In fact, households producing enough rice in paddies in the wet season have less incentive to grow rice in the spring season due to a high opportunity cost of labor. While households with good access to water underuse it, households with poor access to water overuse fragile sloping land to produce rice for self-consumption. Proper use of this irrigable land generates benefits to the whole community. Two complementary strategies can improve the situation. First, develop community-level institutions to manage and share land and water resources. This involves (a) improvements in irrigation infrastructure (dams and canals) so that more households can access water during the spring season and (b) the development of rental arrangements for land so that the land/labor ratio can be more uniform across households and fuller use of land and water resources is encouraged. Second, develop technological innovations to address technical problems. This involves (a) water-saving technologies that would ease the water constraints and (c) the development of short-duration high-yielding rice varieties for the spring season.

2.2.2.3 *Access to water and poverty relationships*

We analyzed water-poverty relationships using a farm household model. We simulate the base results of the farm-household model for the six different household types to study the effect of different factors (market access for cash crops, market access to buy rice, and labor purchase) on household income. The cropping systems and off-farm activities remained fixed for each household type. Table 2.11 presents the main characteristics of representative farms, while Tables 2.12 and 2.13 present results of the simulation model.

We further grouped six typological households into three categories based on household income: poor households (WSLS), average-income households (WSLR), and well-off households (TERUPL, TERLAB, OFFW, and PARI).

Off-farm activity (NFTP and nonfarm labor) is the major source of income of poor groups of households; their crop income is very low. Access to paddy land and irrigation in the spring season can generate a large impact on income of this group of households.

Crop production is the main source of income of the average group households. Although they have no access to irrigated land, relatively large farm size and good connection to markets allow them to generate good income from crop production. Since they are well connected to the market, improved access to water creates new production opportunities. In particular, this would enable the production of cash crops in paddies and a reduction in upland rice area in favor of cash crops such as maize, cassava, tea, and fruit trees. The poverty impact of access to water is likely to be high.

Table 2.11. Main characteristics of representative farms.

Farm type	WSLS	WSLR	TERUPL	TERLAB	OFFW	PARI
Household size (pers.)	4	5	6	8	7	6
Family labor force (person-years)	2	2	3.5	5	5	3.5
Land available in each zone (m²)						
Irrigated paddies (summer + spring)	0	0	100	200	200	1,500
IRRPAD_SU	0	0	250	250	1,500	3,000
IRRTER_SP	0	0	1,000	300	0	0
IRRTER_SU	200	500	3,000	2,100	800	0
SLOPING	6500	14000	16,000	8,000	7,800	15,000
PERMCASH	600	6000	5,000	9,000	200	4,500
Total area (m²)	7,300	20,500	25,350	19,850	10,500	24,000
Developed area (m ²)	7,300	20,500	26,450	20,350	10,700	25,500
Area per worker (m ²)	3,650	10,250	7,243	3,970	2,100	6,857
Area per head (m ²)	1,825	4,100	4,225	2,481	1,500	4,000
Developed area per head (m ²)	1,825	4,100	4,408	2,544	1,529	4,250

Table 2.12. Household sources of revenues and expenses (1,000 VND).

	WSLS	WSLR	TERUPL	TERLAB	OFFW	PARI
Labor sold + Off-farm	7,278	6,415	11,679	18,057	26,830	11,802
Crop products sold	3,232	15,940	30,829	27,580	14,043	29,785
Food crop purchased	1,525	810	0	205	163	0
Ext. inputs purchased	993	3,407	2,618	7,346	7,218	5,762
Labor bought (days)	0	219	241	0	0	183
Cash earnings (only nonfood items are included in expenses)	9,517	22,355	39,648	38,291	33,655	35,641
% cash from labor	76	34	29	47	80	33
% cash from crops	24	66	71	53	20	67
Purchase of food crops	1,525	810	0	205	163	0
Cash balance	7,990	17,920	39,650	38,090	33,500	35,640
Auto-consumption (eval. at market price)	6,030	6,790	4,830	6,440	5,640	4,830
Total revenue (cash + auto-cons.)	14,020	24,710	44,480	44,530	39,140	40,470

Table 2.13. Cash and total revenues per household members and per household workers.

	WSLS	WSLR	TERUPL	TERLAB	OFFW	PARI
Cash revenue (PPP/head/day)	0.90	1.61	2.97	2.14	2.15	2.67
Total revenue (incl. auto-consumption) (PPP/head/day)	1.57	2.22	3.33	2.50	2.51	3.03
Cash revenue (US\$/worker/day)	0.61	1.36	1.72	1.16	1.02	1.55
Tot revenue (US\$/worker/day)	1.07	1.88	1.93	1.36	1.19	1.76

1 PPP = 6,100 VND (International Monetary Fund, 2009), US\$1 = 18,000 VND (2008 reference year)

The well-off households derive income from different sources corresponding to their resource endowments: off-farm for OFFW farmers, plantation crops for TERUPL farmers, lowland rice for TERLAB farmers, and intensive rice cultivation using privileged access to water for PARI farmers. Additional water supply is unlikely to be very attractive for OFFW and TERUPL households because they are already rice-sufficient, and land and labor productivities in rice are lower than in nonrice activities. Thus, poverty impacts of improved access to water are likely to be moderate for households that are rice-sufficient, engaged in off-farm activities, and that have poor access to markets for agricultural products.

Overall, the impact of improved access to water on income and poverty is likely to depend on the rice self-sufficiency status of the household:

- Rice-deficit households use additional water to produce more rice. This frees up some upland sloping areas for longer fallow periods in degraded land or gives new opportunities for cash crops (maize, cassava, tea, and fruit trees) when a market is available.
- Rice self-sufficient households use water for more rice production, for cash crop production, or do not use it depending upon market access and opportunity cost of labor. If market access is poor and off-farm job opportunities are limited, water is used for producing more rice. If the market for cash crops is poor, but off-farm job opportunities are good, farmers are likely to use water to produce cash crops. The poverty impact for rice-surplus households depends mainly on market access.

2.2.3 Thailand

2.2.3.1 Agricultural commercialization in northern Thailand

The Mae Suk catchment has undergone a remarkable agricultural transition over the past four decades. Since 1970, the local economy was drastically transformed, as farmers adopted cash crops as economic alternatives to the two dominant cropping systems of the area earlier—opium poppy and subsistence upland rice. In the 1940s, the opium poppy was introduced in the Mae Suk catchment. Although opium is commonly associated with the Hmong, the first cultivators were the Khon Muang ethnic group. The opium economy reached its peak in the mid-1960s. In response to government policy outlawing opium and the resulting drop in price, the Khon Muang poppy farmers abandoned their fields. The Hmong farmers moved in to settle in the area and took over the cultivation of poppy fields. Karen farmers worked for wages in the Hmong poppy fields and they also started to cultivate poppy on a small scale. The Hmong had already abandoned rice self-sufficiency as a livelihood strategy, choosing rather to purchase rice from the Karen with cash from the sale of opium. In the mid-1970s, the government's opium eradication and crop replacement program promoted coffee and kidney beans, neither of which provided a viable livelihood option for the local farmers. In the mid-1980s, the Royal Project constructed roads, ushering in a new era of commercial agriculture.

Government policies and programs, international donors, the Royal Project, road construction, and implementation of a watershed classification scheme were the main drivers of change in the Mae Suk watershed. The Mae Chaem Watershed Development Project was a major intervention in the Mae Chaem during this period. The project aimed to improve the quality of life of Mae Chaem inhabitants through agricultural development, marketing, infrastructure, and social development activities. The project was unique and the assistance was evenly distributed between villages inhabited by various ethnic groups. The project was also innovative in that it pushed the Thai government to issue land title documents to upland farmers.

By the mid-1990s, the landscape mosaic of Mae Suk catchment had become a mix of permanent field crops, fallow fields of varying age, and various types of forest. This period is characterized by local innovation, and the changes observed were driven by individual initiative to respond to market opportunities. The enabling factors include all-season roads, individual transport capacity, access to credit, and the flow of relevant information. Cabbages, carrots, lettuce, and potatoes were the most popular crops, grown in the rainy season.

The land-use patterns are not evenly distributed over the landscape. Nevertheless, cash crops have penetrated into Karen villages in a substantial way. Across the landscape, the maintenance of intensive cropping of vegetables in permanent fields on steep slopes has required increasingly high levels of fertilizers, herbicides, and pesticides, which has meant higher cost for farmers and has raised suspicions about water pollution in the streams. The advent of dry-season irrigation placed new stresses on the water balance in the catchment, and became another source of tension between local communities, not to mention with lowlanders. Thus, successful opium replacement ushered in a new era of watershed concerns, for which upland farmers find themselves blamed for environmental degradation (Badenoch 2006).

In the upstream of the watershed, the Hmong ethnic groups cultivate mainly upland fields. They practice intensive commercial vegetable production throughout the year in permanent fields on steep slopes. Good access to markets, good road infrastructure, effective extension of technology,

and access to credit led to successful commercial cash crop production in the uplands. Expansion of commercial agriculture led to increased demand for irrigation water, especially in the dry season. Hmong farmers have established efficient water conveyance systems to cope with increased demand for irrigation water. Pipes are used to transfer water from streams to the field by gravity force and sprinklers are established to distribute water over the vegetable fields. Commercial vegetable production in the upstream consumed a large amount of water and reduced the water supply for downstream communities. Farmers applied large amounts of pesticides to protect vegetables from pests and diseases. The negative effect of vegetable production on the quality and quantity of the water supply caused social conflicts between upstream and downstream communities.

In the middle part of the watershed, the Karen ethnic groups cultivate both upland and lowland fields. Several sources of water are available in the uplands for both household consumption and agricultural use. A literature review, group discussion, and farmers' survey indicated that Karen farmers in the Mae Suk subwatershed still practice a short to medium-length rotation fallow shifting cultivation system. Only 65% of the Karen households have access to irrigation water. Only those farmers with lowland holding and access to water can grow paddy rice during the wet season (May-October) and vegetable crops (shallot and cabbage) in the dry season (January-April). Farmers with no access to irrigation need to grow rainfed upland rice.

In the downstream of the watershed, lowland Thai ethnic groups cultivate mainly lowland fields. They use various sources of water for household consumption and agricultural use. Farmers opined that high population pressure, intensive agriculture in upland areas, deforestation for agricultural land, and chemical pollution of water by upstream Hmong and Karen communities are the main reasons for water shortages.

2.2.3.2 Water use and irrigation management systems

Irrigation water use and management in the Thai lowland communities

A traditional irrigation system known as the *Muang Fai* (canal and weir) system was used for distributing agricultural water in lowland communities prior to 1960. The irrigation system has also improved along with the change in farming system from subsistence to commercial, and extension of government control on natural resources (i.e., land, forest, and water) in the Mae Chaem watershed. At the same time, development projects have helped increase the supply by constructing reservoirs and rehabilitating irrigation canals and weirs from earth canals and wooden weirs to concrete canals and weirs, especially for the main canals and big weirs (Kitchaicharoen et al 2008).

In the downstream areas of Mae Suk stream, there are five major weirs along the stream to divert water to fields. In each main weir, farmers who use the water (weir members) select a committee. The committee sets regulation and management systems; weir members need to follow the regulations and help to maintain the weir. If a water shortage exists, the committee manages how the water will be distributed to all members regardless of their distance from the weir. Weir members pay a water use fee according to the size of paddy fields and the money collected is used partially to pay committee members for their service and partially to manage the irrigation system. The weirs and delivery canals are usually cleaned by all members twice a year; the first time is after rice planting and the second time after harvesting.

Household survey results showed that crops grown in the lowland are diversified as new commercial crops are introduced to lowland farmers. However, paddy rice is still the main crop grown for household consumption, whereas shallots, pigeon peas, and rainfed maize are grown as commercial crops. In the wet season, water from irrigation canals (*Muang*) was diverted to terraced paddy fields for rice cultivation. The water requirement is high in June-July for land preparation and rice planting. In a small irrigation system where there is no formal water institution, access to irrigation water depends on the location of paddy fields. Farmers close to the weir receive water first and excess supply is used downstream.

During the rainy season, water from the irrigation canal is diverted mainly to terraced paddy fields for rice cultivation. During the dry season, only a part of the paddy field is used for shallot and soybean production as the water supply for irrigation is limited. Fruit trees, mainly longan and tamarind, grown in the lowlands also consume significant irrigation water during the dry season. The intensive use of lowland areas also demands a large amount of irrigation water. In contrast to

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the wet season, farmers grow different crops in the dry season. This means that the timing of water demand may be somewhat asynchronous. In response to this, farmers started putting in individual pipes carrying water from the main canal to their fields directly without relying upon common irrigation channels. This innovation was made due to the need for flexibility in water supply in response to intensive commercial vegetable production.

The agricultural water supply is normally sufficient in the wet season. But, water shortages occur in the dry season. The reasons for water shortages reported by farmers were high demand for second-rice cultivation. To solve the problem, dry-season rice cultivation was restricted. To cope with water scarcity, some farmers have started using water directly from the Mae Chaem River while other farmers invested in private ponds in their fields.

Irrigation water use and management in the Karen upland communities

In the Karen upland communities, crop production systems have changed significantly from rice and other rainfed upland crops such as maize and soybean to mainly rice and irrigated vegetable crops, such as shallot and cabbage. Commercial vegetable production was introduced to Karen farmers by the neighboring Hmong farmers who also hired Karen laborers to work in their fields during peak labor demand. This change led to greater demand for irrigation water, especially during the dry season, and consequently increasing tension over water use between upland and lowland communities.

There are two different systems of water conveyance in the Karen community: one for subsistence-oriented paddy rice production and the other for market-oriented vegetable production. Paddy rice is grown in traditional terraces. The *Muang Fai* irrigation system with temporary weirs is used for diverting water from streams into terraced rice fields. The residual water from rice cultivation is channeled to flow back into the stream and is made available for downstream water users. Karen farmers considered this water management system as a resource-conserving water management system. Irrigation water used for cash crops is transferred through PVC pipes from streams to reservoirs built near the field. Water is conveyed from reservoirs to fields through small PVC pipes and sprinklers are used to distribute water into the fields. This irrigation system began to expand in the uplands of Mae Suk subwatershed in 2000 (Badenoch 2006).

Karen farmers practice two types of PVC irrigation management: (a) individual water management and (b) collective water management. Prior to 1995, commercial vegetable cultivation in the uplands was relatively small and Karen farmers had sufficient water to grow vegetables. The Karen farmers practiced individual water management in which farmers channeled water from streams to fields using individual pipes. As water in the stream was adequate and competition for water was relatively small, small private investment was enough to get the required volume of water for farming. After 1995, the competition for water increased significantly in response to an increase in commercial vegetable cultivation and the rise in population. The reduction in water availability compelled households to invest in more pipes to bring water from multiple sources as well as build a water storage system near their own fields. When more capacity was needed, farmers started sharing investment in storage structures. Through collective efforts, water is collected in a pond built near the field and water is used based on agreed-upon rules. The common sharing arrangement observed is among kin or neighbors whose field is located nearby. Thus, a shortage of water led to a shift in PVC irrigation management system from a private managed system to collective-managed arrangements. The shift from an individual to collective management system has benefit in terms of sharing the cost of water-storage structures, managing a smooth water flow, providing water access for more farmers, especially the poor (equity), and reducing water conflict by sharing water among many farmers. As more farmers have access to water through sharing arrangements, collective management also affected income and employment positively.

In the upper parts of the stream, the water supply is good and farmers can use the pipes directly in the streams. In the lower parts, the water flow in the stream is small and farmers need to construct weirs to lift the water level before placing water in a tube in the small weir areas. The regulation for using this system (the water use rule) is that, once a farmer has established a weir, a newcomer can use the same stream but only below the existing weirs. However, the regulation was bypassed during peak demand for water (Badenoch 2006). As the number of pipes increased, some users moved their intake upstream to ensure more regular water flows. Consequently, the conflict over water use has been rising. Tension has also increased as lowland communities claim

that land-use practices in the highlands created floods, droughts, sedimentation of water resource infrastructure, and a perceived decline in water quality (Thomas et al 2004).

2.2.3.3 Livelihood analysis

Livelihood outcomes are the achievements of livelihood strategies. The results of farm income analysis as well as family income analysis show that households with good access to water earned more income than households with poor access to irrigation water (Table 2.14). Access to irrigation allows farmers to increase land-use intensity and grow cash crops to increase income. However, the increase in income is still limited due to high market risk. Upland farmers with poor access to water improved their income with other strategies such as using labor for livestock production during the dry season. In lowland areas, Thai lowland farmers with poor access to water earned additional income from nonfarm wage employment. In both uplands and lowlands, farmers with good access to water are more secure in their livelihood than farmers with poor access to water.

Access to private irrigation systems has a strong relationship with livelihood assets compared to communal irrigation systems. Upland farmers who have good access to water can extend their crop production into the dry season and have greater success with commercial crops, whereas farmers who have poor access to water face limited production of cash crops. However, upland farmers with limited access to irrigation improved their income with other strategies such as using labor for livestock production during the dry season, which contributes to more than one-third of their family income. In lowland areas where access to nonfarm jobs is better, farmers with poor access to water earned on average one-fourth of their family income from nonfarm employment. In both uplands and lowlands, farmers having better access to water are better off and feel more secure in their livelihood.

Table 2.14. Livelihood outcomes of sample households in Mae Suk subwatershed.

Particulars	Type of households			
	LL-BadAW (n=66)	LL-GoodAW (n=13)	UL-BadAW (n=50)	UL-GoodAW (n=29)
Farm income (baht/household)	31,975 a	109,601 bc	68,376 b	137,790 c
From irrigated shallot production	13,571	39,457	3,988	54,398
From irrigated soybean production	3,053	23,246	–	–
Family income (baht/household)	46,352 a	202,758 b	77,098 c	161,939 b
From crop production (%)	62	41	52	61
From livestock production (%)	7	13	36	24
From hired agricultural labor (%)	5	1	2	2
From nonfarm activities (%)	26	45	9	13
Farmers' perceptions of their				
Livelihood security (% of households)	58	69	18	41
Land security (% of households)	70	85	10	7

Agricultural production has transformed from subsistence to a commercial system in the past few decades. Intensive commercial vegetable production in both uplands and lowlands has increased water demand and caused conflicts over water use. Irrigation water in the wet season is used for vegetable cultivation in uplands and paddy rice cultivation in lowlands. The water supply is sufficient in the wet season and there is no water-use conflict. Irrigation water in the dry season is used for intensive commercial vegetable cultivation in both uplands and lowlands. Conflict over water use within and between upland and lowland communities has been reported.

Access to water and availability of private irrigation systems have a strong relationship with livelihood assets. Improving access to irrigation for upland farmers can be achieved by providing access to other assets such as credit. Where market access is good, improved access to water can enable farmers to adopt new technologies such as the sprinkler irrigation system and thus to have greater success with cash crops and intensive cultivation, leading to increased income from farming. Similar improvements may not have comparable results in very remote areas where market access is poor. However, improving access to water for upland farmers is likely to reduce the amount of water available to lowland farmers. Participatory management of water at the stream/watershed level may be necessary to achieve a compromise position that will be acceptable to all farmers in the watershed.

2.2.4 Water-poverty relationship: a synthesis of three countries

Water is a vital resource for income generation and poverty reduction. The water-poverty relationship is not linear; it is contextual and it depends on several factors, including geographical, biophysical, technological, social, economic, and policy conditions. Figure 2.2 presents the pathways through which access to water affects poverty in upper catchments. Households access water either directly from natural sources or indirectly through communal or private infrastructure. The productive use of water increases income through direct and indirect conduits. In the upper part of the catchment that is mostly sloping area, farmers use water to produce paddy rice on terraces where population density is high but market access is poor and to produce vegetables where market access is good. The productive use of water for agriculture is limited where population density is low and market access is poor. In the lower part of the catchment that includes flat lands and valley bottoms, farmers use water to produce food crops such as rice where market access is poor and to produce cash crops such as vegetables and fish where market access is good. Income will be higher when farmers adopt improved technologies and crop management practices. Access to credit is a key to the adoption of improved technologies and investments in private irrigation systems. This is the direct use of water to generate income and reduce poverty.

Access to irrigation also contributes to poverty reduction in several indirect ways. The analysis of three countries shows that water affects poverty by encouraging crops/activities that generate income. The poverty impact of improved access to water is dependent mainly on population density, access to lowland, access to improved technology, access to markets, and access to credit.

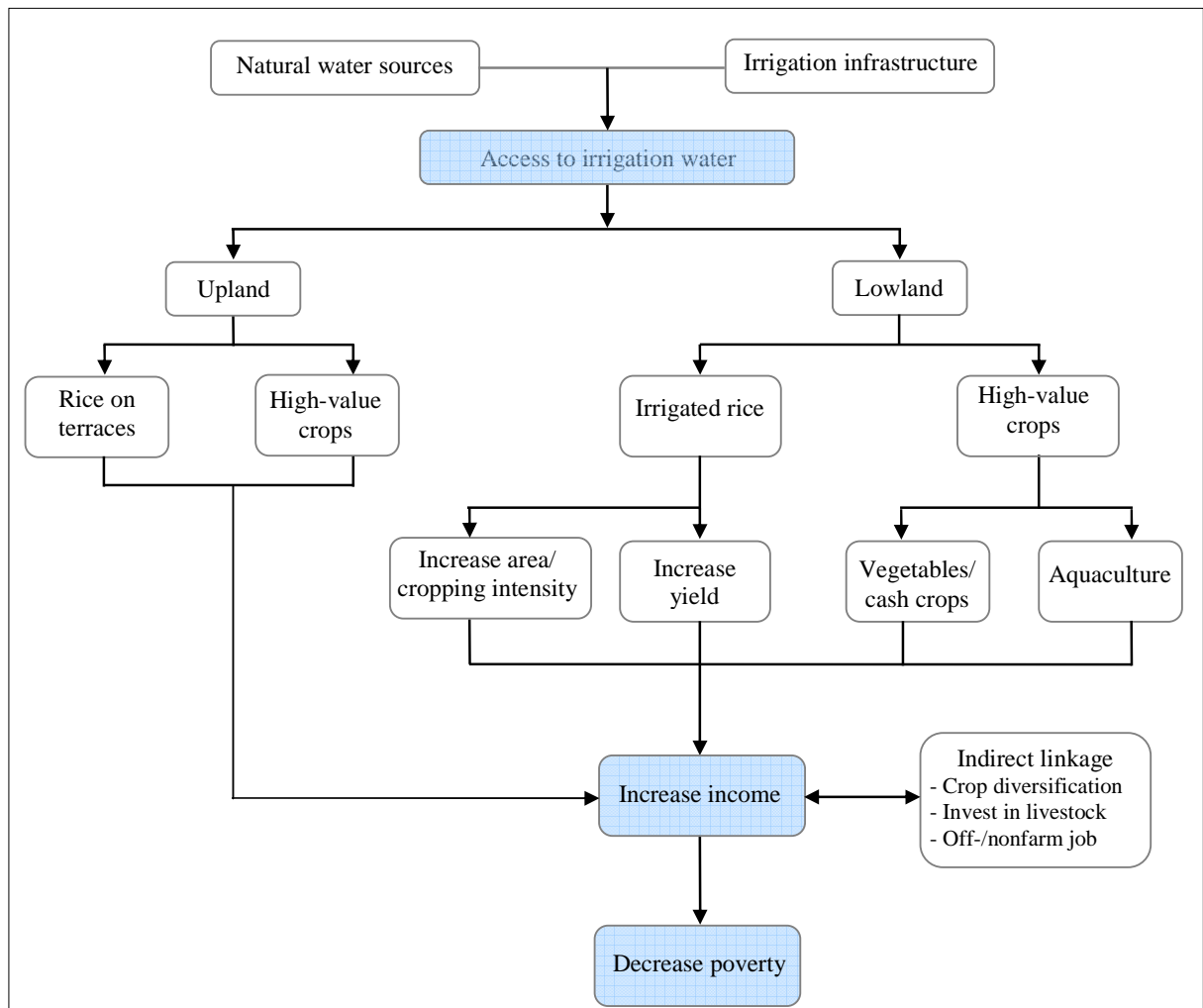


Figure 2.2. Pathways through which water affects poverty.

The water-poverty relationship is nonlinear. Several factors condition the water-poverty relationship, with market access being the most significant. We summarize the three-country results on the enormity of the water-poverty relationship with reference to market access in a stylized typological form in Figure 2.3.

Type I (low water access and low market access)—small lowland holding, subsistence-oriented food crop production, large share of upland rice in total rice production, and high incidence of poverty characterize this group of households. The impact of improved access to water on poverty tends to be weak for this type of households. Silalek Village in Lao PDR is an example. Since the households lack access to markets and own only a small area of terraces for paddy rice production, they are not able to use water for income generation fully, resulting in a limited impact on poverty and livelihoods.

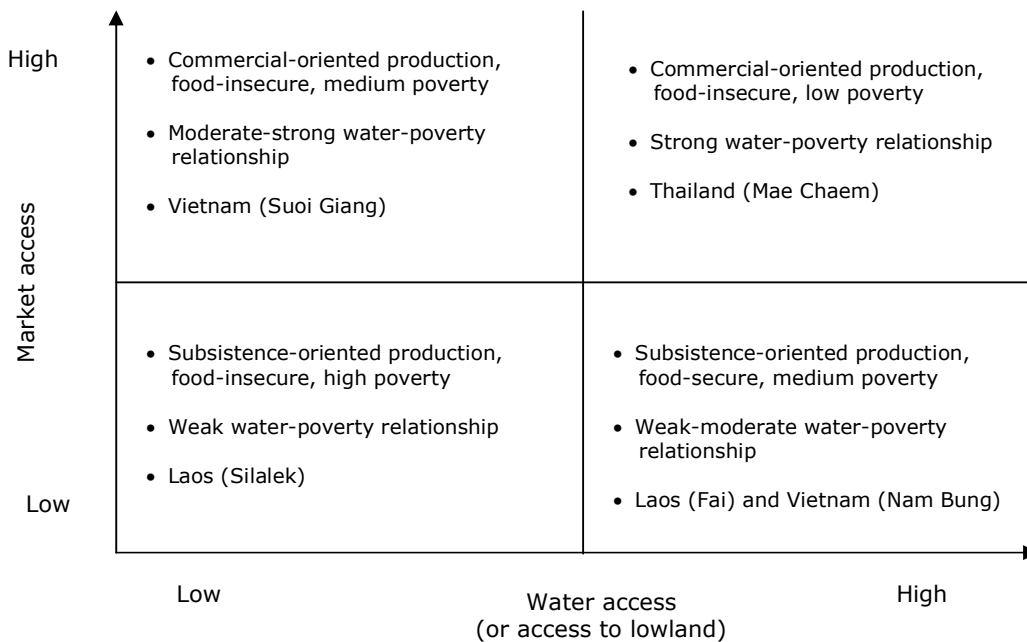


Figure 2.3. Stylized typology showing water-poverty relationship in the upper catchments of Southeast Asia.

Type II (good water access and low market access)—the impact of improved access to water on poverty tends to be weak to moderate for households of this type. There are good commercial opportunities for income gains through the production of irrigated cash crops if access to water can be improved. Similarly, water access helps increase irrigated paddy production, thus contributing to household food security and income.

Type III (poor water access and good market access)—the impact of improved access to water on poverty tends to be moderate to strong for households of this type. Despite strong potential for demand-side water use, water supply constraints limit the poverty impact of water. The Suoi Giang commune in Vietnam is an example. Improved access to water enables households to increase rice production in paddies and releases upland rice area for cash crop production. Moreover, given the small size of paddies and good access to markets, farmers attempt to use water efficiently by adopting water-saving technologies and economically by adopting improved practices and high-value crops, thereby maximizing the marginal value of water. Therefore, improved access to water will have a strong impact on poverty for this group of households.

Type IV (good water access and good market access)—improved access can be expected to have a substantial impact on poverty for this type of households. Increased production of irrigated rice

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and irrigated cash crops is a viable economic activity that contributes directly to poverty reduction. The Mae Chaem watershed in northern Thailand is an example.

To sum up, the water-poverty relationship is strong in areas producing high-value crops for market, moderate in areas producing lowland irrigated rice for domestic consumption, and weak in areas producing upland rice for domestic consumption.

2.2.5 Conclusions

Access to water is very important for overcoming poverty and food insecurity. Improved access to water enhances the productivity of livelihood assets and affects poverty directly and indirectly. The direct pathway includes higher income from increased rice production arising from an increase in area, yield, and cropping intensity. Higher income also results from the production of high-value crops for markets, if market access is also good. Indirect pathways include easing out upland rice area to cash crops, promotion of crop diversification to high-value crops such as aquaculture, capital formation to invest in capital-intensive enterprises such as livestock and nonfarm activities, and employment opportunities. Overall, the water-poverty relationship tends to be strong in market-oriented agricultural production systems and weak in subsistence-oriented agricultural production systems.

3. Objective 3: to develop and test, with farmer participation, water-efficient rice technologies that improve the productivity of highland paddies, and to make such technologies available for delivery and dissemination.

We tested, validated, and disseminated a large number of improved rice technologies for highland paddies. Broadly, we group these technologies into four types: (a) rice varieties, (b) rice crop management, (c) rice-based cropping systems, and (d) water savings. This section details research activities on each technology group conducted in Lao PDR and Vietnam. Research in Thailand focused on the socioeconomic component only, but not technology development. Hence, we excluded Thailand in this objective.

We followed a multi-institutional partnership framework to collect, validate, and disseminate promising rice cultivars for paddies. We tested and validated promising technologies using both research station and farmer trials. We used both multilocation yield trials and farmer participatory varietal selection trials.

3.1 Testing and validating improved rice varieties

3.1.1 Methodology

Rice varietal research focused on higher yield, resistance to biotic and abiotic stresses, production in water-stress conditions (i.e., aerobic), good grain quality, and testing for local adaptability. We evaluated both glutinous and nonglutinous rice varieties to address different preferences of consumers.

We used two approaches to select and test suitable rice lines/cultivars for the range of constraints limiting rice production in highland paddies. One approach was to use promising local cultivars to overcome a range of constraints in our target environments. The complementary approach was to test germplasm materials from other sources, such as materials from ongoing breeding programs at IRRI, International Network for Genetic Evaluation of Rice (INGER) nurseries, and the Yunnan Academy of Agricultural Sciences (YAAS). We conducted scientifically designed observation nursery trials, multilocation testing trials, and on-farm participatory varietal selection (PVS) trials. Field experimental data such as plant height, tiller number, date of flowering, panicle number, panicle length, crop yield, spikelet fertility, shattering, resistance to cold and drought, resistance to pests and diseases, performance under water-limited conditions, etc., were collected to study the performance of popular rice varieties in the target domain.

Rice varieties that performed well at research stations were evaluated in farmers' fields using mother-baby trials. We used PVS protocols to judge the acceptability of improved varieties for farmers. Farmers' acceptance of technologies is critical for rapid and wider adoption. We organized farmers' field days and farmers' training activities during the crop maturing stage so that these events could be used to conduct PVS. Farmers used grain yield, eating quality, grain size, resistance to pests and diseases, crop duration, and plant height as the main criteria for judging the suitability of rice varieties.

3.1.2 Results and discussion

We conducted several field experiments and participatory research to test and validate improved lowland rice technologies in Lao PDR and Vietnam. We discuss the results and discussion pertaining to each technology in this section.

3.1.2.1 Lao PDR

3.1.2.1.1 Testing and validating rice varieties for higher yield and other agronomic traits

We tested and validated rice lines/cultivars collected from various sources using various trials such as "first-year observation nursery," "second-year observation nursery," multilocation yield trial, and PVS trial. This section discusses the testing and validation of collected rice lines/cultivars for higher yield, better quality, and other desired traits.

Observation nursery trial—traditional rice cultivars dominate the highland paddies of Lao PDR. Traditional landraces are highly adapted to the local environment but their yield is low (2.5–3.5

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t/ha). The testing and evaluation of rice lines from different sources, local and imported, present an opportunity to identify adapted traditional cultivars with higher yields and to find new lines or varieties with higher yield and good eating quality suited to local production environments. The project established observation nurseries to evaluate elite breeding lines and varieties based on grain yield, phenotypic characteristics, and other desired traits. We laid out the nursery as an augmented randomized complete block design and blocks for check varieties.

The project evaluated more than 330 lines and cultivars of rainfed lowland rice in a first-year observation nursery (FYON). These rice lines/cultivars were obtained from the International Network for Genetic Improvement of Rice, IRRI. More than 150 best entries selected from the FYON were evaluated in a second-year observation nursery (SYON). Rice lines/cultivars were selected based on gain yield, vegetative vigor, phenotypic acceptability, growth duration, panicle length, spikelet sterility, 1,000-grain weight, shattering, and insect and disease resistance. The yield of selected best lines/cultivars in the nursery ranged from 3.0 to 6.5 t/ha. The best entries selected from the SYON are tested in farmers' fields using multilocation trials.

Many rice lines/cultivars performed well in the nursery. However, grain yield, phenotypic traits, and physiological traits of lines/cultivars varied substantially. For example, the yield of rice lines/cultivars in the nursery ranged from 0.5 to 6.5 t/ha. Similarly, plant height ranged from 90 to 150 cm, days to 50% flowering ranged from 90 to 120, and variation was large in resistance to pests and diseases. Yield components and other phenotypic characteristics of 10 rainfed lowland rice lines selected from the 2009 SYON appear in Table 3.1. Thus, we can conclude that genetic diversity is large among tested rainfed lowland rice lines/cultivars. Researchers can harness these genetic potentials to improve traditional cultivars as well as to develop improved rice varieties suitable to highland paddies.

Table 3.1. Grain yield and phenotypic characteristics of selected rainfed lowland rice lines from a second-year observation nursery, 2009.

Name	Days to 50% flowering	Plant height (cm)	No. of panicles	Panicle length (cm)	Spikelet fertility (%)	Yield (g/ha)	1,000-seed weight (g)
IR78585-98-2-2-1	104	104	10	26	73	4,201	24
IR75417-R-R-R-R-315-3	104	145	8	28	77	3,984	20
IR80411-B-49-1	105	120	8	23	78	3,877	26
Nam Sagui 19	106	152	7	25	76	3,762	31
TCA80-4	109	135	7	26	81	3,722	24
IR75417-R-R-R-R-246-4	107	102	11	24	72	3,688	31
IR46	107	92	10	23	77	3,628	24
IR75416-R-R-R-R-261-4	101	145	8	26	83	3,607	21
IR80413-B-10-3	102	99	10	20	76	3,567	28
IR70215-70-CPA 3-4-1-3	104	106	8	26	69	3,504	26

Multilocation yield trials—the project tested 33 best rice lines/cultivars selected from an SYOB in different farmers' fields under multilocation yield trials. The main objectives of these trials were (a) to compare the yield performance of selected best rice lines/cultivars under varying conditions in farmers' fields and (b) to expose promising lines/cultivars to farmers and to know farmers' preference for those varieties. Entries were grown in farmers' fields using a randomized complete block design (RCBD) with four replications.

Grain yield of accessions in farmers' field conditions ranged from 2.6 to 3.8 t/ha. The highest yielding accessions were LG2419 (3.6 t/ha) and LG7939 (3.2 t/ha) in 2007, TDK9 (3.0 t/ha) and PSBRc68 (2.6 t/ha) in 2008, and IR78878-53-2-2-4 (3.8 t/ha) and IR78878-53-2-2-2 (3.8 t/ha) in 2009. Many lines produced up to 40% higher yield than the local check variety. Farmers preferred many lines based on grain yield and other phenotypic characteristics mentioned above. Researchers found many promising lines/cultivars with high yield and farmers' acceptability potentials. These promising entries and other potential high-yielding varieties were further tested, evaluated, and selected using a PVS approach.

Participatory variety selection trial—the project evaluated 35 improved upland paddy-rice varieties—26 glutinous and 9 nonglutinous—in farmers' fields using farmer PVS protocols. The objective was to judge farmers' acceptance of selected best rice lines/cultivars. Lao consumers

prefer glutinous rice varieties. The adoption of nonglutinous rice varieties is likely to be low unless they are highly superior to glutinous varieties. Therefore, we selected mainly glutinous varieties. In 2006, we conducted PVS trials to evaluate 13 improved black-glutinous paddy-rice varieties. Yields of tested varieties were comparable with those of the local check (4.3 t/ha). During the participatory trial and evaluation, farmers preferred varieties with medium to short duration, large and long panicles, large grain size, high tillering, and medium plant height. Indeed, these characteristics positively correlate with yield. In 2007, we evaluated six glutinous and six nonglutinous cultivars using PVC protocols. All entries in the trial performed poorly relative to the checks. In 2008, out of six cultivars tested using PVS protocols, farmer preferred two cultivars, TKD9 (3.0 t/ha) and PSBRc68 (2.6 t/ha), based on tall plant, long panicle, large grain size, resistance to gall midge, and resistance to lodging, among other traits. Another PVS trial of four black glutinous rice varieties identified LG-2419 yielding 0.2 t/ha higher than the local check (1.74 t/ha). We conclude that farmers accepted many, but not all, promising lines/cultivars tested under PVS trials. The PVS method is an effective way of testing farmers' acceptance of varieties; varieties selected under PVS protocols have a high probability of adoption among farmers.

3.1.2.1.2 Testing and validating rice varieties for cold tolerance

Low temperature during the dry season is an important constraint in areas where farmers have adequate water for growing dry-season rice. The project conducted trials on varietal screening for cold tolerance in dry-season highland paddies. The objective was to compare promising varieties with local cultivars in their tolerance of low temperature as reflected in their yield performance. Trials were laid out as an RCBD in farmers' fields and three lowland rice varieties were tested for cold tolerance against the local check. Yield varied significantly among varieties. A Chinese variety (4.4 t/ha) and IR62445-2B-12-12 (3.6 t/ha) outyielded the local check (3.4 t/ha). We conclude that promising varieties are available to increase rice yield in the dry season.

3.1.2.1.3 Testing and validating rice varieties for insect resistance

Gall-midge insect damage is a major problem in rice production in northern Lao PDR. Built-in resistance is one efficient way to overcome the threats that pests and diseases present to crop production. Research at the Houay Khot agricultural research station in NAFReC identified rice cultivar Meungnga as gall-midge-resistant. We conducted an experiment in farmers' fields to test the resistance of Meungnga to gall midge in field conditions. Yield (3.4 t/ha) and other phenotypic characteristics of Meungnga were not significantly different from those of the local check. Because of the low incidence of gall midge in the experimental year, it was not possible to evaluate the resistance of Meungnga to gall midge. Nonetheless, comparable yield of Meungnga with that of the local check indicates that Meungnga can be introduced as a preemptive means of increasing crop resistance to gall midge resurgence and minimizing crop damage in pockets of high gall midge incidence.

3.1.2.2 Vietnam

3.1.2.2.1 Testing and validating rice varieties for higher yield and other better agronomic traits

Observation nursery trial—we evaluated 90 rice lines/varieties (40 from China, 40 from IRRI, and 10 from Vietnam) in an observation nursery at the NOMAFSI experimental station. More than 30 promising lines/cultivars possessing either one or more traits such as higher yield, better quality, short duration, cold tolerance, and suitable for aerobic conditions have been identified for further testing and evaluation.

Spring-season rice varieties—short-duration rice varieties allow growing two or three crops in a year. Long-duration spring-season rice varieties affect planting and harvesting time of summer-season rice as well as postsummer rice crops such as peanut and soybean grown under residual moisture. Late planting and harvesting of crops reduce yield and sometime make it impossible to grow postsummer rice crops. Therefore, high yield and short growth duration are important to increase cropping intensity. Toward the goal of identifying rice cultivars that will fit into the scheme of two rice crops in a year, we tested five spring rice varieties for higher yield and short duration. Farmers preferred BT13 (5.7 t/ha) and AYT77 (5.6 t/ha), which had slightly higher yields than local check OMCS7 (5.5 t/ha). In another experiment, we evaluated 13 promising spring rice lines received from IRRI, YAAS, and CIRAD at the NOMAFSI research station. All rice lines outyielded the local check (2.7 t/ha). Notable among these were IR74371-1-3-1 (5.8 t/ha) and Luyin 46 (5.3 t/ha).

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Summer-season rice varieties—summer (rainfed) lowland rice is the main rice crop. We tested four summer-season paddy rice varieties for higher yield and short duration to allow early planting of legume crops such as peanut (before 15 November) for good yield. Although rice variety N46 took 10 days longer to mature than check variety AYT77 (105 days), it was ready for harvest by 15 October and outyielded (5.5 t/ha) the check (4.2 t/ha). Thus, N46 is suitable for a two-rice crop system and it gives a higher return. In another experiment, a field trial tested medium-duration rice varieties to replace the common variety Khang Dan 18. Varieties LCV9 (6.2 t/ha), BTR01 (5.5 t/ha), and VD8 (5.5 t/ha) yielded significantly higher than Khang Dan 18 (4.4 t/ha).

Participatory varietal selection trials—we conducted PVS trials to judge farmers' acceptance of five promising summer rice varieties (N46, T10, BT13, HT1, and HT6). Results showed that all rice varieties had 0.1–1.3 t/ha higher yield than the local check (5.1 t/ha). The highest yielder was BT13 (6.4 t/ha), followed by HT1 (5.8 t/ha). Farmers rated these varieties higher than the local check in terms of yield and other phenotypic traits.

3.1.2.2 Testing and validating rice varieties for cold tolerance

Cold tolerance is a desired trait during the seedling and early growth stages of the spring crop. A lack of cold-tolerant varieties prevents timely planting and harvesting of spring-season rice with a subsequent effect on the summer rice crop. This is critical to shift from single (summer) to double (spring and summer) cropping of rice per year. We tested 12 spring rice varieties for cold tolerance. Varieties HYT83, HYT88, HYT93-2, and TH3-3 were found to be more cold tolerant than check variety Nhi Uu 838.

3.1.2.3 Study crop phenology of rice varieties

We conducted an experiment at the NOMAFSI experimental station to monitor crop phenology of rice cultivars under contrasting climatic conditions. The objective was to estimate “thermal constants” of the common rice cultivars grown in northern Vietnam. The information on phenological characteristics of rice varieties linked to thermal constants is useful to (a) analyze (cold) temperature constraints to rice production in the spring season and (b) develop crop calendar and varietal use strategies for two-rice crop systems in areas where cold temperature constrains spring rice production. We considered three factors in designing the plots: (a) altitude of the plot as a proxy for contrasting temperature conditions (300–800 meters), (b) cultivars suitable for cold conditions (Chem Huong and Nhi Uu 838), and (c) planting method (transplanting and direct seeding).

We observed different results for spring and summer seasons. Spring-rice crop durations were not different for the two cultivars and for the two cultivation methods. Moreover, crop durations decreased with a late planting date. In the summer season, rice crop durations were not different for the two cultivars, but crop durations were shorter for direct seeding (5 days) than for transplanting. Moreover, crop durations increased with a late planting date. The length of the double-rice cropping season increases with altitude because of the need for early planting of spring rice and late planting and harvesting of summer rice. A long crop season leads to rice crop death due to low temperature early in the spring season and late in the summer season. We conclude that cold temperature is a major constraint to a shift from single-rice to double-rice cropping in northern Vietnam (above 600 meters). Three ways to overcome the cold-temperature constraint are reducing the time needed between the spring and summer crop (through mechanization or improved nursery management), using short-duration varieties, and using cold-resistant varieties.

3.1.3 Conclusions

Lao PDR's rice varietal improvement work centered on identifying germplasm material, both local and introduced, that is high yielding, has good quality, and meets local farmers' preferences. In contrast, Vietnam's germplasm selection work was pragmatic in orientation in deliberately setting out to select cultivars with high grain production and growth duration that would fit into the objective of shifting farmers from a single rice crop to two rice crops per year. Efforts had been made to involve farmers in the selection process and elicit opinions about the germplasm. These germplasm selection approaches are tempered by government imperatives on the achievement of food security and the local realities involved in the adoption of successful germplasm entries. The replacement of traditional cultivated varieties with high-yielding rice varieties is perceived as a quick fix to food insecurity, but does not take into consideration local tastes and preferences that may greatly hinder the adoption of some high-yielding rice varieties.

3.2 Testing and validating improved rice crop management technologies

3.2.1 Methodology

Rice crop management research focused on nutrient management, weed management, crop establishment methods, optimum age of seedlings for transplanting, and optimum number of transplanted seedlings per hill. Nutrient management in the lowlands aimed at optimizing the productivity of rice and other crops before or after rice. This was systematically approached through a stepwise determination of the nutrient-supplying capacity of the soil. The nutrient management work focused on nutrient omission trials; assessment of feasible options such as green manuring, legume crops, and application of inorganic fertilizers to supply nutrients deficient in the soil; optimum rate of inorganic fertilizer application; and agronomic trials to study the response of rice and other crops to these nutrient management options.

Weed management research focused on determining the extent of yield loss due to weeds, evaluating crop and field management options that may decrease yield losses from weeds, and testing these options using on-station experiments and on-farm field trials. Most of this work was conducted in Lao PDR, where researchers investigated the manipulation of stand density through spacing, establishment methods, and seedling age to achieve varying rates of canopy closure and degrees of competitive interactions between rice and weeds.

We tested and validated crop management technologies through scientifically designed on-station and on-farm trials. Mostly, trials were laid out as an RCBD with enough treatments and replications. We gathered field trial data such as crop establishment method, seedling age, planting density, fertilizer application, soil mulching, weed management, weed biomass, grain yield, and other agronomic variables to examine the performance of the technologies. Yield and other desired traits of improved technologies were compared with local checks/farmers' practices for evaluation. We used cross-tabulation, graphical-form, descriptive statistics, and inferential statistics methods to analyze the data. We performed these methods using Excel, SPSS, IRRISTAT, CROPSTAT, and other appropriate analytical tools.

3.2.2 Results and discussion

3.2.2.1 Lao PDR

3.2.2.1.1 Nutrient management

Low soil fertility and low application of inorganic fertilizers are believed to be important causes of low rice yield in highland paddies. Replacement of mineral nutrients removed by crop plants and losses due to water and sediment runoff is essential to stabilize and increase the productivity of soil. Animal manure, green manure from plant materials, and chemical fertilizers are important sources of nutrients. We conducted integrated nutrient management trials to study (a) the nutrient-supplying capacity of soils and (b) rice yield response to fertilizer application. We conducted trials in several farmers' fields at research sites.

The first experiment relates to nutrient-supplying capacity of the soil. We studied rice yield response to different levels of N, P, and K. We laid out trials in 12 farmers' fields in Fai Village. We applied farmers' practices in the trial plots, but with fertilizer treatments. We used different fertilizer treatments in the experiment: (a) a plot without NPK; (b) a plot with N and K, but no P; (c) a plot with N and P, but no K; (d) a plot with N and K, but no P; K was incorporated inside the soil; and (e) a plot with N and P, but no K; P was incorporated in the soil. Grain yield in a plot without NPK served as an indicator of the potential of the soil to supply NPK nutrient in a cropping season. We used grain yield as an indicator of nutrient-supplying capacity of the soil. Fertilizers were applied at the rate of 60 N-30 P₂O₅-30 K₂O.

Rice yield varied significantly among treatments (Figure 3.1). Zero fertilizer, fertilizers but no K, and fertilizers but no P treatments averaged 3.7, 4.3, and 4.8 t/ha of yield, respectively. The incorporation of fertilizers in soil yielded slightly better results. Nitrogen and phosphorus application raised yield by 1.1 to 1.2 t/ha, while nitrogen and potassium raised yield by 0.6 to 0.9 t/ha. The nutrient-supplying capacity of highland paddy soils in Fai Village was high, enabling an average yield of 3.7 t/ha. Farmers currently apply a very small amount of chemical fertilizers in rice. An increase in fertilizer application raised rice yield above 3.7 t/ha.

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The second experiment relates to rice yield response to different sources of nutrients. Trials were laid out in an RCBD in farmers' fields in 2007 and 2008. Fertilizer treatments in 2007 were (a) control (no fertilizer or green manure), (b) pig manure (5,000 kg/ha), (c) *Chromolaena odorata* green manure (25 t/ha), and (d) inorganic fertilizer (N-P₂O₅-K₂O at 60-30-30 kg/ha). *C. odorata* is an abundant, fast-growing weed in uplands. Crop management follows farmers' usual practices.

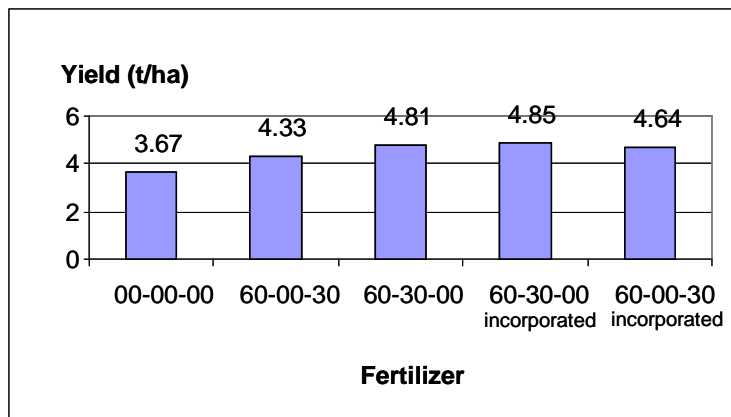


Figure 3.1. Rice yield under different fertilizer treatments.

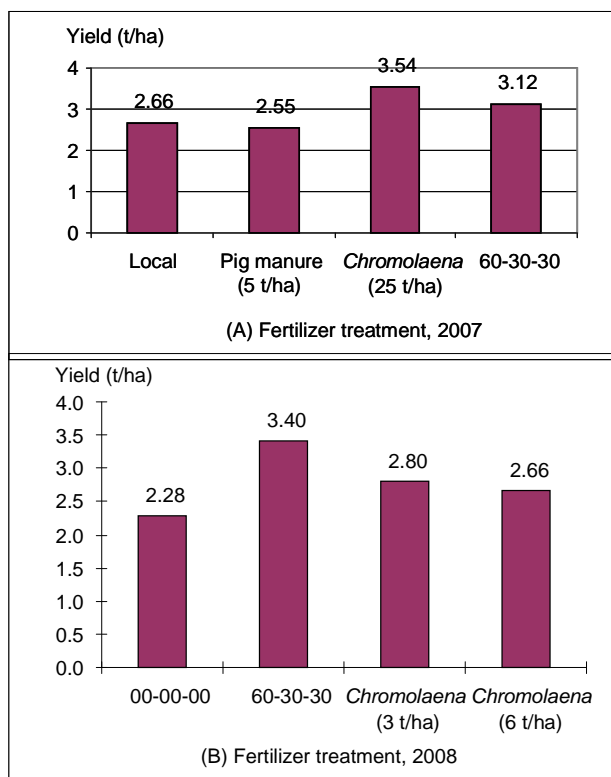


Figure 3.2. Effect of different sources of fertilizer on rice yield, 2007 and 2008.

Yield differed significantly among treatments. In 2007, *Chromolaena* treatment gave the highest yield, followed by inorganic fertilizer and pig manure (Figure 3.2A). In 2008, inorganic fertilizer gave the highest yield, followed by *Chromolaena* (Figure 3.2B). The green manure treatment raised grain yield by 0.4–0.9 t/ha relative to the control treatment depending upon the quantity applied. We conclude that the cultivation of green manure such as *Chromolaena* improves soil fertility and increases rice yield significantly.

3.2.2.1.2 Weed management

Rice yield gap due to weeds—weeding takes up a large proportion of labor input in rice production. Quantifying the yield difference between more intensively weeded and less intensively weeded fields would help to determine the optimum intensity and timing of weeding in paddy rice. We conducted an experiment in farmers' fields to determine yield loss due to weeds in rice production in paddies. Treatments include farmers' practices as a control and additional hand weeding. We compared dry weed biomass and rice yield between treatments. Weed biomass and rice yield were not significantly different between plots with normal weeding and additional hand weeding (Figure 3.3). Weeds are an important yield-reducing factor in paddy rice in northern Lao PDR. The insignificant effect of additional weeding on rice yield is doubtful. Further research covering wider areas is needed to confirm this finding.

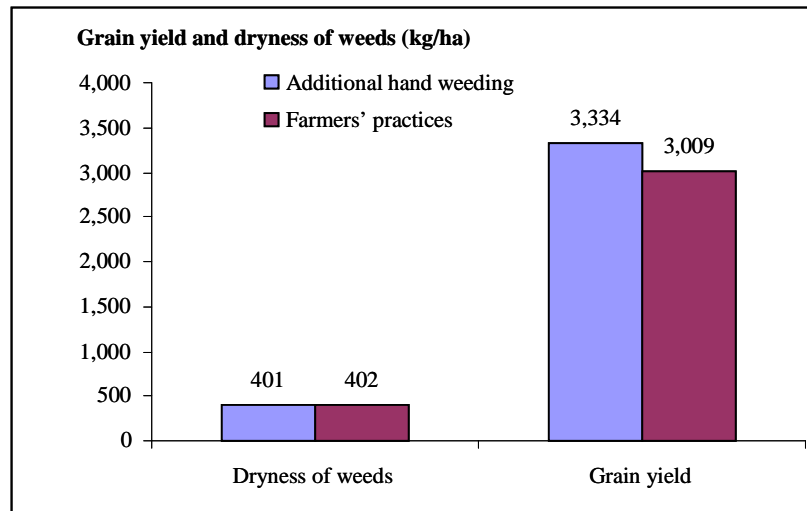


Figure 3.3. Rice yield and weed biomass in farmers' fields and plots with additional weeding.

Weed control through rice crop spacing and planting density—a research trial to study weed control through rice crop spacing and planting density in upland paddy was conducted with farmer participation. The objective was to identify suitable rice crop spacing and plant density to increase rice yield by controlling weeds. Treatments were hill spacing (15 × 15 cm and 20 × 20 cm) and number of seedlings per hill (1 and 2 seedlings) with farmers' practice as a control. The trial was laid out as an RCBD in farmers' fields. Rice variety TDK11 was used in the trial and fertilizer was applied as 60-30-30 kg N-P₂O₅-K₂O per hectare. Within the limits of the trial, closer spacing of hills (15 × 15 cm) yielded the highest (4.7 t/ha) and the farmers' practice yielded the lowest (3.5 t/ha) among hill-spacing treatments. Similarly, 2 seedlings per hill yielded the highest (4.3 t/ha) and the farmers' practice yielded lowest (3.9 t/ha) among number of seedlings per hill treatment. We conclude that improvements in farmers' practices in hill spacing and number of seedlings per hill increases lowland rice yield.

3.2.2.1.3 Rice crop establishment method

The direct-seeding method saves labor because it does not require a seedbed and transplanting of rice. It also ensures timely planting of rice when the onset of rainfall is unpredictable. However, rice yield is low in direct seeding due to more weeds. We laid out an experiment to study the effect of rice establishment method, namely, direct seeding and seedling transplanting, on rice grain yield and weed biomass. Crop establishment treatments consisted of three direct-seeding methods (broadcasting, line seeding, and drum seeding) and transplanting. Rice variety TDK5 was used and fertilizer was applied as 60-30-30 kg N-P₂O₅-K₂O per hectare.

Transplanted rice gave higher yield than broadcasting and line seeding, but lower yield than drum seeding, although the difference in grain yield between the establishment methods was not statistically significant (Figure 3.4). Similarly, weed biomass (oven-dried) in transplanted rice was less than in drum seeding, but more than in line seeding and broadcasting, though the difference was not statistically significant (Figure 3.5). We conclude that direct seeding, particularly drum seeding, is a promising technology for rainfed lowland rice of northern Lao PDR.

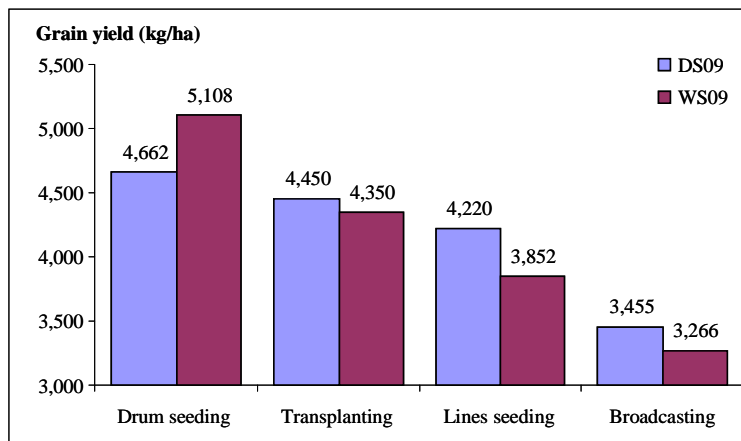


Figure 3.4. Rice yield under different rice crop establishment methods, 2009.

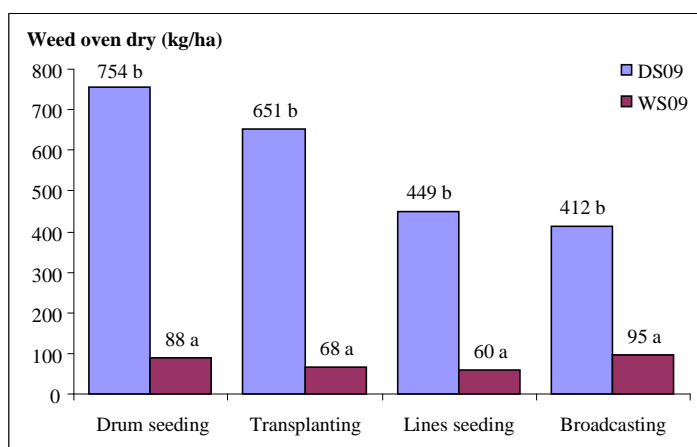


Figure 3.5. Weed biomass under different rice crop establishment methods, 2009.

3.2.2.1.4 *Optimum seedling age and transplanted-seedling density*

Rice crop establishment practices affect yield. Rice farmers in northern Lao PDR follow conventional crop management practices. Improved field and crop management practices coupled with good varieties can raise rice yield. Manipulation of farmers' current practices of using aged seedlings to transplant and the density of seedlings transplanted may be ways to increase rice yield. We conducted an experiment to study the effect of seedling age and seedling density in lowland rice. Treatments for seedling age were 2 weeks old, 4 weeks old, and farmers' practice. Treatments for seedling density were 1 seedling/hill, 3 seedlings/hill, and the farmers' practice.

Results of the wet-season trial indicated that 2-week-old transplanted seedlings gave 1.6 t/ha higher yield than 4-week-old seedlings (3.6 t/ha). Similarly, seedling densities of 1 and 3 per hill gave 1.5 t/ha higher yield than the farmers' practice (4.3 t/ha). When seedling age and planting densities are considered together, transplanting younger seedlings (2-week-old) at lower seedling density (1–3 seedlings/hill) increased rice yield by about 1.6 t/ha over the farmers' practice (4.0 t/ha). We can conclude that manipulating farmers' current practice of using seedling age and seedling densities can raise rice yield significantly.

3.2.2.2 **Vietnam**

3.2.2.2.1 *Testing and validating nutrient management technologies*

Fertilizer omission trials showed that nitrogen and phosphorus application gave higher yield in Sai Luong (6.0 t/ha), while nitrogen and potassium application gave higher yield in Suoi Giang (5.4

t/ha). This indicates that different nutrients are limiting rice yield in Suoi Giang (paddy rice in terraces) and Nam Bung (paddy rice in valley bottoms). A follow-up experiment in Suoi Giang confirmed the results at the site. We evaluated the nutrient-supplying capacity of paddy soil in Suoi Giang under four treatments of N-P₂O₅-K₂O (60-0-0, 60-0-30, 60-0-60, and 60-0-90 kg/ha) and control (farmers' fertilizer practices). Rice yield was highest in treatment 3 (6.7 t/ha) and treatment 4 (6.8 t/ha). We conclude that 60-0-60 kg/ha N-P₂O₅-K₂O is the optimum fertilizer application rate in paddies in Suoi Giang to get maximum yield. This is consistent with the previous findings of relatively high phosphorus content of these soils. We conducted a fertilizer trial in Sai Luong to investigate the response of the popular hybrid rice variety Nhi Uu 838 to nitrogen fertilizer application. Results showed that 100-90-60 N-P₂O₅-K₂O is the optimum fertilizer application rate in paddies in Sai Luong to get the highest economic yield (6.3 t/ha). Results for Sai Luong are also consistent with earlier findings.

3.2.2.2 *Testing and validating weed management technologies*

We set up an experiment in farmers' fields to determine rice yield loss due to weeds. To achieve this, we compared rice yield from farmer-weeded plots with the treatment plots, which received an additional weeding above the farmers' practice (i.e., farmers' practice + 1 hand weeding). The treatment plots produced 3.6 t/ha yield compared with farmers' practice plot yield of 3.3 t/ha, which is a 10% loss in rice yield due to weeds. Thus, we conclude that additional weeding in paddies increases rice yield. This additional gain is economically worthwhile for farmers who have sufficient family labor to carry out the additional weeding.

3.2.3 **Conclusions**

Nitrogen was consistently deficient in the soils of northern Vietnam and Lao PDR. Depending on the parent material of the soil and deposition of sediments, soil phosphorus and potassium may also need to be supplemented in order to optimize grain production. Crop yield consistently improved with the addition of organic fertilizer and green manure, such as *Chromolaena odorata*. Increased yield with an increasing amount of green manure indicates a positive relationship between grain production and "something" in green manure. Whether this something is nutrient in the green manure or improved soil physical and chemical properties from organic matter addition is not known from these experiments and trials.

Weeds may cause at least a 10% yield loss in lowland rice. The yield loss to weeds is likely much more since the trials estimated the yield difference of usual weeding practice and usual practice plus one more weeding. It is apparent also that the timing of weeding events would also influence yield losses due to weed competition. Manipulation of stand spacing and transplanting density in a hill, seedling age, and crop establishment methods affect the competitiveness of the crop stand against weeds through their influence on the crop and vigor.

3.3 **Testing and validating improved rice-based cropping systems technologies**

3.3.1 **Methodology**

Cropping systems that intensified land and water use were evaluated through field demonstrations and on-farm trials. Avenues of resource use intensification that were evaluated were one-season to two-season rice cropping and cultivation of high-value pre- and postsummer rice crops, preferably legumes. Rice varietal work focused on testing short-duration and high-yielding rice varieties. Because soil moisture is of critical importance to the success of these avenues of resource intensification, testing of soil moisture retention and conservation techniques was integrated into some of these field trials.

We tested the performance of improved short-duration and high-yielding rice varieties as well as improved legume crops through scientifically designed on-station and on-farm trials. Mostly, trials were laid out as an RCBD with enough treatments and replications. We gathered and analyzed crop yield and other desired experimental data to examine the performance of the technologies. We analyzed data using Excel, IRRISTAT, CROPSTAT, and other analytical software as needed.

3.3.2 Results and discussion

3.3.2.1 Lao PDR

More intensive production in upland paddies but less intensive production on sloping uplands may be the way to promote sustainable farming in northern Lao PDR. A lack of sufficient moisture and appropriate technology for pre- and post-rice crops constrains intensified production in paddies. Growing legumes after wet-season rice offers a way to diversify crop production, uses residual moisture efficiently, and renews soil fertility through nitrogen fixation. Appropriate legume crops for low-moisture conditions as well as methods to conserve soil moisture are likely to increase cropping intensity in rainfed lowlands. We conducted experiments (a) to examine the feasibility to grow small legume crops after wet-season rice and (b) to compare the performance of post-wet-season rice legumes grown on soils with and without moisture-conserving technology. Treatments in the yield performance of legumes consisted of black bean, mung bean, and two varieties of soybean (CM60 and DT85). Treatments in moisture-conserving technology consisted of no mulch (control), rice straw mulch, and plastic mulch. The trial was laid out as a split plot in an RCBD.

Black bean (1.8 t/ha) and soybean cultivar CM60 (1.6 t/ha) performed better than mung bean and soybean cultivar DT85. Plastic mulch produced the highest legume yield (2.4 t/ha) relative to rice straw mulch (1.0 t/ha) and no mulch (0.5 t/ha). We conclude that black bean and soybean cultivar CM60 as well as mulching practice are suitable post-wet-season rice technologies. Although agronomically feasible, their economic viability and environmental impacts must be evaluated further.

3.3.2.2 Vietnam

Common cropping systems on lowlands in northern Vietnam include spring fallow–summer rice–winter fallow in rainfed areas and spring rice–summer rice–winter fallow in irrigated areas. An additional short-duration rice crop enables farmers to produce more rice and gain extra income. Additional legume crops improve soil fertility and generate extra cash income. We conducted an experiment to test the suitability of soybean and peanut as postsummer rice crops. Results showed that peanut produced more yield (1.2 t/ha) than soybean (0.1 t/ha) on terraced paddy fields. Peanut may be able to produce harvestable yield in the face of soil moisture deficits that typically occur in the spring season. Toward the goal of shifting from a monocrop to a double crop and from a double-crop to triple-crop system in an irrigated environment, we tested the suitability of spring rice–summer rice–winter legume cropping systems technology. Local check Nhi Uu (3.8 t/ha) and hybrid rice HYT 83 (3.5 t/ha) performed better than hybrid rice HYT 100 (2.5 t/ha) as the spring rice component of the three-crop system. Peanut performed better as the winter-crop component.

Two cropping patterns that integrate different components of farming systems were found suitable for paddies in northern Vietnam:

- Spring legumes (soybean and peanut with or without mulching) + high-quality summer rice + winter legumes
- Spring high-quality rice + summer high-quality rice + winter legumes

We found three promising varieties of soybean (DT12, DT2004, and DT84) and peanut (L14, L23, and L24) suitable for the spring season. Similarly, we validated three traditional rice varieties (N46, BT13, and T10) with high quality and acceptable yield suited to the three crops a year cropping system. These varieties have yield potential of 7–8 t/ha, are resistant to pests and diseases, and are adaptable to the northern mountainous region. We conclude that this three-crop system is a viable option in irrigated paddies with enough water supply.

3.3.3 Conclusions

Results of field trials in Lao PDR and Vietnam demonstrated the agronomic feasibility of intensifying land and water use by shifting from one crop of rice a year to two rice crops plus a legume crop per year. This level of intensification requires the use of the right combination of rice varieties and legumes so that they fit into a cropping system and complement each other in the use of resources. The work in Lao PDR demonstrated the importance of managing residual soil moisture in the drive toward crop diversification and intensification. These experiments and trials, however, do not delve into the question of the sustainability of these systems. The legume components may contribute to the nitrogen economy of the soil, but external inputs would probably still be required to maintain productivity over time.

3.4 Testing and validating improved *agricultural water management technologies*

3.4.1 Methodology

The interest of the project in these technologies is their potential to facilitate expansion of area in rice or other crops during the dry season. Trials on improved water management technologies (saturated soil culture and alternate wetting and drying) were initially conducted on-station to test the local suitability of the technologies. The on-station validated technologies were then tested on-farm with farmers' participation.

On-station and on-farm trials were laid out as an RCBD with enough treatments and replications. We gathered and analyzed crop yield and other desired experimental data to examine the performance of improved water management technologies relative to farmers' practices. We analyzed data using Excel, IRRISTAT, and other analytical software as needed.

3.4.2 Results and discussion

3.4.2.1 Lao PDR

3.4.2.1.1 Saturated soil culture

A lack of irrigation water hinders the cultivation of rice and nonrice crops in the dry season. Water-saving technologies provide opportunities to expand dry-season cultivation as more area can be irrigated using the same total quantity of water. We conducted an experiment on-station and in farmers' fields to examine rice productivity under a saturated soil culture (SSC) water regime. Water regime treatments were flooding (farmers' practice), saturated soil culture with straw mulch, and saturated soil culture without mulch. We maintained SSC by digging canals around the planting area and raising the level of the soil planted area by 10 cm. Rice varieties TDK5 and B6144F-MR-6 were used in the trial.

Rice yield varied significantly among water treatments (Figure 3.6). SSC gave 0.1–0.3 t/ha higher yield than the farmers' current practice (flooded). SSC without mulch had the highest yield. Rice yield difference between TDK5 and B6144F-MR-6 was not statistically different in all treatments. We conclude that dry-season cultivated area can be expanded to some extent by adopting SSC technology.

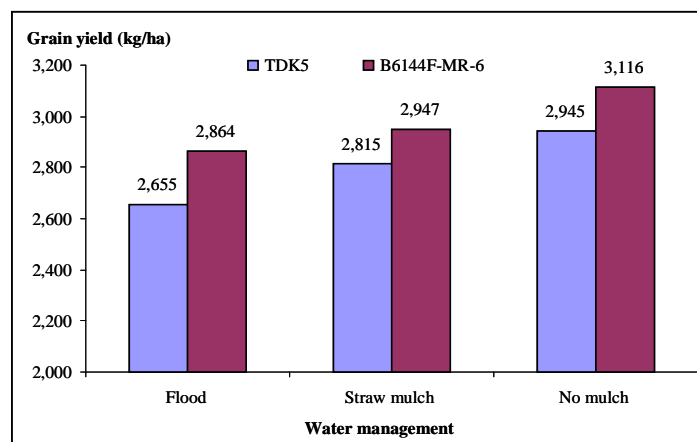


Figure 3.6. Rice yield under different water management practices, 2009.

3.4.2.1.2 Alternate wetting and drying

The adoption of alternate wetting and drying (AWD) water-saving technology is one important way to increase dry-season rice production. We conducted an experiment to determine rice productivity under AWD water regimes. The trials were laid out as a split-plot RCBD in farmers' fields. Water regime treatments were normal field flooding practice by farmers, AWD once a week, and AWD

every 48 hours. We used improved lowland rice variety TDK5 and improved aerobic rice variety B6144F-MR-6 in the trials.

Rice yield differences between continuously flooded and alternately wetted and dried fields—whether for 48 hours or over a week—were not statistically significant between TDK5 and B6144F-MR-6 (Figure 3.7). Nonetheless, TDK5 (3.4 t/ha) yielded 0.7 t/ha higher than B6144F-MR-6 (2.7 t/ha). Rice yield in AWD was comparable, if not higher, than in continuously flooded soil culture. Water saved from the technology enables farmers to expand dry-season crop cultivation. Thus, we can conclude that adoption of AWD technology can increase dry-season rice production. AWD technology needs to be combined with suitable rice cultivars to take full advantage of the water savings and limit any losses in grain yield.

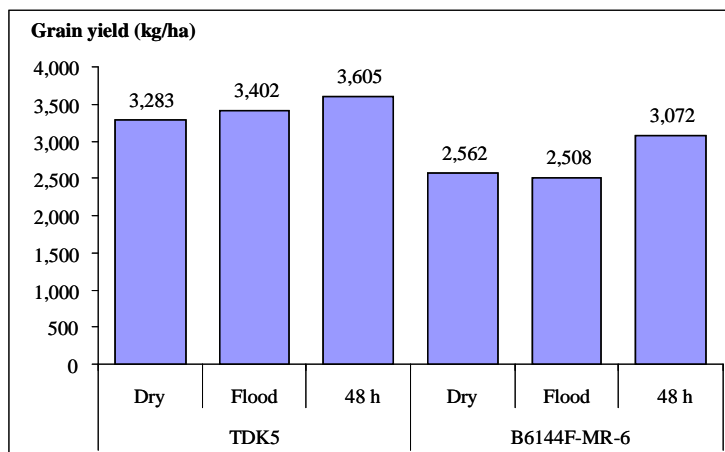


Figure 3.7. Effect of water management techniques on rice yield.

3.4.2.2 Vietnam

We conducted an experiment on saturated soil culture for spring rice at the NOMAFSI experimental station. The objective was to explore the potential of SSC technologies to save water in paddy rice cultivation in northern Vietnam. We tested two conventional inbred rice varieties (CIRAD 141 and Khang Dan 18) in three treatments and a control: SSC + no mulch, SSC + mulch with plant materials, SSC + plastic film mulch, and farmers’ practice of continuous flooding. Results showed that grain yield of CIRAD 141 and Khang Dan 18 grown in SSC was not significantly different from that in the farmers’ practice. SSC with mulch reduced crop duration by 5–7 days compared with the control. Relative to the control group, SSC without mulch increased labor input to weeding by 14–21 days/ha, but labor input to weeding decreased by 0–3 days/ha in SSC with plant mulch and by 55–58 days/ha in SSC with plastic mulch. However, the cost of production was highest in plastic mulch and lowest in the control.

A repeat of the trial, with rice variety DV108, at the NOMAFSI experimental station in the spring of 2009 confirmed the results of the initial trials. Maturation of DV108 was 5 days earlier in SSC with plastic mulch than in controls plots. SSC with plastic mulch and SSC with plant mulch produced 0.9 t/ha and 0.2 t/ha more yield, respectively, than SSC plots without mulch. In Suoi Giang, an on-farm trial showed that IR74371-3-1-1, an aerobic rice line, produced about 1.0 and 2.0 t/ha more yield in plots with plastic and plant mulch, respectively, than in no-mulch plots. We conclude that SSC technology saves water, saves labor, and reduces crop growth duration without a yield penalty. Therefore, this is a suitable water-saving technology to increase rice production in paddies and hence contribute to food security. SSC with mulching technology saves labor and increases yield compared with SSC without mulch. Nonetheless, SSC with mulch, particularly plastic films, increases rice production cost substantially. We therefore recommend SSC technologies for water-scarce conditions. SSC with low-cost mulching increases crop profitability.

3.4.3 Conclusions

Rice productivity under SSC and AWD water management technologies was not significantly different from continuously flooded soil culture. The work in Vietnam showed that mulching treatment paired with SSC might be suitable to fit a post-rice crop earlier into the cropping pattern.

The work in Lao PDR showed that there were no significant losses in productivity with AWD; hence, water not used in a plot while it is in the drying phase could be diverted to irrigate other plots without any significant grain yield loss in the AWD crop. This will help increase overall production by a more efficient use of water. Greater water savings may be derived from more infrequent irrigation (once a week instead of every other day) without a yield penalty, but this depends on the rice variety used in the AWD fields. AWD technology needs to be combined with appropriate cultivars to take full advantage of the water savings and limit any grain yield losses.

4. Objective 4: to develop and test, with farmer participation, water- and soil-conserving technologies for rice-based production systems on sloping uplands and to make such technologies available for delivery and dissemination.

Research activities under objective 4 are congruent with those on objective 3, except that objective 4 was focused on sloping upland. We tested, validated, and disseminated a large number of crop- and nutrient-efficient and soil- and water-conserving technologies for rice-based production systems on sloping uplands. Broadly, we grouped these technologies into three types: (a) rice varieties, (b) rice crop management, and (c) rice-based cropping system. This section details research activities on each technology group conducted in Lao PDR and Vietnam. We excluded Thailand because technology development was not a part of its research program.

We followed a multi-institutional partnership framework to collect, validate, and disseminate promising rice cultivars for sloping uplands. Then, we tested and validated promising technologies using both research station and farmer trials (multilocation yield trials and PVS trials).

4.1 Testing and validating improved rice varieties

4.1.1 Methodology

We used a two-pronged approach to select and test suitable rice lines/cultivars for the range of constraints that limit rice production in sloping uplands. One approach was to use purified traditional cultivars, which have been identified as promising materials from a range of constraints in the upland. The other approach, which was complementary, was to test germplasm materials from a variety of sources, such as ongoing breeding programs in different countries and at IRRI, and observation nurseries from INGER and YAAS. We conducted scientifically designed on-station observation nursery trials, multilocation testing trials, and on-farm PVS trials. Field trial data such as planting date, plant height, tiller number, date of flowering, panicle number, panicle length, grain yield, spikelet fertility, shattering, resistance to cold and drought, and resistance to pests and diseases, among others, were collected to study the performance of popular rice cultivars in the target domain.

Promising rice lines/cultivars from on-station trials were evaluated in farmers' fields using mother-baby trials. We used PVS protocols to judge the farmers' acceptance of promising entries. Farmers rated rice lines/cultivars based on grain yield, eating quality, grain size, resistance to pests and diseases, crop duration, and plant height, among other traits.

4.1.2 Results and discussion

4.1.2.1 Lao PDR

Observation nursery trial—we tested 433 upland and aerobic lines/cultivars collected locally (61 lines) as well as received from IRRI-INGER (315 lines) and YAAS (57 lines) under a “first-year upland rice observation nursery (OBN1).” From the OBN1, we selected 65 promising lines/cultivars and tested them in the “second-year observation nursery (OBN2).” The promising lines were selected based on grain yield (1.6–3.1 t/ha), phenotypic acceptability, and resistance to pests and diseases, among other important traits. Of these 65 entries, the 10 best rice lines/cultivars were selected for further evaluation in a multilocation trial.

Multilocation yield trial—we tested 19 rice lines/cultivars (10 from OBN2 and 9 others) in a multilocation yield trial with farmer participation. Of the tested varieties, Khaw Kang, a glutinous upland rice variety, gave the highest and most consistent yield (3.1 t/ha) across locations. Khaw Kang has farmer-preferred phenotypic traits such as good early vigor, less shattering, long panicles, and large grain.

Participatory varietal selection trial—we tested six upland rice cultivars (3 glutinous and 3 nonglutinous) in farmers' fields using PVS trials. The farmers preferred two cultivars, TDK9 (3 t/ha) and PSBRc68 (2.6 t/ha), because of their phenotype (tall plant type), long panicles, percentage of filled grains in the panicle, large grain size, resistance to gall midge, and resistance to lodging.

4.1.2.2 Vietnam

Observation nursery trial—we tested 403 aerobic and/or upland rice lines/cultivars collected locally (28 cultivars) and introduced from IRRI (170 cultivars) and YAAS (205 cultivars) under OBN1 and OBN2. These selection trials were conducted at Phu Ho and Suoi Giang research stations during the spring and summer seasons. From the observation nursery, we selected 38 rice lines/cultivars for further testing and evaluation. The selected rice lines/cultivars were mainly upland and aerobic rice with desirable grain yield, insect and disease resistance, good crop duration, and appropriate phenology.

Participatory varietal selection trial—eight upland rice varieties were tested in farmers' fields under a PVS trial. Four cultivars outyielded the local check variety (0.8 t/ha). Of the four best entries, two were improved, Luyin 46 (1.0 t/ha) and IR78875-1-3-1 (0.9 t/ha), and two were promising traditional ones, Bao Dam (1.0 t/ha) and Nep Suoi Giang (1.1 t/ha). Lines 8FA 67-5, CIRAD 141, and 8FA 281-2 had equal or higher grain production than the local checks Bao Dam and Macha in on-farm trials in Suoi Giang.

4.1.3 Conclusions

Rice varietal improvement work in Lao PDR and Vietnam centered on identifying germplasm materials, both local and introduced, that were high yielding, had better eating quality, had resistance to pests and diseases, and met the preferences of consumers. We tested about 850 upland and aerobic rice lines/cultivars in observation nurseries to identify promising lines suitable to the sloping uplands of Southeast Asia. Both glutinous and nonglutinous rice cultivars were included in the testing and validation because of consumer preference. The best-performing rice cultivars from observation nurseries were further evaluated under multilocation and PVS trials. Seeds of farmer-preferred cultivars selected through PVS protocols were multiplied through a community-based seed production approach and distributed to farmers at project sites and beyond. The distributed improved rice varieties had a yield advantage of 0.2–1.5 t/ha over the currently popular varieties. The large yield advantage of the rice varieties, which are suitable to local agroecology and meet farmers tastes and preferences, substantially contributes to the project goal of improving food security for the poor, who are primarily dependent on upland rice. This approach of varietal testing and validation also contributes to biodiversity conservation through the spread of large numbers of rice varieties. We found the farmer PVS approach very effective in selecting varieties suitable to local conditions, that are faster to disseminate, and that ensure a higher adoption rate. Farmers used multiple criteria such as plant height, crop duration, resistance to insects and diseases, panicle length, shattering, grain size, and yield, among others, to select cultivars.

Vietnam conducted evaluation and selection trials to identify promising lines from a variety of sources but did not pursue a systematic course of narrowing the choices to a few selected recommended rice lines. This approach is consistent with the well-established and centralized crop certification and registration system in Vietnam. Crop performance information over several years and seasons has to be submitted and considered by the crop certification and registration board before a line can be recognized and released as a recommended variety.

Lao PDR, on the other hand, has a scattered out system of certification and registration. The urgency to produce more rice placed a premium on identifying materials that would be suitable for identified application domains and would comply with farmers' concept of a good rice plant and their preferences.

4.2 Testing and validating improved rice crop and field management technologies

4.2.1 Methodology

We conducted demonstration and field trials to address specific issues concerning the management of upland rice crops and fields. Rice crop and field management research focused on nutrient management, weed management, optimum quantity of seed, optimum time of sowing, and land preparation methods. Nutrient management work focused on examining the yield response of upland rice varieties to inorganic fertilizer application, the optimum rate of inorganic fertilizer application for upland rice, and the optimum combination of rice and *Stylosanthes* to increase rice yield. Weed management trials focused on determining rice yield loss due to weeds and the effect of mulching on weed biomass accumulation during the crop-growing season. Other trials examined

yield effects of different methods of rice crop establishment, interactions of land preparation techniques, varieties, and fertilizer use.

We tested and validated crop management technologies using scientifically designed on-station and on-farm field and demonstration trials. Mostly, trials were laid out as an RCBD with enough treatments and replications. We gathered field trial data such as land preparation methods, seed rate, sowing time, fertilizer application rate, weed biomass, harvesting time, grain yield, and other relevant agronomic variables to examine the effects of management practices on crop performance. Crop yield and other desired traits of improved varieties were compared with checks/farmers' practices for evaluation. We analyzed data using cross-tabulation, graphical-form, descriptive statistics, and inferential statistics methods by employing Excel, SPSS, IRRISTAT, and other appropriate analytical tools.

4.2.2 Results and discussion

4.2.2.1 Lao PDR

Nutrient management—we evaluated 10 rice varieties (4 glutinous, 2 black rice, and 4 nonglutinous) for their local suitability, farmers' acceptance, and fertilizer response. Grain yield and other characteristics of these varieties were compared with local checks under fertilizer application (60:30:30 kg/ha N:P₂O₅:K₂O) and no fertilizer application. Grain yield was not significantly different among varieties under the two fertilizer application rates. However, improved varieties were relatively more responsive to fertilizer than a local variety such as Nok. Although we examined varietal response to fertilizer, the farmers indicated that they will grow their preferred varieties with no chemical fertilizer application.

We conducted another farmer-participatory nitrogen-fertilizer application experiment to determine the optimum rate of nitrogen fertilizer for upland rice and to determine rice cultivar × fertilizer interactions. The trials included five fertilizer treatments: (a) no fertilizer, (b) 30 kg/ha N, (c) 60 kg/ha N, (d) 90 kg/ha N, and (e) 120 kg/ha N. Three traditional varieties (Makhinsoung, Nok, and Non) and three improved varieties (IR55423-1, B6144F-MR-6, and IR60080-46) were included in the trial. On average, nitrogen fertilizer at 30 kg/ha gave the most economical yield (2.5 t/ha) among all treatments for both traditional and modern cultivars. Rice varieties showed significant cultivar by fertilizer interactions. Traditional varieties performed better than modern varieties without fertilizer. Weed biomass decreased with fertilizer application, probably from weed growth inhibition because of increased rice growth and earlier rice canopy closure in the plots, which had been fertilized. We conclude that nitrogen fertilizer application up to 30 kg/ha significantly increases yield of upland rice and reduces weed biomass. Yield response to nitrogen fertilizer is virtually the same for traditional and modern cultivars.

Effect of land preparation techniques on yield—we conducted an on-station trial, which is a part of the long-term research to study the effect of land preparation techniques, fertilizer application rate, and rice cultivars on upland rice productivity and soil fertility. Factors in the experiment were land preparation techniques (slash-and-mulch and slash-and-burn), fertilizer application (60:30:30 kg/ha N:P₂O₅:K₂O, 30:30:30 kg/ha N:P₂O₅:K₂O, and no fertilizer added), and rice cultivars (B6144F-MR-6 and Laboun). Trial results showed that slash-and-burn plots had about double the yield of slash-and-mulch plots in the first year. Improved variety B6144F-MR-6 yielded 25% higher than local check variety Laboun. Fertilized slash-and-burn plots produced 16% more yield than slash-and-burn plots without fertilizer. Productivity of slash-and-burn and slash-and-mulch plots was no longer significantly different by the second year of the study. B6144F-MR-6 rice grain yield (1.0 t/ha) was still significantly higher than Laboun (0.7 t/ha). Nitrogen fertilizer application had no effect on rice productivity in the second year of cultivation. We conclude that cultivation of improved varieties using slash-and-mulch practices with small amounts of fertilizer increases rice yield and benefits the environment.

Weed management—experiments to determine upland rice yield loss because of weeds in farmers' fields showed no significant difference in grain yield and weed biomass between farmers' plots and the treatment plots, which received one hand weeding in addition to farmers' practice (i.e., farmers' practice + 1 hand weeding). However, plots with additional hand weeding had a slightly higher yield (2.0 t/ha) than farmers' practice plots (1.9 t/ha). We conclude that one hand weeding in addition to farmers' current practice does not increase rice yield significantly. Plots in lower toposequence positions produced more grain whether they were weeded following the farmers' practice or they received an extra weeding.

Weed seed germination and growth—research to study soil weed seedbank and factors affecting seed germination of two troublesome upland weeds, *Digitaria ciliaris* and *Mimosa invisa*, was undertaken in farmers' fields. Soil samples from depths of 0–15 cm at four points each from four 50-meter transects in the fields were obtained to study the weed seedbank in the laboratory.

Results indicate that *M. invisa* did not require light for germination but was stimulated by scarification, suggesting germination inhibition by the seed coat. Seedling emergence of *M. invisa* was 80–94% at depths of 0–2 cm, which decreased progressively with increasing depth. No seedlings emerged from seeds buried at 10 cm. Seed germination of *D. ciliaris* was stimulated by light, although some seeds germinated even in the dark. Seedling emergence for *D. ciliaris* was greatest (98%) for seeds on the soil surface; this also declined with depth, such that no seedlings emerged from a soil depth of 8 cm. We conclude that deep plowing to bury weed seeds below 10 cm from the surface is an effective way to control these weeds.

Effect of rice seed rate on yield—on-farm trials to study the effect of seed rate (3, 6, and 9 seeds per hill with farmers' practice) on upland rice yield showed increased rice yield with increased seed rate. Seed rates 3, 6, and 9 seeds/hill gave rice yield of 1.5, 1.7, and 1.9 t/ha, respectively. Thus, we conclude that increased seed rate with farmers' practice increases rice yield.

Effect of sowing time on yield—experiment to study the effect of sowing time (30 April, 30 May, and 30 June) on two upland rice varieties, Nok (traditional) and IR55423 (improved), showed that sowing in May is optimal in terms of harvested yield. The crop survived and had minimal root aphid and gall midge damage. We observed statistically significant differences in flowering time, spikelet fertility, root aphid and gall midge damage, 1,000-grain weight, and grain yield among sowing dates. We conclude that sowing time significantly affects upland rice yield and planting and that sowing in May is optimal for grain production.

4.2.2.2 Vietnam

Weed management trial—cumulative weed biomass increased linearly during the course of the growth and development of the rice crop. Trial results indicated faster growth of weeds from 30 to 60 days after sowing than from 60 to 90 days after sowing. Result of trials on upland rice yield loss due to weeds showed no significant rice yield difference between plots weeded following the farmers' practice and those that received an additional weeding. We conclude that one additional weeding with farmers' current practice does not increase rice yield.

Soil mulching trial—we conducted trials in Suoi Giang and Nam Bung communes to study the effect of soil- and water-conserving technologies (mulching) on rice yield, soil erosion, and women's drudgery. Results from both communes indicated that incorporation of rice straw mulch cut weed biomass to about half, increased rice yield by 31%, and reduced labor for weeding by 66% compared with the plots without mulch. Suoi Giang glutinous upland rice produced about 0.3 t/ha more grain with a much of *Crotalaria* + other plant species compared to without mulch. Thus, soil mulching (using plant materials and plastic films) keeps higher soil moisture, reduces weed infestation, reduces soil erosion, and increases rice yield on sloping lands. As women mostly do weeding, mulching technologies in rice production can reduce weeding drudgery for women. We conclude that adoption of mulching technologies increases soil moisture, reduces weed infestation, reduces weeding drudgery for women, and increases rice yield.

4.2.3 Conclusions

Lao PDR partners implemented a broad range of crop and field management trials to understand processes and test technologies that move this goal forward. The long-term experiment was notable for shedding light on the trends in rice productivity over time on sloping uplands and the influences that land preparation, varieties, and fertilizer use have on these trends.

Small amounts of fertilizer significantly increase yield but large amounts do not. This is because rains easily wash away fertilizer in poor soil conditions. Therefore, it is not economical to apply large amounts of fertilizer to upland rice.

Traditional cultivars are less fertilizer-responsive than improved rice varieties. Some traditional cultivars produce good yield without chemical fertilizers. Improved rice cultivars are fertilizer-responsive and produce more grain than traditional cultivars when fertilized. This implies a significant cultivar by fertilizer interaction. Fertilizer application decreased weed infestation

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probably because of weed growth inhibition by increased rice growth and earlier rice canopy closure.

Slash-and-burn is an effective way to rapidly convert biomass to ash, give the crop a nutrient boost, and kill weed seeds as long as there is enough biomass to raise soil temperatures. In the subsequent crop season, however, yield differential between land preparation methods disappeared and adding fertilizers did not improve yield. Although the slash-and-burn method yielded higher than the slash-and-mulch method, it is not healthy for the environment.

The literature shows that weeds are a major yield-constraining factor in upland rice in both Lao PDR and Vietnam. In upland rice, weeds grow faster from 30 to 60 days after sowing than from 60 to 90 days after sowing. Hand weeding is a common method of weed control. Farmers use many person-days for weed control. However, trials to quantify rice yield losses due to weeds did not produce clear results. Additional weeding together with the farmers' practice increases rice yield marginally. This is probably because the timing of weeding is important, and perhaps more important than the number of weeding events during the crop season. However, mulching as a technology addresses weed control, moisture conservation, and soil fertility improvement. Mulching cuts weed biomass growth, probably by shading weeds out. Improving rice seedling competitiveness by manipulating seedling density in a hill raises grain yield, possibly through early closure of the crop canopy. Rice planting time significantly affects rice yield; the month of May is the optimum time for rice planting to achieve maximum yield.

Cultivation of improved varieties using slash-and-burn land preparation techniques and small amounts of fertilizer give the highest yield and conserves resources. Soil mulching (using plastic films or plant materials) increases soil moisture, reduces weeds, reduces soil erosion, and increases rice yield. As women mostly do the weeding, mulching technologies in rice production reduce weeding drudgery for them.

4.3 Testing and validating improved rice-based cropping system technologies

4.3.1 Methodology

Evaluation of alternative cropping systems aimed to improve soil fertility, increase rice crop productivity, and raise farm income. We approached these objectives through the cultivation of legumes in the spring season (presummer rice crop), rice and *Stylosanthes* intercropping, rice and maize intercropping, and alternate growing of rice and pigeon pea/stick lac in an upland rotational fallow system. We conducted the cropping system work in Lao PDR through field demonstration trials and aimed to enhance soil nitrogen content and integration of livestock into the rice-based farming system. The Vietnam cropping system work conducted through field trials and experiments aimed to promote and support the goal of farmers who move from a single summer rice crop to at least two crops a year. We laid out experiments as an RCBD with enough treatments and replications. Crop data on tiller number, plant height, grain yield, weed biomass, input use, farmgate price, crop income, etc., were collected. Data were analyzed using appropriate statistical methods and analytical tools.

4.3.2 Results and discussion

4.3.2.1 Lao PDR

Rice-Stylosanthes intercropping—*Stylosanthes* intercropped with rice can increase the rice crop's nitrogen supply and control weeds by limiting light penetration to the soil surface. We conducted an on-station trial to examine the effect of rice-*Stylosanthes* intercropping on rice yield. Treatments were (a) rice only, (b) 75% rice and 25% *Stylosanthes*, (c) 50% rice and 50% *Stylosanthes*, and (d) 25% rice and 75% *Stylosanthes*. Results showed that rice yield of plots with rice-*Stylosanthes* intercropping was higher (1.2 t/ha) than in plots with rice only (0.7 t/ha). One row of *Stylosanthes* planted with three rows of rice produced the highest yield. We conclude that rice-*Stylosanthes* intercropping increases rice yield; one row of *Stylosanthes* and three rows of rice is the optimum combination to obtain high rice yield.

Rice-maize intercropping—Maize intercropped with rice can control weeds and insects and increase resource-use productivity in sloping uplands. We conducted an on-farm trial to compare crop income between rice only and the rice-maize intercropping system. Results showed that rice and maize intercropping gave 28% higher income than the rice-only (\$196/ha) cropping system. We conclude that rice-maize intercropping is a viable option for increasing farm income.

Pigeon pea-sticklac fallow system—sticklac, a secretion by the lac insect and found in pigeon pea trees, is a high-value commodity. A shift from upland rice to pigeon pea cropping improves not only soil fertility but also farm income. We conducted an on-farm trial to examine the effect of sticklac production on farm income. Crop income under rice only, sticklac production without previous experience, and sticklac production with previous experience was compared. We found 12–140% higher income per hectare in sticklac production plots than in rice production plots (\$308/ha). Farmers with experience earned double income than farmers without experience. We conclude that a shift from rice to sticklac cropping systems increases farm income but it requires good access to markets. Farmers' training on sticklac production can further boost crop income.

4.3.2.2 Vietnam

Introduction of legume crops in the spring season—as an alternative to mono-cropped upland rice systems, we introduced legumes (peanut and soybean) in the spring season with an objective to improve soil nitrogen and earn more cash from the sale of pods/grains. The spring legume (peanut and soybean) + summer rice (Luyin 46) cropping system yield (3.7 t/ha) was higher than spring fallow + summer rice (Luyin 46) cropping system yield of 2.2 t/ha. Green manure in the form of crop residues from the legume crop was added to the legume + rice rotation (1.2 kg peanut + 0.24 kg soybean + 1.5 kg fresh *Chromolaena* per square meter) in addition to inorganic fertilizer that was added to both crop rotation systems.

In a separate experiment, we evaluated three promising varieties of soybean (DT12, DT2004, and DT84) and peanut (L14, L23, and L24) that fit into the spring season. Results showed that all three varieties of soybean and peanut fitted into the spring crop season. Short-duration soybean varieties (DT12 and DT2004) were suited for early-sown summer areas. Long-duration DT84 fitted in with late-sown summer rice. All peanut varieties had long growth duration and suited well with late-sown summer rice. We conclude that soybean and peanut in the spring season on sloping lands can increase land productivity and farmer incomes. Short- and long-duration legume crop varieties that fit into the early or late planting of summer rice are available.

4.3.3 Conclusions

Farmers practice spring fallow–summer rice–winter fallow cropping systems in the sloping uplands. Farmers can improve this cropping system by growing legume crops in the spring season as well as rice and nonrice crops intercropped in the summer season. Farmers can grow legume crops (peanut and soybean) in the spring season rather than leaving the land fallow. Growth duration of soybean and peanut varieties evaluated in Vietnam fit into the early- and late-sown summer rice crops. Growing legume crops in the spring season increases farm income and enhances soil nitrogen, which benefits summer rice. Upland rice reaps benefits from residual nutrients, especially nitrogen, from previous legume crops such as soybean and peanut. A similar conclusion is drawn from the improved performance of rice with a *Stylosanthes* intercrop. Both trials showed that legumes cultivated as a relay or as an intercrop with rice are beneficial to rice productivity. However, low soil moisture is a constraint in the production of legumes in the spring season; moisture-conserving technologies are required to obtain economic yield of legume crops in the season.

Results from Lao PDR showed that summer rice can be successfully intercropped with other crops such as *Stylosanthes* and maize. Rice with a *Stylosanthes* intercrop performed better than rice alone. Increased productivity of rice may be because of additional nitrogen fixed by *Stylosanthes*. However, intercropping decreased the total rice grain yield of the whole field since rice was growing on a proportion of the total land area determined by its intercrop ratio with *Stylosanthes*. Research on the introduction of legumes in the spring season and rice-*Stylosanthes* intercropping showed feasibility and benefits of combining rice with legumes in relay or intercrop. Rice-maize intercropping increases land and labor productivity and farm income. A change in cropping pattern from upland rice to stick lac, which is found in pigeon pea trees, increases farm income substantially. Stick lac is a knowledge-intensive high-value cash crop, which requires training of farmers to obtain good yield. Farmers can change from a current mono-crop system to a double-crop system by growing legumes and other cash crops. This not only improves soil condition but also increases farm income substantially. Successful cultivation of cash crops, however, requires good access to markets.

5. Objective 5: to assess the trade-offs in the use of water, labor, and other resources across the landscape as they affect food security and the environment, and to develop community-based strategies for efficient water management

Upstream and downstream communities in a watershed are linked in terms of stock, flow, and use of biophysical and socioeconomic resources. Farmers allocate their labor and limited capital resources between sloping uplands and upland paddies to produce rice and undertake other farm activities. A change in the productivity of resources in one part of the catchment will hence generate some effect (positive or negative) in other parts of the catchment. We assessed the potential trade-offs in the use of biophysical and socioeconomic resources across the landscape using both qualitative and quantitative analyses.

5.1 Methodology

Subsistence farmers try to achieve multiple objectives from their production activities. A rational farmer chooses a set of activities out of all feasible activities subject to a given environment (biophysical and socioeconomic) and farm-level constraints (land, labor, capital, etc.) to maximize his or her objective functions. We developed a whole-farm decision-making model that captures the major interactions between livelihood activities given the resource base of households. We analyzed the resource use trade-offs quantitatively using the farm-household decision-making model and qualitatively using focus group discussions.

We used a mathematical programming approach to develop optimization models for decision making regarding resource allocation to competing enterprises to achieve multiple objectives. We used a mathematical programming approach (linear programming and goal programming) to develop a whole-farm decision-making model. We designed these models to reproduce the behavior of typical households in upper catchments that select a set of farm and off-farm activities to meet their objectives subject to constraints with respect to available factors of production and technical opportunities. The mathematical programming models were analyzed using different software, namely, Excel Solver, LINGO, and General Algebraic Modeling System (GAMS). We also used the causal loop diagram (CLD) method to analyze household decision-making processes.

Linear programming model

We describe the structure of the linear programming problem in a mathematical form as below:

$$\begin{array}{ll}
 \text{Maximize} & \sum_{j=1}^n c_j X_j \\
 \text{Subject to} & \sum_{j=1}^n a_{ij} X_j \leq B_i \quad \text{for all } i = 1, 2, \dots, m \\
 & X_j \geq 0 \quad \text{for all } j = 1, 2, \dots, n
 \end{array}$$

Where X_j are levels of activities (or outputs) j , a_{ij} are input-output coefficients representing the amount of input i required to conduct one unit of activities X_j , B_i are the total amount of resource i available for the farm to use, and c_j are returns per unit of activity X_j .

Figure 5.1 presents the conceptual framework and data requirements of such a model. In a given external farm environment and internal farm-level constraints, the farmer chooses a combination of crop production, livestock production, and off-farm activities that satisfies household food security and maximizes household income, thereby yielding the highest utility. To analyze this, we used a linear programming model for Lao PDR and Vietnam and a goal programming model for Thailand.

Goal programming model

When households confront multiple conflicting objectives, goal programming seeks a compromise solution based on the relative importance of each objective (Taha 1998). We used the weighted goal programming method to represent multiple goals in a single objective function. We describe the structure of the weighted goal programming in a mathematical form as below:

Objective function:

$$\text{Minimize } \sum_{g=1}^5 (W_g d_g^- - W_g d_g^+)$$

Subject to

$$c_{gj} X_j + d_g^- - d_g^+ = e_g$$

$$a_{ij} X_j \leq b_i$$

$$X_j, d_g^-, d_g^+ \geq 0$$

where

d_g^- = the negative deviational variables of g^{th} objective

d_g^+ = the positive deviational variables of g^{th} objective

W_g = the weights of g^{th} objective

X_j = the level of activity j

e_g = the target measure of g^{th} objectives

g = the number of objectives

a_{ij} = technical coefficient (amount of i^{th} input required to produce one unit of j^{th} activity)

b_i = amount of i^{th} resource available

c_{gj} = the coefficients of g^{th} objective

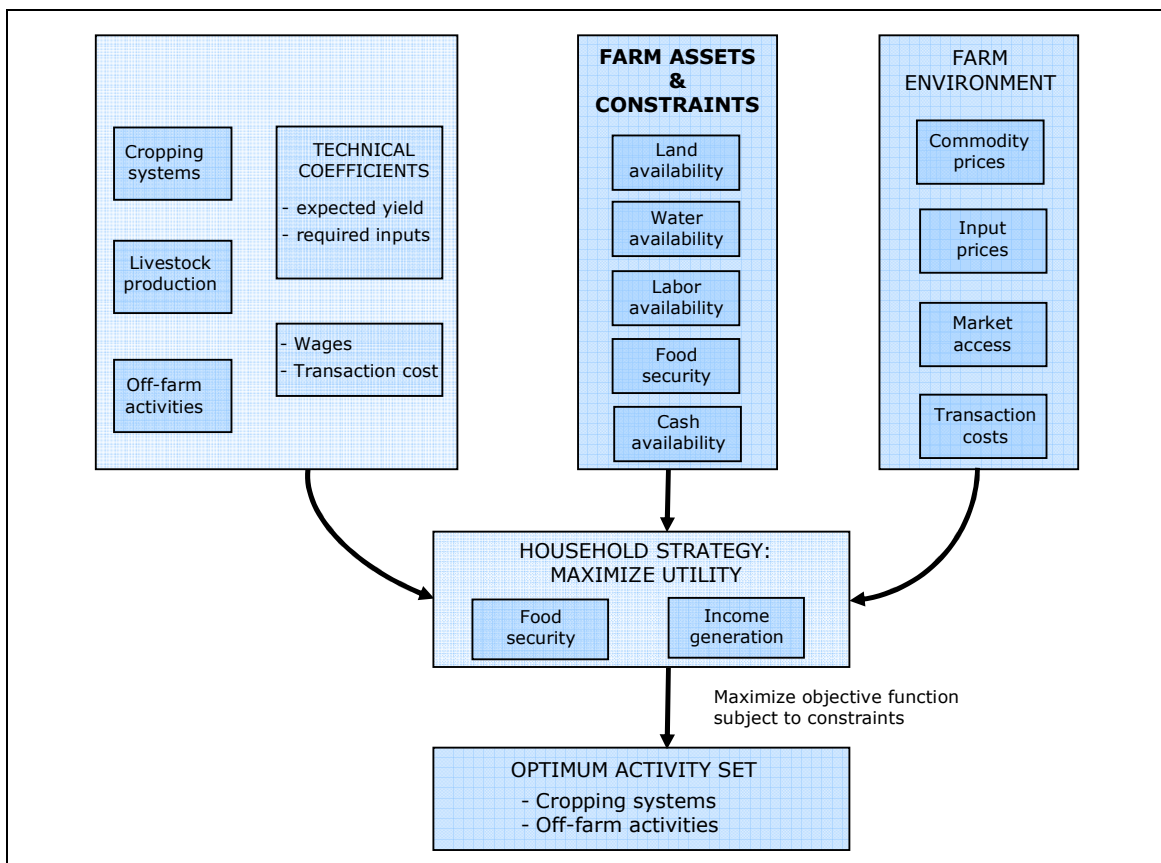


Figure 5.1. Conceptual framework for farm-household decision-making model.

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Causal loop diagram method

A causal loop diagram (CLD) or system diagram is used to describe the conceptual model of the household decision-making process. The CLD helps understand the working of complex systems. We use CLD to describe the decision-making process through causalities between variables and to explain how they form a dynamic circular influence. We use this to show how a change in one factor will affect other factors in the system and may have a feedback loop.

We draw a causal diagram based on sample household survey data and expert information on various relationships. We validated the diagram with farmers through group discussions. The CLD works as follows:

- An arrow links two factors in a system. The arrow shows the direction of the relationship with which a variable or a factor at the tail of the arrow affects the variable at the head of the arrow.
- A plus (+) sign near the arrowhead indicates that the variable at the tail and the head of the arrow changes in the same direction while a minus (-) sign means a change in the opposite direction.
- The letter B in the middle of the loop indicates that the loop is balancing and moves the system in a direction toward equilibrium or fluctuation around the equilibrium point.
- The letter R in the middle of the loop indicates that the loop is a reinforcing behavior in the same direction, causing either a systematic growth or decline.

Household-level resource use interactions

We integrated information collected from baseline surveys, participatory resource mapping, typological work, and targeted surveys on agricultural practices. We then obtained input-output coefficients and farm-level constraints for a typical farm household in the upper catchments. We considered a one-year time horizon, but we further divided the year into subperiods to account for the seasonality of agricultural activities in the model. We defined a set of agroecological zones corresponding to types of land where farmers practice a certain cropping system. We defined water use and food security in terms of constraints. We described each activity by a set of technical coefficients given for each period and cropping system. The coefficients included crop yields; input and output prices; and requirements with respect to labor, cash, and external inputs such as water, fertilizers, seeds, pesticides, etc. We specified a base model with the objective function of maximizing the household income subject to food security and other farm-level constraints. A base optimal farm-household model was developed, calibrated, and validated for a typical farm household. The main outputs of the model were the optimal farm operational plan that satisfies household food security and maximize household income. The impact of technological and policy interventions (rice yield increase, expansion of lowland rice area, expansion of irrigation facilities, market access, etc.) on poverty, food security, and conservation of natural resources was analyzed through simulation of "what-if" scenarios.

Community-level resource use trade-offs across the landscape

We analyzed resource use trade-offs across the landscape by linking outputs of the hydrology model (see objective 1) and the farm-household decision-making model. The working hypothesis was that conversion of upland rotation area to forest increases the base water flow in the watershed substantially. This extra water flow could be used economically in the lowlands for generating additional rice production or production of other crops. Thus, the trade-off analysis was focused on income loss in uplands from conversion of upland rotation area to forest and income gain in lowlands from the use of extra water supply. A second-round effect that was modeled included income gains from a shift from upland rice to the production of cash crops on sloping uplands as household food requirements are increasingly met from lowland rice production.

5.2 Results and discussion

5.2.1 Lao PDR

We discussed optimal land-use patterns and resource allocation decisions of households in upper catchments of Lao PDR based on the information of a typical household in northern Lao PDR. We analyzed the effect of better water access and improved rice-based technologies on two types of farms: largely lowland households and largely upland households. We parameterized the input-

output coefficients of the optimal farm plan of a representative farm and consequently simulated the results for this purpose. We discussed resource use trade-offs based on land-use changes, water flow, and economic activities based on the information collected in the Hom subwatershed in Fai Village, Pak Ou District, Luang Prabang Province. Our trade-off analysis focused on the economic viability of converting upland rotational shifting cultivation area to forest in the upper parts of the watershed. We analyzed this in terms of the effect of increased forest area on base water flow in the streams and the consequent economic value of the increased water flow. Thus, trade-off analysis focused on three factors: (a) economic loss from conversion of upland rotational shifting cultivation area to forest, (b) the amount of additional water available in the watershed, and (c) the total economic gain from the use of additional water.

We analyzed the model using LINGO and GAMS software. We calibrated and validated the base model to ensure the representation of actual farm situations. We ran several simulations to analyze the resource flow interactions between upland and lowland fields. Four important simulations discussed below are (a) the expansion of wet-season paddy area, (b) expansion of dry-season paddy area, (c) increase in paddy rice yield, and (d) improvements in access to markets. We tested the hypotheses that increased productivity of paddy rice, expansion of paddy area, or improved market access substantially reduce the area under upland rice and increase the area under cash crops. Such changes contribute directly and indirectly to improvements in food security, poverty reduction, and environmental protection.

5.2.1.1 Farm-household model development

A “typical” household in Fai Village consists of six family members, with three working adults. The household operates 0.06 ha of irrigated lowland, 0.18 ha of rainfed lowland, 3.66 ha of rotational upland crop area, and 0.42 ha of upland plantation area. The typical household grows both lowland and upland rice. Rice is grown in lowlands in wet and dry seasons. Dry-season rice is grown in irrigated fields during January-May. Wet-season rice, which can be irrigated or rainfed, is grown during June-November.

Upland rice is grown during April-August, mostly as part of a rotation with other upland crops. The first crop in the rotation is typically upland rice, which is grown for 1 year after the land is opened for crop production. Maize, Job’s tear, sesame, and sticklac are other important upland crops grown for 1 year after upland rice. After two consecutive years of cropping, the land is fallowed for 2–3 years. Farmers classify upland fields into two categories, fertile and infertile. On fertile land, farmers grow upland rice and other upland annual crops in rotation. On infertile land, farmers grow plantation crops such as mulberry, fruit trees, rubber, and teak. Table 5.1 presents typical crop rotations in the area.

Table 5.1. Major crop rotations in uplands of Fai Village, Pak Ou District, Luang Prabang Province.

Land type	Land-use activities ^a
Lowland	Wet-season rice (1 June-15 December) Dry-season rice (1 January-30 May)
Fertile upland	Dry-season vegetables (1 January-30 May) Rice-rice-fallow-fallow Rice-maize-fallow-fallow Rice-sesame-fallow-fallow Rice-sticklac-fallow-fallow Rice-JT-fallow-fallow Maize-JT-fallow-fallow Maize-maize-fallow-fallow Sesame-maize-fallow-fallow Sesame-JT-fallow-fallow Sesame-sesame-fallow-fallow Sticklac-maize-fallow-fallow Sticklac-sesame-fallow-fallow Sticklac-JT-fallow-fallow Sticklac-sticklac-fallow-fallow JT-JT-fallow-fallow
Infertile upland	Banana Fruit trees Mulberry Rubber Teak

^aJT = Job’s tear.

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Rice is the staple food crop. Maize, Job's tear, sesame, nontimber forest products, and livestock are cash commodities. A very limited exchange of rice in the market occurs in the study village. The rough rice requirement is estimated to be 350 kg/person/year (WFP 2007). Farmers try to meet their rice needs through their own production. The model permits a limited quantity of rice purchase whenever own-rice production is inadequate. Transfer constraints were specified to permit surplus rice to be carried forward to the next consumption period or sold at a fixed price. Rice sale in the area is very small as most farmers are deficient in rice.

Other activities included were plantations and buying and selling of seasonal labor. Upper limits on these activities built into the model were consistent with current practices of farmers. For perennial crops, the gross margins used were the annuity calculated based on a planning horizon of 10–30 years depending upon the life cycle of crops. Input-output coefficients for these perennial crops were the average values over the growth period. Similarly, input-output coefficients for various crop rotations were the average values for the duration of the crop rotations. We make these simplifications because of the lack of input-output data for each year. A year was divided into six periods (2 months each) for modeling production and consumption, based on farming and labor use activities. Production and consumption activities were specified for each subperiod.

Rice consumption subperiods, which correspond to production subperiods, are related to the chronological order of harvesting of rice grown under different rice ecosystems. Upland rice, normally harvested in September, is the main source of food in the first period (September–October). Wet-season rice is consumed in the next three subperiods (November–April) and dry-season rice is consumed in the other two subperiods (May–August). The analysis of land allocation based on temporal variations in rice demand and supply during these periods is an important feature of the model developed here.

Gross value of production minus cash cost is the gross margin of each farm activity. Cash costs are minimal in most cases. Hence, gross margin closely follows the gross value of production. Physical outputs were converted into value terms using existing market prices, even through some markets are very thin. The sum of all individual gross margins is the total gross margin from the farm. The sum of the total gross margin and any other income such as from nonfarm employment included in the model is the total household income.

A limitation of the model is that livestock production and nonfarm employment are not explicitly included in the optimization model. Information on livestock production was not collected in detail enough to incorporate this in the model. Nonfarm employment in the study village is of very minor importance and hence unlikely to have had any major impact on labor allocation among various farm activities. Income resulting from nonfarm employment was included as a fixed income to calculate total household income. The model thus abstracts from the household labor allocation decisions on these activities, and, in this sense, is partial. However, the model results and the sensitivity analyses conducted do, nevertheless, provide valuable information regarding trade-offs involved in the allocation of resources to cash crops and subsistence crops. The basic structure of the matrix appears in Appendix A.

5.2.1.2 Model results—base run

Table 5.2 presents the optimal solution of the linear programming model. The model output from the base run was compared with the actual value for the production of rice and the total gross margin. The model results are sufficiently close to the current typical farm situation with respect to the major variables such as rice production.

The base-run output indicates that a typical household earns US\$650 annually under the optimal farm plan. We must note that this value includes household initial capital endowment and living expenditure but excludes income from nontimber forest products and livestock. The household optimal income after adjusting these values is \$1,290. This is 36% higher than the household current actual income of \$946. This implies that the household can earn an additional \$340 if the optimal farm plan is followed. Upland area accounts for 86% and lowland area accounts for 14% of the total income in the optimal plan. In the lowland, almost all income is from rice. Rice accounts for 25% while nonrice crops account for 75% of the total upland crop income.

The initial endowment of upland and lowland plays a vital role in household food security and poverty status. Rice can be produced in both uplands and lowlands, but upland rice is harvested earlier (September) and provides food during the “hungry” months (September–October) when the

previous year's food stock is almost exhausted. The "shadow" price of rice during these lean months tends to be high and this encourages farmers to produce upland rice. An alternative strategy would be to use a stored surplus of lowland rice, if any, from the previous cropping year. However, households normally lack this option, as their lowland endowment in the mountainous regions is too small in most cases.

Table 5.2. Optimal solution of the linear programming model, Lao PDR.

Goal and activities	Optimal value
Net cash income (US\$/hh)	650
Crop area (ha/hh)	
Lowland wet-season rice area	0.24
Lowland dry-season rice area	0.06
Rice—sesame—fallow—fallow area	1.18
Rice—sticklac—fallow—fallow area	0.91
Rice—Job's tear—fallow—fallow area	0.48
Sesame—Job's tear—fallow—fallow area	1.09
Plantation crop area	0.43
Rice production (kg/hh)	
Lowland wet-season rice production	600
Lowland dry-season rice production	203
Upland rice production	1,157
Lowland wet-season rice area (ha)	0.24
Lowland dry-season rice area (ha)	0.06

An average 6-member household requires 2,100 kg of rough rice annually based on 350 kg per capita rough rice consumption in Lao PDR (WFP 2007). Of the total requirement, 90% is self-produced and 10% is purchased in the market. Overall, upland rice meets the total rice requirement for 6.5 months, with the balance of rice supply coming from lowland rice and rice purchases. Model results illustrate that upland rice is very important for the food security of upland households as the lowland base is too small to generate an adequate rice supply. As alternative opportunities for generating incomes are limited, households tend not to rely on a market-based strategy to meet household food needs, but to produce as much as possible on the farm.

5.2.1.3 Scenario construction and assumptions

We used the above base model to evaluate the effects of lowland area expansion, lowland rice technology improvement, and improved market access on household resource allocation patterns between uplands and lowlands, food security, and income status of households that have different endowments of upland and lowland fields. The first scenario assumes expansion of lowland rice area in two ways. The wet-season rice area can be expanded by constructing terraces or by expanding the area of dry-season rice. The expansion of dry-season rice area requires the development of irrigation facilities. In both ways, expansion of lowland area increases rice production in lowlands and thereby reduces upland rice area. Another scenario evaluates the effect of improvements in lowland rice technologies by assuming a disembodied technological change. This implies that yield gains result from a general improvement in the productivity of all resources currently being used for rice production. Improvements in rice varieties as well as better management of soil, moisture, and nutrients result in such technological changes. The third scenario assumes lowland rice yield (in both wet season and dry season) growth by 25% inclusive of scenario 2.

In the previous scenarios, we assumed limited market access in which a household can buy only 10% of the rice requirement, sell only 10% of own rice production, and allocate a maximum of 25% of area to cash crops. The fourth scenario has improved access to markets inclusive of scenario 3. The assumption of a fully competitive market in the remote uplands is an extreme one. We assumed an upper limit of 75% on the use of land for commercial production. Similarly, an upper limit of 75% was specified for the purchase of rice for consumption.

A somewhat problematic issue in scenario analyses using linear programming approaches is the incorporation of endogenous changes in prices that may result from different cropping choices. For

example, an increase in area of a crop generates additional supplies, which may dampen market prices. We need to consider this endogenous market response in determining the optimal area allocation. Although such endogenous price responses can be captured in a linear programming framework, estimates of the relevant demand and supply elasticities are not available for the upland area being investigated here. We excluded the endogenous price effects in much of this analysis on the assumption that any such responses resulting from marginal changes in cropping choices are likely to be small.

5.2.1.4 Scenario results and discussion

Results of different scenario analyses appear in Table 5.3. The main objective of scenario analyses was to evaluate the effect of different technological and policy interventions on the direction and magnitude of resource allocations and the consequent impact on income. Therefore, we present values in terms of index values rather than absolute values. Results of the base-run model appear as 100; any scenario value higher than 100 indicates a percentage increase and lower than 100 indicates a percentage decrease. Results of scenario 1 demonstrate that lowland rice production increased by 38% relative to the base case. Lowland rice now meets a larger proportion of household rice needs. This means that part of the land and labor resources formerly tied up in upland rice production is used for growing cash crops that are more profitable. Cash crop income increases by 12% and farm income increases by 13% relative to the base case, assuming that farm-gate prices of cash crops remain constant. The expansion of lowland rice area increases farm income in two ways. First, the income from lowlands increases because of more rice production.

Table 5.3. Optimal land use and household income under different scenarios, Lao PDR, 2010.

Scenario	Index value			
	Production of lowland rice	Production of upland rice	Value of cash crops	Household income
Base case	100	100	100	100
Scenario 1	138	74	112	113
Scenario 2	162	55	120	123
Scenario 3	203	27	132	139
Scenario 4	157	8	184	284

- Base case: farm size (4.3 ha), lowland wet-season area (0.24 ha), and lowland dry-season area (0.06 ha).
- Scenario 1: lowland wet-season area (0.36 ha) and lowland dry-season or irrigated area (0.06 ha).
- Scenario 2: lowland wet-season area (0.36 ha) and lowland dry-season area (0.12 ha).
- Scenario 3: lowland wet-season area (0.36 ha), lowland dry-season area (0.12 ha), and lowland rice yield increases (25%).
- Scenario 4: lowland wet-season area (0.36 ha), lowland dry-season area (0.12 ha), lowland rice yield increases (25%), and improved access to markets (up to 75% of rice, cash crops, and labor supply and demand can be transacted in the market).

Second, the income from uplands increases as more land goes into the production of cash crops. Thus, the model results support the hypothesis that an expansion of lowland rice area results in a reallocation of farm resources toward more cash crop production. Scenario 2 demonstrates a process similar to that of scenario 1. As households obtain more rice from lowlands due to increased rice area in both the wet season and the dry season, rice production in uplands declines further under this resource endowment pattern.

The effect of improved technologies that increase the current yield of upland rice by 25% is examined in scenario 3. Nearly 80% of rice requirements are met from rice production in lowlands and about 10% of rice is purchased in the market under this scenario. Thus, households produce only about 10% of their rice needs in uplands. Food production in uplands is less critical under this scenario. Scenario 3 also demonstrates the “time value” of upland rice and explains why, under poorly functioning rice markets, the production of upland rice is important even for households that may have access to some lowlands. Under the scenario, upland rice is produced mainly to meet the rice requirements during the hungry months when lowland rice, which matures later than upland rice, is yet to be harvested.

Scenario 4 examined the effect of improved access to markets inclusive of scenarios 1–3. Rice production in both lowlands and uplands declined relative to scenario 3 because of a more competitive market to sell and purchase food and cash crops at fixed prices. Households grow rice mostly in lowlands in the wet season. Only a small quantity of rice is grown in uplands, especially to meet rice needs during the hungry months in period 1. Households use a large proportion of

uplands for cash crops. Even in lowlands, households produce cash crops in the dry season. The overall production system is market-oriented. Household income improves significantly. Cash income increased by 84% and farm income increased by 184% relative to the base case. This implies that the impact of expansion of lowland rice area and technological improvements is higher when complemented by improved access to markets.

When rice production in lowlands increases due to area expansion and technological improvements, the area under market-based crops expands and cash income increases. Positive environmental benefits can accrue if this shift favors perennial crops. However, preference toward perennial plants depends upon their resource endowments and relative profitability of crops. Although households derive income from fruit trees and plantation crops, there is generally no private income from protection forests. A compensation mechanism such as a “payment for environmental services” may be needed in such situations to promote perennial crops that generate environmental benefits.

What is the magnitude of income loss for households when the main objective of production is food security as opposed to profit maximization (or subsistence versus commercial production)? We can analyze this by comparing scenario 3 (rice needs are met through own production) and scenario 4 (rice needs are met through own production or purchase in the market depending upon the profitability of rice and substitute crops). In the contrasting scenario (i.e., 3), the market for rice and other crops is nearly fully competitive. As a result, rice production declines in both uplands and lowlands in favor of cash crops. Rice production takes place mainly in the wet season in lowlands. With some supplement from uplands, lowland rice meets 65% of the total consumption requirement and 35% is purchased from the market. Farm income rises by 104% because of this shift in land use from rice to highly remunerative cash crops.

How vulnerable are households if they adopt the market-based strategy as exemplified in scenario 4 relative to the food security strategy of scenario 3? The market-based strategy while raising income can increase the vulnerability of “falling back” into poverty or falling even deeper into poverty. For example, if the gross margin from cash crops were to fall to half of its value relative to scenario 4, households would be barely able to purchase rice because of income shortfalls of nearly 50%. The market price of cash crops can be very volatile and a collapse in price can be disastrous for those whose livelihood strategy is market-oriented. A way of reducing this vulnerability is to provide self-insurance by producing the required food. This is a common strategy practiced by most households in poorly accessible uplands.

5.2.1.5 Trade-off analysis

We examined the economic trade-off involved in converting upland crop rotation area to forest to increase the water supply in the watershed. We used the water balance model and the linear programming model discussed above to examine the resource use trade-off between upstream and downstream in a watershed. The hydrology model produced an amount of water flow in the watershed under different land-use scenarios (see objective 1.2 for details). We used the incremental water flow as an input in the household decision-making model to estimate expansion of paddy area, resource allocation patterns, and household income. We tested the following hypotheses to assess the trade-off:

- An increase in forest area in uplands increases the base water flow substantially.
- Extra water flow can be used economically for early planting in the wet season and for increasing rice area in the dry season.
- The economic gain from the use of increased water flow is substantially higher than the economic loss from conversion of upland rotational crop area to forest. Thus, conversion of upland rotational cultivation area to forest is economically viable at the watershed level.

5.2.1.6 Scenario development and assumptions

The trade-off analysis is based on the information collected in the Hom watershed in Lao PDR. The general characteristics of the Hom watershed appear in Table 1.8. The rotational crop areas (cropped and fallow areas) constitute 82%, paddy areas constitute 1%, and forest and plantation areas occupy 17% of the watershed area of 364 ha. Under the existing land-use conditions, the estimated base water flow at the watershed outlet was 264,300 cubic meters in the wet season (June-November) and 27,500 cubic meters in the dry season (December-May). Based on current estimates of water requirement (Bouman et al 2007), the available water supply can potentially irrigate 22 ha of rice area in the wet season and 1.8 ha in the dry season. We downscaled this

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linearly to the average watershed size (4.3 ha) managed by a household to estimate the potential irrigable area at the household level. This translates into an average irrigable area of 0.26 ha in the wet season and 0.06 ha in the dry season. These values are very close to the actual values of the typical household considered in the economic model.

We conducted trade-off analysis based on the costs and benefits of converting upland crop area to forest. We estimated the costs in terms of income loss when the crop land is set aside for forest. We estimated the benefits in terms of income gain resulting from the use of incremental water flow. There is no real water shortage for irrigation during the wet season, so options for the use of incremental flow occur mainly in the dry season. Therefore, we considered the use of incremental water supply in the dry season only to estimate the economic benefit. Under the scenario of 25% rotational crop area conversion to forest, the base water flow increased by 18% in the wet season and by 37% in the dry season. This means that household access to water in the dry season increased from 320 cubic meters under the base case to 440 cubic meters under the 25% forest conversion scenario. This additional flow of water can be used to expand the dry-season rice area from 0.02 ha to 0.03 ha per household. Although this implies a 50% increase in dry-season rice area, the incremental production will be small in absolute terms as the rice area expands by only 0.01 ha.

5.2.1.7 Results of trade-off analysis

The results of household-level income trade-off involved in setting aside upland rotational crop areas to forests showed that a household incurs an income loss of about \$220 from uplands when 25% of the upland crop rotation area is converted to forest. On the other hand, the household gains an income from expanded area of dry-season rice of only about \$15. Therefore, we can conclude that conversion of upland crop rotation area to forest is not economically viable when we consider the economic value of the incremental water supply in the dry season only and no economic value of forest. Income gain increases when we consider the economic value of forest as well as other environmental services that forest generates. However, some of these benefits are externalities that do not accrue to farmers but to society at large.

We conducted a break-even analysis to examine how much increase in water supply (or increase in rice area) in the dry season is needed to recoup the income loss in uplands under the current assumption. The results showed that a fivefold increase in water supply is needed relative to the base water flow to generate sufficient income from additional rice production to compensate for the income loss in uplands. However, such a large increase in the base flow is unlikely to be realized in these uplands. Thus, this option does not appear to be viable. If water is used for high-value crops (such as vegetable production as against rice production), the economics turns out to be much more favorable.

There are important equity implications if policies are implemented to encourage conversion of upland area to forests to increase downstream water flows. Upland farmers will lose their incomes and livelihoods unless they are compensated for the loss and alternative livelihood options are provided. Programs for providing such compensation in an efficient and equitable way while keeping the transaction costs low have their own challenges, especially in the context of upland areas of Asia.

5.2.2 Vietnam

We discuss resource use interactions and trade-off analysis based on six farm typologies (see objective 2 for details on farm typology). We built a base farm-household model representing each of the typological groups. We obtained technical coefficients for each typology from baseline surveys, a detailed survey on agricultural practices, and focus group discussions conducted at the study sites. We calibrated and validated the base model to reflect the actual farm situations. We ran simulations to analyze the effect of various technological and policy interventions (introducing spring technologies, redistribution of irrigated land, and alternate land-use systems) on resource use and trade-offs between uplands and lowlands. We did not present a detailed analytical framework here for brevity (see Jourdain et al 2010 for model specification).

5.2.2.1 Base run

We calibrated and validated a base farm-household model without spring-season crops (rice and nonrice crops in irrigated areas). We calibrated the model representative of six farm typologies.

The calibration parameters were the off-farm opportunities (in terms of farm labor available) and the minimum percentage of food crops obtained from the farm (i.e., not purchased). We obtained a satisfactory correspondence between simulated and actual farm plans.

5.2.2.2 *Introducing spring technologies*

We introduced new cropping systems in the set of households' possible activities and analyzed their effect on resource use interactions between upland and lowland fields. We analyzed three potential spring-season cropping systems: (a) introduce a summer crop after maize on sloping land, (b) introduce a dry crop in the spring season on rainfed terraces, and (c) introduce an irrigated crop in the spring season on irrigated terraces. We can draw several conclusions based on the results of simulation analysis.

- Farmers can adopt additional spring-season crops on terraces and in paddies. Farmers can grow soybean on upper terraces and irrigated rice in paddies. Labor and capital are not constraints to adopting spring-season cropping systems.
- Where the opportunity cost of labor is high due to off-farm opportunities, rice self-sufficient farmers (i.e., PARI) will not adopt a spring rice crop. However, rice-deficit households are less sensitive to off-farm opportunities and tend to stay with spring rice.
- Farmers with good access to water adopted irrigated rice in Van Chan District. In contrast, the adoption of soybean, a cash crop, is very low partly due to underdeveloped markets for cash crops such as soybean.
- Farmers are less likely to adopt peanut in sloping areas because of a labor constraint.
- Adoption of a spring-season crop in lowlands (terraces and paddies) did not induce significant changes in cropping systems in sloping uplands. Out of six farm typologies, only PARI farmers altered their cropping activities in sloping uplands. This group of farmers reduced continuous maize area and increased long-fallow rotation area mainly due to competition for their small labor supply from irrigated rice.

Overall, the intensification of irrigated areas does not substantially diminish the pressure on sloping land due to a very tight land constraint. Farmers with a small endowment of paddies are still food-deficient and therefore they continue to grow rice in uplands. Farmers with a medium endowment of paddies are self-sufficient in rice, but continue to grow cash crops for market. Only farmers with large paddies but a small labor supply reduce area and increase the fallow period on sloping lands. This is mainly due to a labor shortage during critical periods.

The adoption of spring rice technologies increases revenue for all household types (Table 5.4). However, the income impact is higher for households with large land and water assets (i.e., richer households); the impact is lower on households with lower resource endowments (WS-LS and WS-LR). Spring crop technologies also reduce the relative importance of off-farm activities in household total revenue. The highest impact is for OFFW farms, for which the percentage share of off-farm income in total household income decreases by 40%.

Table 5.4. Impact of spring technologies on household revenue.

Particular	WS-LS	WS-LR	TERUPL	TERLAB	OFFW	PARI
Ranking in revenue per head	1	2	6	3	4	5
Difference in revenue per head	0.73%	1.0%	6.3%	10.7%	11.1%	15.2%
% change in contribution of off-farm income to total revenue	3.6	0.7	5.1	9.7	43.8	9.5

To summarize, farmers are likely to adopt spring-season crops in lowlands (terraces and paddies) when suitable technologies are available. The spring crops have a positive impact on household revenues. However, the impact is higher for households with relatively large paddies, good water access, and a higher labor supply. The development and dissemination of spring rice technologies benefit all household types, but more for those with relatively better resource endowments.

5.2.2.3 *Alternative land use at the micro-catchment level*

In this scenario, we analyzed the impact on farmer incomes of upland set-aside for forest natural re-growth in order to restore watershed functions. Since we do not have information on the impact of forest area on water flows, we made two alternative subscenarios. First, we hypothesized that expansion of forest in the upper part of the catchment will not increase the water supply to expand irrigated area in the lower part of the catchment. Second, we hypothesized that water access to irrigation improved to a certain extent in the lower part of the catchment. We can interpret the

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second subscenario in two ways: (a) the increased area of forest in the upper parts of the catchment increases water flows and more water will be available for irrigation downstream; (b) besides that land set-aside program, new irrigation infrastructure is built that increases the amount of water available for the community. If this infrastructure is paid for with external funds, it can be interpreted as a compensation or reward for the efforts made by the village to restore the watershed ecosystem functions (equivalent to some payment in-kind for ecosystem services at the community level). We modeled these three alternative ways of sloping land set-aside to analyze the trade-off analysis across the landscape: (ALL8) equal proportion (8%), (FIX) equal area of land (0.09 ha/household), and (FPOOR) equal area (0.16 ha/household) only for richer farms.¹

Table 5.5. Impact of sloping land set-aside on farm revenues.

	% Revenue loss			Payment needed to obtain zero revenue loss (US\$/ha/year)		
	ALL8	FIX	FPOOR	ALL8	FIX	FPOOR
OFFW	-1	-2	-4	580	560	590
PARI	-2	-1	-3	440	430	460
TERLAB	-1	-2	-4	580	560	630
TERUPL	-2	-1	-3	420	410	440
WS-LR	-2	-1	0	250	240	-
WS-LS	-20	-21	0	3090	1840	-
Village (aggregate)	-4.4	-4.3	-2.3			

Farm revenues are affected under all three scenarios (Table 5.5). The effect is particularly strong for the poorest households. Because of the high opportunity cost of land for WS-LS farmers, they would need a higher level of compensation to participate in activities in scenarios 2 and 3.

Payments required to compensate for the loss of sloping land are relatively high. However, for WS-LS farmers representing one-third of the population and requiring high levels of compensation, the scenario FPOOR would be more cost-effective (Table 5.6). Excluding WS-LS farms from the set-aside program, other farmers would require an average compensation of \$480/ha/year.

Table 5.6. Cost of compensation per type of farm and for the entire village (US\$/year).

	ALL8	FIX	FPOOR
OFFW	-260	-360	-670
PARI	-1,170	-860	-1,620
TERLAB	-520	-710	-1,420
TERUPL	-870	-600	-1,130
WS-LR	-450	-350	0
WS-LS	-5,950	-6,130	0
<i>Total</i>	<i>-9,190</i>	<i>-8,980</i>	<i>-4,820</i>

In the second simulation scenario, we assumed that the combined effect of increased water flow and/or infrastructure developed permitted the development of new terraces. We analyze the impact of new terrace development under three subscenarios: (a) each household receives an additional 180 m² of upper terraces with summer-season cultivation only (SUM); (b) each household receives an additional 150 m² of upper terraces with irrigation in both the summer and the spring seasons (SUSP); and (c) poor households receive an additional 300 m² of upper terraces with irrigation in both the summer and the spring season (SPOOR). The total area of new terraces available is 2 ha under SUM and 1.6 ha each under SUSP and SPOOR. Overall, we tested nine combinations of set-aside and new irrigated land allocation rules (Table 5.7).

The proposed changes will result in only a small impact on the aggregate village revenues—a maximum positive change of 1.8%. The revenue gain from terrace development is greater than the income loss from sacrifice of sloping land thereby making some efficiency gain. Yet, the tested changes will have important effects on the distribution of revenues among farmers. For all scenarios, changes had important impact on the poorest households (WS-LS and WS-LR). Constrained by land, even minor changes in land allocation has an important impact on poor

¹ For simulation, two groups of farms were considered: the poor households (WS-LS and WS-LR) and the richer households (TERUPL, TERLAB, OFFW, and PARI).

households’ revenues; percentage change in total revenues of WS-LS farm types was as high as 20%.²

Table 5.7. Farm revenue impact of the different scenarios.

	ALL 8	ALL8	ALL8	FIX	FIX	FIX	FPOOR	FPOOR	FPOOR
Group	SUM	SUSP	SPOOR	SUM	SUSP	SPOOR	SUM	SUSP	SPOOR
	Change in revenue (%)								
OFFW	-0.6	-0.3	-1.5	-1.1	-0.9	-2.1	-3.0	-2.7	-3.9
PARI	-1.3	-1.1	-2.0	-0.8	-0.5	-1.5	-2.1	-1.9	-2.8
TERLAB	-0.6	-0.3	-1.3	-1.0	-0.8	-1.8	-2.9	-2.6	-3.7
TERUPL	-1.4	-1.1	-2.0	-0.7	-0.5	-1.4	-2.0	-1.7	-2.6
WS-LR	-0.8	3.5	7.9	0.1	4.3	8.5	3.1	7.3	10.4
WS-LS	11.6	12.5	15.6	8.9	10.0	13.1	15.6	16.2	19.2
Village	0.7	1.5	1.8	0.6	1.5	1.7	0.8	1.6	1.6

A village-level program will be more efficient and equitable than individual financial rewards for setting aside sloping land (ALL8, FIX, and FPOOR). The combination of land set-aside and increase in irrigated land reduces the negative impact (or compensation required to have farmers participate in the scheme), and amplifies the positive effect for poor households. The combination FIX/SPOOR is particularly interesting in that respect (Table 5.8). This is not a true win-win scenario since it requires investment to create an additional area of irrigated land. It would be worth investigating this possibility further, however, through pilot schemes.

Table 5.8. Positive and negative impact on revenues and village revenue impact (US\$/year).

Item	ALL 8	ALL8	ALL8	FIX	FIX	FIX	FPOOR	FPOOR	FPOOR
	SUM	SUSP	SPOOR	SUM	SUSP	SPOOR	SUM	SUSP	SPOOR
Tot. negative	-1,838	-1,264	-2,769	-1,331	-953	-2,457	-3,614	-3,243	-4,763
Tot. positive	3,364	4,488	6,483	2,609	3,988	5,913	5,289	6,517	8,169
Village balance	1,526	3,224	3,714	1,278	3,036	3,455	1,675	3,274	3,406

5.2.3 Thailand

We studied trade-offs between economic, environmental, and social outcomes associated with changes in agricultural production and resource use in the Mae Suk subwatershed. We analyzed the trade-offs in both qualitative and quantitative terms. We used focus group discussion (FGD) as a tool for qualitative analysis of trade-offs and causal loop diagram (CLD) and goal programming method as tools for quantitative analysis of trade-offs.

We used FGD for qualitative assessment of trade-offs between economic, social, and environmental outcomes. We solicited information from upland and lowland communities on the following issues: (a) main agricultural production activities, objectives of engaging in these activities, and the relative importance of each activity in farmers’ livelihood. This information helps to determine the key factors of farmers’ decisions on land use. (b) Availability of natural resources and relative importance of natural resources in farmers’ livelihoods to see whether farmers are aware of environmental protection. (c) Changes in natural resources in quantity and quality terms, reasons for changes, and impact of changes on livelihoods and agricultural production. (d) Finally, farmers’ strategies to reduce the negative impact of degradation of natural resources.

5.2.3.1 Use of natural resources in the Mae Suk subwatershed

Lowland communities—glutinous rice, maize, pigeon pea, and shallots are the four most important crops of lowland farmers ranked from first to fourth, respectively. Nonglutinous rice, garlic,

² Changes in cash revenues not shown here are even more important and reached more than 50% of the changes for WS-LS farmers.

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cabbage, pumpkin, beans, cucumber, and livestock are other relatively less important commodities in lowlands. Farmers grow glutinous rice as a subsistence crop for household consumption. Farmers grow maize, pigeon pea, and shallot as cash crops for the market. Results revealed that food security is the most important factor in farmers' decisions on which crops to grow.

Upland communities—rice (upland and paddy), maize, vegetables (cabbage, shallot, chili, and others), small animals (chicken and pigs), and cattle are important crops and animals produced by upland farmers. Rice ranks first in importance and is followed by chili and small animals. Maize is the third most important crop in farmers' lexicographic ordering; farmers use maize as feed for pigs and chickens. Commercial vegetable and cattle production ranked relatively less important. Results showed that food security is the main concern of the upland community. The high priority for all subsistence crops indicates that food security concern is greater for upland communities than for lowland communities.

Changes in natural resources in Mae Suk subwatershed—both upland and lowland communities reported a decrease in all natural resources (i.e., land, forest, and water) in both quantity and quality (Table 5.9). Farmers reported fast and strong water flow causing flashfloods in the rainy season but a decline in water flow in the dry season. Farmers cited deforestation arising from the increase in population and expansion of agricultural land into the forest as the main cause of changes in water quantity in the watershed. No farmers reported a decline in quantity of water due to an increase in water demand for commercial crops in the dry season. Upland farmers reported the highest impact of changes in water quality on their livelihoods, while lowland farmers ranked this in third place. In terms of water quality, both upland and lowland communities reported increases in water pollution. Lowland farmers reported that an increased use of pesticides for commercial crops upstream made water nondrinkable. Upland farmers cited washing activities and cow dung as the main factors reducing water quality. The livelihood impact of reduced water quality is likely to be more for lowland communities than for upland communities.

Farmers perceived that soil fertility has declined in both lowlands and uplands. Upland farmers reported that the shorter fallow period from 7–8 years about 20 years ago to 4–5 years now is due to limited land. Both upland and lowland farmers reported a decline in forest area and biodiversity over time. The decline in forest area affected livelihoods through increased flashfloods and decreased availability of nontimber forest products.

Table 5.9. Changes in natural resources and rank of their impact on farmers' livelihood from largest to smallest impact (1 refers to largest impact).

Resources	Changes	Rank	
		Lowland	Upland
1. Water			
- water quantity	Decrease during dry season but flooding during rainy season	3	1
- water quality	Increase in chemical contamination	4	6
2. Soil			
- soil fertility	Soil fertility depletion, declining yields	1	2
- soil erosion	Soil erosion increases	6	5
3. Forest			
- forest area	Deforestation due to increases in population and demand for agricultural land	2	3
- diversity	Loss of diversity, wild animals decrease, natural forest products decrease	5	4

Overall, subsistence crops rank first, followed by cash crops in the lexicographic ordering of commodities in terms of their importance to livelihoods. This implies that food security is the main concern of both upland and lowland communities. Nevertheless, farmers are also concerned about the environmental and health impacts of intensive land and water use for commercial production. We used these factors as the basis for trade-off analysis discussed in the next section.

5.2.3.2 Qualitative analysis of resource use trade-off

In this section, we discuss trade-off in terms of resource use and consequent outcomes qualitatively based on results from group discussion. We discussed the outcomes in terms of economic (cash income and food security), environment (deforestation, water quantity and quality, and soil fertility and soil erosion), and social (health problems from pesticide use).

Trade-off between food security and soil degradation (soil fertility depletion and soil erosion) associated with the change in upland rice production system

Upland rice production under a long rotational forest fallow shifting cultivation system is the original livelihood of Karen farmers. In the early 1990s, farmers practiced 7–8 years of forest fallow to avoid soil fertility depletion and weed infestation. Population growth increased the pressure for intensification and the fallow period dropped to 3–5 years. This process has contributed to increased soil erosion and decreased soil fertility. The decreased fallow period reduced rice yield by 20–30%. Farmers with enough cash apply chemical fertilizers to compensate for soil fertility depletion.

Trade-off between cash income and deforestation as well as soil erosion in the upland areas associated with the increase of cabbage production in the community level

Population pressure and market opportunities for cash crops forced farmers to expand agricultural land to forest areas or to use land more intensively for cash crop production. Land-use changes show that field crop area in the watershed increased from 7% in 1984 to 20% in 1996 (Table 1.3). Cabbage is the most important crop in upper catchments grown 2–3 times a year. Farmers produce cabbage in permanent fields (no fallow system) on steep slopes without soil conservation practices. The expansion of cash crops augmented farm income but at the cost of soil erosion.

Trade-off between cash income and health impact from pesticide use associated with cash crop production (shallot and cabbage)

Farmers have increased the use of pesticides in vegetable crops over time. In the lowland, farmers spray pesticides 2–3 times in a crop season. As crop fields are near the village, pesticide application, which occurs around the same time in the whole village, affects not only the sprayer but also other villagers by air pollution. Farmers are aware of the problem; there were reports of finding chemicals in the blood during lab tests, but they reported that there is no other choice for cash crop production. However, only 7.5% of the sampled farmers reported illness from agricultural chemical use; farmers spent only around 8% of net profit from shallot for all health services. Farmers also mentioned pesticide residues in water from streams, making it nondrinkable. In uplands, farmers reported health problems after pesticide application; the most important symptoms were headache, dizziness, weakness, and skin allergy. However, only 7.5% of the sampled farmers reported illness from agricultural chemical use; they use only about 5% of the profit from cabbage production for overall health services. Farmers lack knowledge about safe pesticide use. Thus, expansion of commercial crops increased income but at the cost of increased chemical use and consequent health problems.

Trade-off between cash income and tension regarding water use in the Mae Suk subwatershed associated with commercial crop production in the dry season

Shallot is the most important cash crop in both uplands and lowlands. Farmers grow it in the dry season after harvesting wet-season rice. Higher demand for water in the dry season resulted in tension within upland communities (Hmong and Karen) as well as between upland and lowland communities. Bandenoch (2006) stated that the conflict over water use in the Mae Suk subwatershed is more pronounced as dry-season cropping opportunities have increased with increased market demand for shallot.

5.2.3.3 *Quantitative analysis of resource use trade-off*

We developed a multiobjective farm household decision-making model to capture interactions between the resource base and livelihood strategies of households. We classified households into three groups based on ethnicity, farming practices, and market orientation: (a) the lowland paddy farming-based Thai ethnic group, (b) the upland semi-subsistence farming-based Karen ethnic group, and (c) the upland intensive commercial farming-based Hmong ethnic group. For lowland Thai farmers, resource use decisions are mainly concerned with various enterprises within lowland fields as opposed to upland and lowland fields. We used a goal programming method to analyze the decision-making process of Karen and Hmong farmers.

5.2.3.3.1 *Weighted goal programming method*

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We developed a weighted goal programming model for the Karen and Hmong ethnic groups to determine an optimal land use and plan and analyze resource use trade-offs among alternative activities. We describe economic and environmental objectives of the model below.

Economic objectives—the first subobjective was to maximize income over cash cost, which we calculate as gross production value less cash costs. The maximization of income over cash cost is determined as the target value (e_1) and the negative deviation (d^-_1) from the target value is minimized. The second subobjective was to produce sufficient rice for household consumption. We used this objective only in the model of semi-subsistence farming (Karen) as upland rice is not grown in commercial farming (Hmong). The amount of rice required per family is determined as the target value (e_2) and the negative deviation (d^-_2) is minimized.

Environmental objectives—the first subobjective was to minimize the environmental impact of water use in agriculture. The positive deviation (d^+_3) from the target level of water use is minimized in choosing cropping options. The second subobjective is to minimize the environmental impact of pesticide and insecticide use measured in terms of expenditure. The positive deviation (d^+_4) from the target level of expenditure on plant protection chemicals is minimized. The third subobjective is to minimize the impact of crop production on soil fertility. Soil infertility was proxied by the amount of fertilizer used to produce a given yield. The positive deviation (d^+_5) from the target level of cost of fertilizer used to improve soil fertility is minimized. We weighted economic and environmental objectives as well as subobjectives under each of the objectives equally.

In order to build a mathematical model at the household level, more data about input-output coefficients of all crops grown in the two upland communities are required. In the Karen communities, we interviewed the same samples as in the first survey for additional data required for modeling. For the Hmong communities, we selected 39 households from two villages, namely, 15 samples from South Pui Village and 24 samples from North Pui Village. Results of qualitative trade-off analysis discussed above showed that economic and environmental outcomes are associated with the land use for farm activities. Hence, we built a household decision-making model for land-use optimization for multiple economic and environmental objectives.

Model activities

Farming activities—these consist of cultivation of cabbage, potato, tomato, maize, and paddy rice during the wet season, and cabbage and shallot during the dry season. Farmers can grow two crops of cabbage, potato, and tomato in the rainy season.

Labor activities—farmers use both family and hired labor for farming. We use the same wage rate for family and hired labor to avoid a problem of labor allocation bias.

Model constraints

Land—we use average area of owned land as the upper limit of land available for cultivation. Further, we classified land by wet and dry seasons. We considered existing cultivated area per family in the dry season as the maximum land available for cultivation during the dry season, due to the constraint of water availability.

Labor—we considered the average number of workers per family as the upper limit of family labor supply. We put family labor in person-day units equally for each month. We assumed that hired labor is available as needed.

Credit and savings—the Bank of Agriculture and Agricultural Cooperatives provide a credit limit of 200,000 per family. Similarly, farmers can borrow up to 20,000 from the village development fund. Hence, we consider 220,000 as the upper limit for borrowing. The credit is available only at the beginning of the agricultural year. In addition, we included the average savings per family in the capital available for investment.

Crop balance—farmers have different options to use their produce for sale, consumption, and storage. We applied an average yield per hectare for each crop in the model.

Cash balance—we determined cash inflow based on the cash from selling farm products, credit, and savings. We determined cash outflow based on crop production costs, hired labor, and credit repayment. In the model, we constrained cash outflow to be less than cash inflow.

The model results

The results of the goal programming model indicated that current land-use practices are not optimal for both Hmong and Karen communities; farmers can maximize both economic and environmental benefits through better land-use practices. The results of a multiobjective optimal land-use plan suggested that Hmong communities could achieve better economic and environmental outcomes by increasing the area under tomato and maize in the first crop of the rainy season, increasing potato and tomato area in the second crop of the rainy season, and growing no crops in the dry season. The net profit from the multiobjective optimal plan is more than twice the profit resulting from the current land-use practices (Table 5.10).

Table 5.10. Farming activities and household income under current practices and under single-objective and multiple-objectives programming models of Hmong and Karen households.

Land-use activities	Hmong community			Karen community		
	Optimal plan			Optimal plan		
	Current practice	Single objective	Multiple objectives	Current practice	Single objective	Multiple objectives
Rainy season (May–Nov)						
First crop						
Potato	0.3	4.4	–	0.3	4.1	–
Tomato	1.3	0.2	3.8	0.2	–	3.4
Maize	0.5	–	0.7	0.4	0.5	0.9
Paddy rice	0.6	2.1	–	6.3	6.5	4.1
Cabbage	5.4	–	–	0.5	–	–
Chinese cabbage	0.2	4.5	–	0.3	–	–
Second crop						
Potato	0.8	12.3	3.8	0.2	8.9	3.9
Tomato	0.3	–	7.3	0.1	–	4.3
Cabbage	1	2.9	–	0.1	–	–
Chinese cabbage	0.1	–	–	0.2	1	–
Dry season (Jan–Apr)						
Shallot	3.9	10.3	–	1.5	4.1	–
Cabbage	0.2	–	–	0.1	–	–
Chinese cabbage	0.1	–	–	0.1	1	–
Income over cash cost (US\$/household/year)						
	3,074	14,652	7,455	1,394	9,919	6,363

For Karen communities, the results of a multiobjective optimal land-use plan suggested that economic and environmental benefits could be improved by increasing tomato and maize area but decreasing rice area in the first crop of the rainy season, increasing potato and tomato area in the second crop of the rainy season, and growing no crop in the dry season. The net profit from the multiobjective optimal land-use plan is almost five times higher than that from the current land-use practices. Overall, results suggested that opportunities exist for achieving higher incomes and better environmental effects through suitable modifications of the cropping plan. Results suggested a reduced production of cabbage and shallot that require high chemical input. We found tomato to be the most preferred crop in terms of economic and environmental impacts. Under the optimal plan, agricultural income is 96% lower for Hmong and 56% lower for Karen when we consider both economic and environmental objectives as opposed to only one objective of profit maximization. This indicates a strong trade-off between economic and environmental outcomes. Income under the optimal plan with both economic and environmental objectives is still higher than under the existing land-use practices. Therefore, promoting the optimal land-use plan suggested by the model benefits both the individual and community levels. However, it is worth noting that we developed the model with unlimited market access for selling crops. We should evaluate the model with some reasonable limit on market size for its practical application.

Overall, results showed that current land-use practices of Hmong and Karen farmers are not optimal. A change in cropping practices could increase economic benefits. There are, however,

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strong trade-offs between economic and environmental objectives although some crop choices can generate a win-win situation on both counts.

5.3 Conclusions

Rice-based extensive to semi-intensive farming systems dominate in the sloping uplands of Lao PDR and Vietnam, while a cash crop-based intensive farming system is dominant in the sloping uplands of northern Thailand. In subsistence-oriented production systems of Lao PDR and Vietnam, initial endowment of upland and lowland holdings plays a vital role in household food security and poverty status. Households meet their rice needs through own production; less than 10% of rice consumption is traded in the market. Upland rice meets the total rice requirements for 6.5 months, with the balance of the rice supply coming from lowland rice and rice purchases. Model results illustrate that upland rice is very important for food security of upland households as the lowland base is too small to generate an adequate rice supply. As alternative opportunities for generating income are limited, a market-based strategy to meet household food needs is simply untenable. However, in the market-oriented production system of Thailand, the role of rice, particularly upland rice, in household livelihoods is much less. Lowland rice and rice purchased from the market satisfy the major chunk of household rice needs. Well-functioning competitive markets and access to support services play a vital role in enhancing household food security and reducing poverty.

The mathematical model results showed that sloping upland accounts for more than two-thirds of household income. Farmers' current cropping practices are not optimal. Other alternative cropping options can generate higher income but success depends on many factors, including the efficiency and reliability of marketing systems. Results of scenario analysis showed that an increase in expansion of lowland rice area (i.e., better access to water) reallocates resources toward cash crops by relaxing the food security constraint. In effect, household food security and income can both be improved substantially.

The upstream and downstream communities in upper catchments are tightly linked in terms of stock, flow, and use of natural and people-created resources. Interventions in one community affect, directly or indirectly, the other community. We conducted trade-off analysis based on the costs and benefits of converting upland crop area to forest. Conversion of upland crop area to forest has negative equity consequences. Many upstream households that are poor and food-insecure do not own lowland. They will lose their income and livelihoods from such conversions unless alternative opportunities are provided to them.

The qualitative assessment of trade-offs in a commercialized agricultural production system in northern Thailand showed that a shift from a subsistence-oriented to market-oriented production system increased farm income and food security, but also adversely affected the environment, human health, and social relationships. This implies a strong trade-off between income growth and environmental effects. These trade-offs should be considered and options to minimize them are needed for promoting upland development while protecting the environment.

6. Objective 6: to develop promising strategies that integrate both improved farming technologies and institutional arrangements for the use of water at pilot test sites and to monitor their impact.

The ultimate goal of the project was to reduce food insecurity, raise farmers' income, and reduce environmental degradation in upper catchments. In this endeavor, the project identified, validated, and disseminated several promising rice varieties, cropping system management, and water management technologies. It followed several innovative technological, managerial, and institutional approaches to generate maximum impact. This section discusses the project impacts and institutional models for technology development and dissemination under two activities: (a) the economic, social, and environmental impact of improved farming technologies and water management regimes at the household and catchment levels; (b) translating the research outputs from pilot sites into generalizable principles, models, and approaches for extrapolation and scaling up.

6.1 Assess the economic, social, and environmental impact of improved farming technologies and water management regimes at the household and catchment levels.

6.1.1 Methodology

Assessment of realized impact of a project within its short life cycle of 4 years is not meaningful. Technologies developed and validated in the project need to be widely disseminated and this process typically requires several years after the project is completed. Given this, an "impact pathway" framework is the appropriate framework for judging the likely impact of agricultural projects of this kind in an ex ante sense. Such a framework permits the identification of progress along the impact pathway from inputs to outputs to outcomes. The final stage of this pathway is impact. Here, the approach taken is to assess the project achievements in terms of outputs and outcomes.

The project produced a large number of validated technologies suited to different agroecologies of the upland landscape (long fallow slash-and-burn in uplands, short fallow slash-and-fallow in uplands, paddies in lowlands, etc.) and farmers' socioeconomic conditions. For the ease of discussion, we classified these technologies based on land type and technological group. Land-type basis classifies technologies into two groups: (a) for sloping upland and (b) for upland paddies (valley bottoms and terraces). Technology basis classifies technologies into three groups: (a) rice variety, (b) rice-based cropping system management, and (c) water management. We present technology development and dissemination results on this basis. Detailed characteristics of these technologies were discussed in objectives 3 and 4.

We used field experiments, baseline surveys, adoption and impact study surveys, key informants surveys, and focus group discussions to collect necessary information on adoption and farm-level effects of the technologies validated and disseminated. We analyzed and presented data in cross-tabular, graphical, descriptive statistics, and mathematical modeling forms.

6.1.2 Results and discussion

The major technology products, initial outcomes, and potential impacts for Lao PDR and Vietnam are discussed below. Table 6.1 summarizes the total number of validated technologies and Table 6.2 summarizes rice seed distribution in Lao PDR and Vietnam. The characteristics and extrapolation domain of each of the validated technology are presented in Appendix B and Appendix C.

Table 6.1. Number of validated technologies in uplands and lowlands, Lao PDR and Vietnam.

Country	Upland			Total	Lowland			Total
	Rice varieties	Crop management	Cropping system		Rice varieties	Crop/water management	Cropping system	
Lao PDR	18	6	3	27	12	8	1	21
Vietnam	11	2	4	17	16	8	5	29
Both	29	8	7	44	28	16	6	50

Table 6.2. Seed distribution of upland and lowland rice varieties, Lao PDR and Vietnam.

Country	Upland rice			Lowland rice		
	No. of varieties	No. of farmers	Seed quantity (t)	No. of varieties	No. of farmers	Seed quantity (t)
Lao PDR	18	701	14.7	10	1,333	28.3
Vietnam	10	45	0.4	11	2,799	23.3
Both	28	746	15.1	21	4,132	51.6

6.1.2.1 Lao PDR

The project validated 27 upland rice system-based technologies in Lao PDR (Table 6.1). Of these technologies, 67% were higher yielding upland rice varieties, 22% were upland rice crop management, and 11% were upland rice-based cropping systems. Similarly, the project validated 21 lowland rice system-based technologies. Of these technologies, 57% were higher yielding lowland rice varieties, 38% lowland rice crop management, and 5% lowland rice-based cropping systems.

The project took a major initiative from its early stage to translate these technology products into “outcomes” by promoting the dissemination of validated technologies. The project distributed more than 43 tons of seeds of upland and lowland rice varieties to more than 2,000 farmers in three provinces of northern Lao PDR. This distribution was done directly or indirectly through extension agencies and NGOs for self-testing and for potential farmer-farmer dissemination for multiplicative effects (Table 6.2). The project distributed about 15 tons of seeds of 18 upland rice varieties to 700 farmers residing at research sites, in adjoining villages, and in villages in neighboring districts and provinces. The project similarly distributed more than 28 tons of seeds of 10 lowland rice varieties to more than 1,300 farmers residing at the research sites, in adjoining villages, and in villages in other districts and provinces. These seed quantities, however, do not include a large quantity of seeds disseminated through farmer-farmer means.

The project validated and disseminated 48 different technologies, including improved rice varieties as well as crop and resource management technologies suitable for upland and lowland agroecologies. These technologies are suited to poor farmers with low purchasing power. The results of an initial assessment of adoption showed that one-third of the validated upland rice varieties and half of the validated lowland rice varieties are becoming popular among farmers at research sites. Many farmers continued growing rice varieties such as Non, IR6080-46A, TDK1, and TDK 6 during 2006-08. The validated rice varieties have a yield advantage of 200–1,400 kg/ha over traditional ones. This level of yield gain is sufficient to provide food for an additional 1–2 months for an average upland family of six members. As adoption increases over time, the additional food production can meet the food needs for an additional 4–5 months (Figure 6.1). The expected increase in rice production in the entire northern region through the adoption of these validated improved rice varieties is estimated to be 4% within the next few years and 22% in 8–10 years from now. Thus, the project has the potential to contribute to a substantial improvement in food security.

In addition to reducing the number of hungry months, the project technologies also have the potential to raise farm incomes by releasing land and labor for the production of marketable crops. The farm household analysis showed that a 25% increase in current rice yield of lowland rice (2.5 t/ha in the wet season and 3.5 t/ha in the dry season) raises the income of a typical upland household by 16% (see objective 5 for details). This income growth is even higher when the yield of upland rice also increases simultaneously. Thus, the validated technologies have the potential to increase income of an average upland household by 15–20% and contribute substantially to poverty reduction. Cropping systems and improved water management technologies will likely further augment this potential through technological complementarities.

The project has established a multi-institutional platform for the exchange of technologies and information within and across the border. The platform thus established a strong foundation for impact not only from the technologies validated currently but also from development, exchange, and dissemination of technologies in the future. In addition, this platform has helped foster “south-south” collaboration among partner countries in the region.

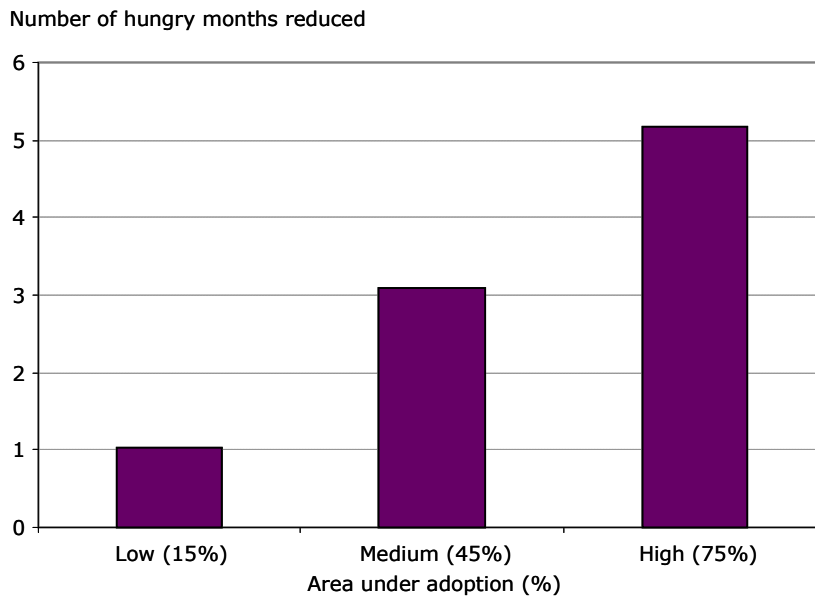


Figure 6.1. Number of hungry months expected to decrease through adoption of validated improved rice varieties, Lao PDR.

Other aspects of impact include a strong emphasis of the project on capacity building of NARES and of farmers. Large numbers of farmers' training activities, farmer field days, and farmer exchange visits were organized across research sites. Farmers and extension workers were provided with fact sheets on technologies and hands-on training on seed production. Information on technologies was disseminated through various means, including leaflets and brochures in local languages and English.

The project trained 206 NARES staff members on agricultural research and development activities. These training programs included both in-country and regional training. The specific topics and design of the training program were based on the needs identified by the NARES collaborators. Some 180 farmers learned about improved agricultural technologies through participation in various field visits and exchange visits. In addition, the project prepared and distributed more than 2,200 fact sheets about improved technologies. These training and capacity-building endeavors of the project will result in a positive social, economic, and environment impact on farmers' livelihoods.

6.1.2.2 Vietnam

The project validated 17 upland rice system-based technologies in Vietnam (Table 6.1). Of these technologies, 65% were higher yielding upland rice varieties, 12% were technologies for improved management of upland rice, and 23% were upland rice-based cropping systems. Similarly, the project validated 29 lowland rice-based technologies. Of these technologies, 55% were higher yielding upland paddy rice varieties, 28% were technologies for improved management of upland paddies, and 17% were upland paddy rice-based cropping systems.

The project distributed about 24 tons of seeds of 21 upland and lowland rice varieties to almost 3,000 farmers in northern Vietnam either directly or indirectly through extension agencies and NGOs, for self-testing and potential farmer-farmer dissemination for a multiplicative effect (Table 6.2). These seed quantities, however, do not include a large quantity of seed disseminated through farmer-farmer means.

The project validated and disseminated 46 different rice system-based technologies related to improved rice varieties, rice crop management, rice-based cropping systems, and water management suitable for upland and lowland agroecologies of northern Vietnam. These technologies are suited to the taste and preference as well as resource endowments of poor local farmers. The results of an initial rapid assessment study showed that over 40% of validated upland rice varieties and over 60% of validated lowland rice varieties are becoming popular among

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farmers at research sites. The validated rice varieties have a yield advantage of 200–1,500 kg/ha over the traditional ones.

The project tested water-saving technologies such as saturated soil culture with plastic mulch and vegetal mulch, alternate wetting and drying, and aerobic rice varieties. Results showed that these technologies are economically viable and can save 15–20% of irrigation water. In irrigated rice fields, adoption of such water-saving technologies can increase rice production by expanding the dry-season rice area even with the existing water supply.

Similar to Lao PDR, the project has established a multi-institutional platform for the exchange of technologies and information within and across the border. The platform thus established a strong foundation for impact from current as well as future technologies.

In terms of capacity building, the project trained 114 NARES collaborators on agricultural research and development activities. These training programs included both in-country and regional training. Some 174 farmers were trained on improved rice varieties, crop management practices, water-saving technologies, and rice seed production. In addition, 327 farmers learned about improved rice varieties and crop management technologies through farmer field days and farmer exchange visits. Furthermore, the project prepared and distributed nearly 3,700 fact sheets to farmers and extension workers on different technologies. These training and capacity-building endeavors of the project will result in long-term positive social, economic, and environmental impacts on farmers' livelihoods.

6.2 Translate the research outputs from pilot sites into generalizable principles, models, and approaches for extrapolation and scaling up.

The project produced a number of international public goods that will have impact beyond the project sites and the project life. These include tools and structured formats developed and used to collect farm household data, collected data, validated technologies, knowledge of improved technologies, hydrology model, and approach to linking the hydrology model with an economic decision model for an economic assessment of the trade-off involved in resource use across the landscape. In addition, the institutional analysis of irrigation systems, the framework for multi-institutional partnerships, and the community-based approach to seed production and distribution could be applied to other locations as well.

6.2.1 Tools and methodology

The project developed several semi-structured and structured questionnaires and pro forma items for farm household surveys and the collection of village-level basic information. Such data collection instruments include questionnaires for baseline surveys, questionnaires for water institution surveys, questionnaires for farm household model surveys, pro forma focus group discussions, pro forma historical analysis of land-use changes, pro forma qualitative trade-off analysis, and pro forma participatory rural appraisal.

The project collected a large number of data sets, including field experiment, climate, field hydrology, and farm household characteristics. Likewise, the project collected numerous data on rice and nonrice crop production, basic characteristics of villages and provinces, and local irrigation schemes.

In Lao PDR, we developed a watershed hydrology model that shows the relationship between land use and water flows in the catchment. The model was developed using intensive data on land uses, soil properties, subsurface hydraulic properties, climate, topography, and stream flows collected during 2007 and 2008. It provides useful information on the effects of land-use changes on water flow in the watershed.

In all three countries, we developed a farm-household decision-making model to understand household resource allocations among different enterprises. We constructed the model using wide-ranging biophysical and socioeconomic data. The model is useful for determining the optimal allocation of resources of smallholder farmers that maximize household income after satisfying household food security. It is a powerful tool for analyzing the effect of rice technological development and other farming interventions on household livelihoods.

In Lao PDR, we developed a hydroeconomic model by combining a hydrology model and an economic model. This model was used to analyze resource use trade-off between uplands and

lowlands. The water flow input from the hydrology model served as an input in the economic model. This model helped quantify income losses from land-use changes in uplands and income gains from lowlands from the use of incremental water flow. This is a powerful tool not only for combining biophysical and economic data for policy analysis but also for exploring the viability of ways of compensating upland dwellers for their production of environmental services.

The participatory approach promoted uptake of the tested technologies. It comprised multilevel stakeholder (farmers, extension workers, and local authorities) participation from the beginning (site selection) to the implementation and evaluation of the technologies. Endorsement and cooperation from district and provincial authorities were pivotal in enabling extension workers to obtain adequate resources for disseminating rice varieties, recommended cropping systems, and component technologies.

The project started with a multi-institutional framework in Lao PDR, which involved international agricultural research centers, advanced research institutes, national agricultural research and extension systems, including nonproject countries, for example, YAAS, provincial and district extension agencies, IRRI-led consortium CURE and research project, and other projects working on upland research and development in the country. This framework later included NOMAFSI in Vietnam. This platform initiated linkage and fostered collaboration, especially, between NAFReC of Lao PDR, NOMAFSI of Vietnam, and YAAS of China. The platform thus established provides a strong foundation for impact not only from the technologies validated currently but also from the development, exchange, and dissemination of technologies in the future. In addition, this platform has helped foster south-south collaboration among partner countries in the region.

The project developed the concept of multiple pathways for the dissemination of project-validated technologies. The dissemination collaborators included government extension agencies (at provincial, district, and service center levels) other development projects, NGOs both local and international, and farmers primarily to exploit the potential farmer-to-farmer dissemination of technologies.

Quality seed is the most important input of production but its availability is very poor in developing countries. The problem is more severe in remote upland areas where production as well as marketing infrastructure and institutions are weak. The project started a village-based farmer participatory seed production program under the technical supervision of national collaborators. Participating farmers were trained on scientific aspects of seed production. This program has helped improve the availability of quality seed in areas with otherwise poor market access. Village-based farmer seed production has the potential to contribute to sustainability if farmers take up seed production as a rural commercial enterprise. This concept can be applied to other projects also.

6.2.2 Project insights

The project collected many landraces that are adapted to upland environments and can directly result in productivity enhancements when distributed to areas other than where they are being grown. Some of these landraces can also be used as parental lines in a breeding program. Similarly, successful crop management technologies, profitable cropping system technologies, water-saving technologies, and technologies that generate ecosystem services for agriculture (soil improvement, reducing soil erosion, increasing water supply, etc.) can be replicated to other areas within the country and beyond. We already observed the spread of some of these technologies beyond the project sites. The knowledge and processes on improved technologies, hydrology modeling, and economic modeling were shared among project partners and other scientists. This knowledge and processes will be useful for developing similar technologies and models in other places in the future.

In Lao PDR and Vietnam, farming practices with new production systems and technologies were documented and distributed. Leaflets, fact sheets, technical advisory notes, training handouts, and other information materials on rice varieties, aerobic rice, soybean and peanut varieties, nutrient management, weed management, water-saving practices, field experimental data analysis, hydrology data analysis, and socioeconomic data analysis, among others, were prepared in English and local languages and distributed to farmers, extension agencies, and NGOs. The project produced many insights on new technology, new knowledge, and process understanding. Many scientific publications (on biophysical, hydrology, and socioeconomic aspects) are evidence of these insights.

6.2.3 Partnership achievements

The project has established a multi-institutional platform for the exchange of technologies and information within and across the border. Eight institutions were directly involved in project implementation, including four NARES institutes in three countries, two CG centers, and two advanced research institutes.

In Lao PDR, NAFReC under NAFRI was the focal institute to implement the project. It collaborated with district and provincial agricultural offices, village authorities, local NGOs, universities, and other projects to validate and disseminate technologies.

In Vietnam, NOMAFSI under VAAS was the focal institute for technological components and TUEBA was the focal institute for socioeconomic components. The experts from TUEBA trained NOMAFSI staff on socioeconomic research; the experts from MOMAFSI trained TUEBA staff on technology development components. Thus, two institutes worked very closely to implement the project. Moreover, these two institutes collaborated with district and provincial authorities, village authorities, and other projects to validate and disseminate technologies.

In Thailand, CMU was the focal institute to implement the project. It collaborated with ICRAF and local authorities to conduct project activities.

The project initiated linkages, established partnerships, and fostered strong collaboration among different institutions within the country. Such a strong network provides a lasting foundation for future work.

National collaborators visited other countries and learned about project activities. The experts from CMU, CG centers, and advanced research institutes trained national collaborators. Moreover, the project helped national collaborators to receive a large number of rice landraces and component technologies from other countries. The CG centers and advanced research institutes worked together with national collaborators.

The collaboration among international institutions, including the International Rice Research Institute (IRRI), French Research Center for International Agricultural Development (CIRAD), University of California at Davis (UC Davis), and World Agroforestry Center (ICRAF), allowed the development of a strong network of interdisciplinary teams to analyze upland problems comprehensively. Some of these institutions entered into partnership for the first time. The considerable diversity in expertise among institutions allowed a holistic systems approach to be employed to provide sound solutions to the common problems of uplands. Expertise included anthropologists, economists, agronomists, soil scientists, hydrologists, and breeders. The interdisciplinary teams provided unprecedented intellectual strength and diversity to the project. In addition, the partnership benefitted international institutions in terms of mutual learning and establishing a foundation for future collaboration.

6.3 Conclusions

The project employed several innovative technological, managerial, and institutional strategies for technology validation and dissemination. These include the paradigm of landscape management approach, multi-institutional partnership, multidisciplinary teamwork, farmer participatory approach to technology evaluation, community-based seed production, and public-private partnership in technology dissemination. The strategy employed by the project simultaneously enabled (a) the evaluation and dissemination of improved varieties and technologies and (b) the development of PVS and other processes to promote farmer-to-farmer spread and spontaneous diffusion.

The project identified, validated, and disseminated 57 improved rice varieties, 19 crop management technologies, 13 cropping system technologies, and 5 water management technologies for wetland paddies and sloping uplands. Similarly, the project distributed 67 tons of seeds of improved rice varieties to about 5,000 farmers. Nearly half of the distributed rice varieties are spreading and becoming popular among farmers at research sites. The yield advantage of these improved rice varieties ranged from 200 to 1,500 kg/ha over the popular traditional varieties. This level of yield gain can reduce the number of hungry months of average upland households by 1 to 5 depending upon short run to long run. Thus, the project technologies have

the potential to make substantial contributions to food security and poverty reduction. The enhanced capacity of NARES and farmers will have a long-term impact on national agricultural development and farmers' livelihoods. The innovative approaches employed by the project led to the successful generation and dissemination of technologies. Initial monitoring of adoption showed a good indication of spread and promising impact on farmers' livelihoods.

Part II: OUTCOMES AND IMPACTS

This portion of the study focuses on the main outcomes and impacts of the project provided during the project periods indicated.

2.1 Outcomes and Impacts Pro Forma Summary Description of the Project's Main Impact Pathways

Actor or actors who have changed at least partly due to project activities	What is their change in practice? i.e., what are they now doing differently?	What are the changes in knowledge, attitude, and skills that helped bring this change about?	What were the project strategies that contributed to the change? What research outputs were involved (if any)?	Please quantify the change(s) as far as possible
Farmers at the project sites in Lao PDR, Thailand, and Vietnam	<p>Farmers in project areas in uplands of Lao PDR and Vietnam are now growing improved rice varieties disseminated by the project.</p> <p>Farmers in Vietnam are now growing high-quality rice varieties in upland paddies and they obtained higher farm income.</p> <p>Farmers are practicing a legume-based rotation and are using green-manure crops in pre-rice and post-rice crop seasons.</p>	<p>Farmers understood that improved rice varieties promoted by the project produce a higher yield than local varieties.</p> <p>Farmers have learned that high-quality rice can be grown in the spring season in their fields.</p> <p>Farmers have learned that they could grow additional legume crops in the spring and winter seasons by using residual soil moisture.</p> <p>Farmers have learned about the cropping systems that best work under their field</p>	<p>Improved new rice cultivars were identified from a rich pool of germplasm collected locally and externally and they were tested across several locations in a participatory manner.</p> <p>The project followed a "research for development" approach with strong emphasis on the dissemination of the validated technologies.</p> <p>Farmers' preference and acceptability of the technologies were evaluated through PVS trials.</p> <p>Organized farmers' days and farmer field visits every crop season.</p> <p>High-yielding rice cultivars coupled with farmer-desired traits and techniques to improve crop-water-nutrient management remain the main thrusts of the project.</p> <p>Field trials and demonstration trials were implemented in farmers' fields with their participation.</p>	<p>In Lao PDR and Vietnam, the project distributed more than 15 tons of 28 upland rice variety seeds to more than 700 farmers.</p> <p>In Lao PDR and Vietnam, the project distributed almost 52 tons of 21 lowland rice variety seeds to more than 4,100 farmers. A large quantity of seeds was also disseminated through farmer-to-farmer spread.</p> <p>At least 6,000 farmers adopted improved varieties of rice in Lao PDR and Vietnam.</p> <p>In Lao PDR and Vietnam, 30–40% of validated upland rice varieties and 50–60% of validated upland paddy rice varieties are gaining wider acceptance among farmers.</p> <p>In Vietnam, more than 50 farmers in the study villages started growing spring-season rice for the first time.</p> <p>In Lao PDR and Vietnam, the project validated 44 sloping upland rice-based technologies, inclusive of 29 rice varieties, 8 crop and field management practices, and 7 cropping systems.</p> <p>In Lao PDR and Vietnam, the project validated 50 upland paddy rice-based technologies, inclusive of 28 rice varieties, 16 crop and water management</p>

	<p>Farmers diversified cropping systems in uplands by shifting from rice to other crops or by growing cash crops in relay or intercrop.</p> <p>Farmers intercropped <i>Stylosanthes</i> (fodder) with rice and thus they integrated livestock in their farming system.</p> <p>Farmers applied optimum fertilizer rate, seed rate, seedling age, and planting time to obtain higher rice yield.</p> <p>Farmers are practicing improved methods for managing weeds.</p> <p>Farmers tried out water-saving technologies such as aerobic rice varieties, AWD, and saturated soil culture in paddies.</p> <p>Farmers produced seeds of improved varieties of rice in the community.</p> <p>Farmer participation in crop variety selection and evaluation increased.</p>	<p>conditions. They have also learned that it is feasible to grow pre- and postrice legume crops.</p> <p>Farmers have learned that diversification of cropping systems not only provides more income but also reduces environmental risk.</p> <p>Farmers have learned that <i>Stylosanthes</i> intercropped with rice improves soil fertility and provides fodder for livestock.</p> <p>Farmers have learned that optimum fertilizer rate, seed rate, and planting time raise rice yield.</p> <p>Farmers have learned that weeds could be controlled effectively through better land preparation, mulching, and altering plant density.</p> <p>Farmers learned that water-saving technologies do not have a yield penalty and can help expand rice area in the dry season.</p> <p>Farmers have learned benefits of quality seeds to increase rice production.</p> <p>Changes in attitudes among scientists that farmers' participation ensures selection of varieties that meet their needs.</p>	<p>New rice cultivars as well as crop, water, and nutrient management systems technologies were tested with farmer involvement and demonstrated to other farmers in the community.</p> <p>Prepared technology information in local language and distributed it to farmers, extension agents, NGOs, etc.</p> <p>The project provided seeds of improved rice varieties to farmers and trained them to produce high-quality seeds in the village.</p> <p>Involved farmers, both men and women, in planning of research activities.</p> <p>Strong partnership with extension agents, GOs, NGOs, and farmer-to-</p>	<p>practices, and 6 cropping systems.</p> <p>In Lao PDR and Vietnam, about 700 farmers participated in the farmer training and visited the field trials and demonstration trials. Including those who participated in rice seed production, about 5,000 farmers learned the new crop and field management techniques, new cropping systems, and new water-saving techniques.</p> <p>In Lao PDR and Vietnam, about 6,000 copies of information sheets in 61 topical areas were produced and distributed to farmers and extension agents. Thus, at least 6,000 farmers learned about the new technologies.</p> <p>In Lao and Vietnam, about 200 farmers started growing legumes in the spring season and winter season.</p>
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	<p>Women are more confident in talking with scientists and their participation in training and project implementation is increased.</p> <p>A large number of women participated in field visits, training activities, and technology evaluation.</p> <p>Farmers are more food-secure.</p> <p>Household farm income is increasing due to increasing production for markets.</p> <p>Farmers have started practicing sustainable crop production practices.</p>	<p>It also ensures fast spread and rapid adoption.</p> <p>Changes in scientists' perception on the potential capacities of women to be agents of change.</p> <p>Researchers better understood that improved agricultural technologies and farm income increases women's access to productive assets and improve their nutritional status.</p> <p>Researchers understood that the use of a landscape approach for upland technology development and targeting could be effective in overcoming food insecurity; farmers learned skills to use improved technologies.</p> <p>Farmers have learned skills to grow and sell cash crops.</p> <p>Farmers understood the negative impact of land degradation and learned potential approaches to reduce environmental degradation.</p>	<p>farmer dissemination.</p> <p>Rice landscape management, multi-institution partnership, multidisciplinary teams, and farmer participation were the main implementation approaches.</p> <p>The project emphasized technologies that increase rice production and promote sustainable land-use systems in uplands by reducing intensive use of sloping uplands.</p>	<p>Yield advantage of upland improved rice varieties ranged from 0.2 to 1.5 t/ha compared with the local check (1.5 t/ha).</p> <p>Yield advantage of lowland improved rice varieties ranged from 0.2 to 1.3 t/ha compared with the local check (2.5 t/ha).</p> <p>The yield advantage of validated rice cultivars is sufficient to feed an average upland family for an additional 1–5 months. Thus, the potential project contribution to food security is substantial.</p> <p>The farm household model showed that a 25% increase in yield of lowland rice raises the income of a typical upland household by 16%. The adoption of improved varieties, whose yield advantage is 10–100%, can increase the income of average upland households by 15–20%. Thus, the project has demonstrated substantial potential for poverty reduction.</p>
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<p>Researchers in participating countries and international research institutes.</p>	<p>Researchers increasingly involve farmers and other local stakeholders in technology testing and validation.</p> <p>The multidisciplinary research team spent more time in the field interacting with farmers.</p> <p>Researchers were able to develop alternative scenarios for resource management and raise new research questions.</p> <p>Researchers developed and linked hydrology and household economic models to identify options for optimal land use.</p> <p>NARES partners planned and implemented project activities well.</p> <p>Collaboration between scientists in participating countries and in advanced research institutes is strengthened.</p>	<p>Scientists understood that farmers' participation not only ensures selection of right technologies but also facilitates rapid spread and adoption.</p> <p>Researchers understood that multidisciplinary approach and spending more time in the field help better understand farmers' constraints and opportunities.</p> <p>Researchers understood that development of model and scenarios help better understand resource flow interactions and trade-off analysis.</p> <p>Training enhanced NARES staff skills to better plan and implement research activities.</p> <p>Scientists understood that NARES would benefit from multi-institutional collaboration.</p> <p>Researchers understood opportunities and constraints to increasing rice production.</p>	<p>Followed established protocols of PVS trials.</p> <p>Most research activities were organized in farmers' fields with their participation.</p> <p>The project followed a multidisciplinary team approach so that scientists could learn from each other.</p> <p>Developed standard methodology for data collection and analysis.</p> <p>Hydrologist, economist, and agronomist worked as a team.</p> <p>Farmer-scientist regular interactions provided opportunities to refine and develop need-based research activities.</p> <p>Organized project planning and review meetings annually and involved partners in planning and meetings.</p> <p>The project trained NARES collaborators in socioeconomic, hydrology, plant breeding, crop management, and water management techniques.</p> <p>The project involved many national and international institutions with varied expertise.</p> <p>Organized cross-country field visits to see and discuss project findings.</p>	<p>In three countries, 321 NARES staff members were trained on different topics, including socioeconomic research methods, crop experiments, rice breeding, study tours and exchange visits, technical writing, and thesis research.</p> <p>The project team consisted of an economist, anthropologist, hydrologist, agronomist, plant breeder, and weed scientist.</p> <p>The project was implemented in partnership with 8 institutions from collaborating countries and international organizations.</p> <p>Researchers conducted more than 150 field trials and demonstration trials to test and validate technologies.</p>
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<p> Policymakers in the participating countries and in international institutes working in the region.</p>	<p>In Lao PDR and Vietnam, policymakers increased investment in agricultural research and development in northern region.</p> <p>In Lao PDR and Vietnam, policymakers increased investment in small irrigation and are promoting terrace construction.</p> <p>In Vietnam, commune authorities revised policies and provided technical services to farmers to grow spring rice where possible.</p> <p>In Lao PDR and Vietnam, provincial and local authorities revised and refined the land-use plan for cash crop production.</p> <p>In Lao PDR and Vietnam, policymakers are more aware of the need to invest for sustainable land use in sloping uplands.</p> <p>In Thailand, policies are reoriented toward community based NRM and sustainable land-use systems.</p> <p>Policymakers understand the need to increase access of poor to irrigation.</p>	<p>Policymakers understood the potential of and opportunities in the uplands to reduce food insecurity and poverty.</p> <p>Policymakers understood that an increase in rice production in paddies reduces food insecurity and poverty as well as protects the environment.</p> <p>Policymakers understood the potential of the spring season to increase rice production.</p> <p>Local government authorities' knowledge on resource endowment of the community and potential trade-off in resource use at the catchment level is improved.</p> <p>Policymakers' knowledge on the effect of land-use changes on water flow and other resource use trade-offs in the catchment is improved.</p> <p>Local authorities understood negative environmental effects and social conflicts of commercialization in sloping lands.</p> <p>Policymakers' knowledge on relationship between water access and poverty is improved.</p>	<p>The project team worked closely with national research and development institutes to influence the use of project findings while developing the plans.</p> <p>Policymakers were invited to the project completion workshop to inform them about the project findings.</p> <p>Experimental and demonstration trials implemented by the project with farmers were shown to local and provincial authorities.</p> <p>The project documented negative impacts of commercial production in sloping uplands.</p> <p>The project, through modeling, demonstrated the benefits of access to water for poverty, food security, and livelihoods.</p>	<p>In Lao PDR, the government is giving higher emphasis to increasing rice production in the dry season. The government has increased emphasis on the repair and maintenance of small-scale irrigation systems.</p> <p>In Vietnam, local authorities provided subsidies and technical services for spring-season rice production.</p> <p>In Lao PDR and Vietnam, the government has started large-scale production and distribution of seeds of improved rice varieties validated by the project.</p> <p>In Vietnam, the government committed to continuing research and dissemination of water-saving technologies.</p>
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Of the changes listed above, which have the greatest potential to be adopted and have impact? What might the potential be for the ultimate beneficiaries?

The specific technologies that have the highest potential for impact are rice and nonrice crop varieties, rice crop management technologies, rice-based cropping systems, and water-saving technologies. Rice varietal traits leading to high adoption are high yield, sticky and nonsticky quality, insect and disease resistance, cold tolerance, short duration, high quality, aerobic rice, and less shattering. Soybean and peanut varietal traits leading to high adoption are high yield, short duration, consuming less water, and fitting in the rice-based cropping system. Rice crop management technologies with greatest potential for adoption include a small amount of fertilizer application, weed control through mulching and plant density, optimum number of seeds per hill, and optimum time of planting. Rice cropping systems with the greatest potential for adoption are spring rice–summer rice in irrigated paddies, summer rice–legume in rainfed paddies, and spring legume–summer rice in sloping uplands. Water-saving technologies with high adoption potential are saturated soil culture, AWD, and aerobic rice varieties.

The new practices and knowledge that have the greatest potential for adoption are PVS for rice varietal improvement and participatory experiments on new farming practices, especially nutrient, weed, and water management.

All these changes are expected to improve land, labor, and water productivity. When adopted over a large area, they are expected to generate a significant positive impact on poverty, food security, and resource conservation. The ultimate beneficiaries are the men and women from poor upland farming households who heavily depend on rice for their livelihoods.

What still needs to be done to achieve this potential? Are measures in place (e.g., a new project, ongoing commitments) to achieve this potential? Please describe what will happen when the project ends.

The project was very successful in testing, validating, demonstrating, and disseminating a large number of rice system technologies in limited areas in a short period of 4 years. More needs to be done to further validate technologies that are still in the experimentation stage and to upscale and outscale technologies that were validated. More efforts are needed to strengthen seed production of improved rice varieties, which are in high demand. To achieve the potential impacts, the following actions are needed.

- Continue experiments and demonstrate technologies with participation of farmers that were implemented and disseminated only during a short period of 3–4 years under the project.
- Upscale and outscale validated technologies.
- Train farmers to produce high-quality seeds, increase production of high-quality seeds, and disseminate them over large geographical areas.
- Continue to help researchers and farmers in collaborating countries to continue project-related research and development activities.
- Continue to support national, provincial, and local authorities in setting up their priorities and strategies for sustainable development of upland landscapes.
- Document and quantify impacts of the project for future support.

After the project ends, the collaborating countries will continue further experiments and dissemination of the technologies that the project started. Lao PDR and Vietnam have started producing and distributing seeds through national research and development programs.

Each row of the table above is an impact pathway describing how the project contributed to outcomes in a particular actor or actors.

Which of these impact pathways were unexpected (compared to expectations at the beginning of the project?)

- The project tested a large number of rice lines/cultivars (1,300) and validated a large number of rice varieties (57), crop management technologies (19), cropping system technologies (13), and water-saving technologies (5).
- The project not only trained farmers in quality seed production but also produced and distributed a large quantity of seeds (67 tons) of improved rice varieties.
- Farmers adopted improved rice varieties within a short period.
- Change in attitudes of policymakers toward the potential and opportunities to improve

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- livelihoods and conserve resources through a rice landscape management approach.
- A large number of women participated in the project activities.
- Some 13 students from different universities conducted thesis research under the project.

Why were they unexpected? How was the project able to take advantage of them?

- The project expected to test and validate only a small number of technologies due to limited resources and a short project cycle. The strong participation of NARES collaborators, including the provision of matching resources, their strong commitment, and hard work, produced results above expectations.
- The project expected to produce a small quantity of seeds at research stations. The project, however, was able to generate interest in a community-based seed production approach for the production of larger quantities of seeds. GOs, NGOs, CBOs, and other project partners got involved in the dissemination of seeds.
- Ordinarily, adoption of new technologies takes a long time. However, we observed a fast adoption of improved technologies primarily due to the farmer participatory approach in technology testing and evaluation.
- The project invited policymakers to various project meetings and presented the impact of research and development on the livelihoods of upland households and on the environment. The project quantified the trade-offs between uplands and lowlands by combining hydrology and economic models.
- Women's participation in farmer training, farmer field days, and farmer participatory trials was significant. The project ensured the participation of women in all of its activities.
- The initial plan of the project was to involve a few students in the project activities, but multi-institution partnership helped the project train many students.

What would you do differently next time to better achieve outcomes (i.e., changes in stakeholder knowledge, attitudes, skills, and practice)?

If we have to do a similar project in the future, we will focus on the following activities to achieve better outcomes:

- Improve the participatory approach to allow better and faster involvement of different groups of stakeholders.
- Extend the project period to at least five years for complete testing and validation of technologies, dissemination of technologies, and documentation of project impacts.
- Cover more geographical areas with more resources to have a larger impact.
- Integrate research and development activities, particularly focusing on community-based production of seeds and dissemination of technologies.
- Give more emphasis to farmer training on new technologies for faster adoption, NARES staff training for better implementation of project activities, and policy dialogues to make policymakers aware of the potential impact of project findings.

2.2 International public goods

The project produced a number of international public goods (IPG) that will have impact beyond the project sites and the project life. These include tools and structured formats developed and used to collect farm household data, collected data, validated technologies, knowledge of improved technologies, hydrology model, and approach to linking the hydrology model with an economic decision model for an economic assessment of the trade-off involved in resource use across the landscape. In addition, the institutional analysis of irrigation systems, the framework for multi-institutional partnerships, and the community-based approach to seed production and distribution could be applied to other locations as well.

2.2.1 Tools and methodology

The project developed several semi-structured and structured questionnaires and pro forma items for farm household surveys and collection of village-level basic information. Such data collection instruments include questionnaires for baseline surveys, questionnaires for water institution surveys, questionnaires for farm household model surveys, pro forma focus group discussions, pro forma historical analysis of land-use changes, pro forma qualitative trade-off analysis, and pro forma participatory rural appraisal.

The project collected a large number of data sets, including field experiments, climate, field hydrology, and farm household characteristics. Likewise, the project collected numerous data on rice and nonrice crop production, basic characteristics of villages and provinces, and local irrigation schemes.

In Lao PDR, we developed a watershed hydrology model that shows the relationship between land use and water flows in the catchment. The model was developed using intensive data on land uses, soil properties, subsurface hydraulic properties, climate, topography, and stream flows collected during 2007 and 2008. It provides useful information on the effects of land-use changes on water flow in the watershed.

In all three countries, we developed a farm-household decision-making model to understand household resource allocations among different enterprises. We constructed the model using wide-ranging biophysical and socioeconomic data. The model is useful for determining optimal allocations of resources of smallholder farmers that maximize household income after satisfying household food security. It is a powerful tool for analyzing the effect of rice technological development and other farming interventions on household livelihoods.

In Lao PDR, we developed a hydroeconomic model by combining a hydrology model and an economic model. This model was used to analyze resource use trade-off between uplands and lowlands. The water flow input from the hydrology model served as an input in the economic model. This model helped quantify income losses from land-use changes in uplands and income gains from lowlands from the use of incremental water flow. This is a powerful tool not only for combining biophysical and economic data for policy analysis but also for exploring the viability of ways of compensating upland dwellers for their production of environmental services.

The participatory approach promoted uptake of the tested technologies. It comprised multilevel stakeholder (farmers, extension workers, and local authorities) participation from the beginning (site selection) to implementation and evaluation of the technologies. Endorsement and cooperation from district and provincial authorities were pivotal in enabling extension workers to obtain adequate resources for disseminating rice varieties, recommended cropping systems, and component technologies.

2.2.2 Project insights

The project collected many landraces that are adapted to upland environments and can directly result in productivity enhancements when distributed to areas other than where they are being grown. Some of these landraces can also be used as parental lines in a breeding program. Similarly, successful crop management technologies, profitable cropping system technologies, water-saving technologies, and technologies that generate ecosystem services for agriculture (soil improvement, reducing soil erosion, increasing water supply, etc.) can be replicated to other areas within the country and beyond. We already observed the spread of some of these technologies beyond the project sites. The knowledge and processes on improved technologies, hydrology

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modeling, and economic modeling were shared among project partners and other scientists. This knowledge and processes will be useful for developing similar technologies and models in other places in the future.

In Lao PDR and Vietnam, farming practices with new production systems and technologies were documented and distributed. Leaflets, fact sheets, technical advisory notes, training handouts, and other information materials on rice varieties, aerobic rice, soybean and peanut varieties, nutrient management, weed management, water-saving practices, field experimental data analysis, hydrology data analysis, and socioeconomic data analysis, among others, were prepared in English and local languages and distributed to farmers, extension agencies, and NGOs. The project produced many insights on new technology, new knowledge, and process understanding. Many scientific publications (on biophysical, hydrology, and socioeconomic aspects) are evidence of these insights.

2.3 Partnership achievements

The project has established a multi-institutional platform for the exchange of technologies and information within and across the border. Eight institutions were directly involved in project implementation, including four NARES institutes in three countries, two CG centers, and two advanced research institutes.

2.3.1 Strengthen partnership among national institutions

In Lao PDR, NAFReC under NAFRI was the focal institute to implement the project. It collaborated with district and provincial agricultural offices, village authorities, local NGOs, universities, and other projects to validate and disseminate technologies.

In Vietnam, NOMAFSI under VAAS was the focal institute for technological components and TUEBA was the focal institute for socioeconomic components. The experts from TUEBA trained NOMAFSI staff on socioeconomic research; the experts from NOMAFSI trained TUEBA staff on technology development components. Thus, two institutes worked very closely to implement the project. Moreover, these two institutes collaborated with district and provincial authorities, village authorities, and other projects to validate and disseminate technologies.

In Thailand, CMU was the focal institute to implement the project. It collaborated with ICRAF and local authorities to conduct project activities.

The project initiated linkages, established partnerships, and fostered strong collaboration among different institutions within the country. Such a strong network provides a lasting foundation for future work.

2.3.2 Strengthen partnership of national institutions with international institutions as well as strengthen partnership among international institutions

The project established a strong multi-institution partnership. National collaborators visited other countries and learned about project activities. The experts from CMU, CG centers, and advanced research institutes trained national collaborators. Moreover, the project helped national collaborators to receive a large number of rice landraces and component technologies from other countries. The CG centers and advanced research institutes worked together with national collaborators.

The collaboration among international institutions, including the International Rice Research Institute (IRRI), French Research Center for International Agricultural Development (CIRAD), University of California at Davis (UC Davis), and World Agroforestry Center (ICRAF), allowed the development of a strong network of interdisciplinary teams to analyze upland problems comprehensively. Some of these institutions entered into a partnership for the first time. The considerable diversity in expertise among institutions allowed a holistic systems approach to be employed to provide sound solutions to the common problems of uplands. Expertise included anthropologists, economists, agronomists, soil scientists, hydrologists, and breeders. The interdisciplinary team provided unprecedented intellectual strength and diversity to the project. In addition, the partnership benefitted international institutions in terms of mutual learning and establishing a foundation for future collaboration.

2.4 Recommendations

2.4.1 Research

- Rice is an important component of livelihoods. Low rice yield, in both paddies and sloping uplands, is a major cause of poverty, food insecurity, and land degradation in uplands. Raising rice productivity is an important entry point to improve food security and reduce poverty in these uplands. Clear potentials exist for raising rice productivity through the development of improved rice varieties and cropping systems. Increased investments in agricultural R&D are needed to exploit this potential.
- Selection of research sites based on comprehensive baseline surveys and explicit use of poverty criteria is critical to project success and the development of pro-poor technologies. Moreover, this helps sensitize researchers to poverty reduction issues and builds a strong poverty orientation into their work. Therefore, we recommend careful selection of research sites in any research program, but especially in projects addressing poverty and food security issues.
- The current dominant cropping systems in upper catchments are spring rice–summer rice–winter fallow in irrigated paddies and spring fallow–summer rice–winter fallow in rainfed paddies. The lack of short-duration rice varieties prevents growing additional crops. This cropping pattern would need short-duration, photoperiod-insensitive varieties to increase cropping intensity.
- We found the introduction of legume crops in the spring season in irrigated paddies and in the winter season in rainfed paddies and in uplands to be technically and economically feasible. We need further research to test the feasibility of other cropping patterns that maximize income, offer flexibility to farmers, and provide ecosystem services to agriculture.
- Soil erosion, soil fertility decline, and loss of environmental services are increasing problems in sloping uplands. It is important to quantify the effect of intensive cultivation on the loss of environmental services. The modeling approaches used in the project to analyze the economic-environmental trade-offs and the effects of various interventions need to be further developed for a more comprehensive analysis.
- There are good prospects for further scaling up the developed approaches and technologies in ongoing projects and initiatives in participating countries, as well as pursuing next-generation R&D questions in relevant projects that are in the pipeline. Therefore, we recommend continuation of project activities, particularly for scaling out.
- Water scarcity is an important constraint to rice production. An initial study on water-saving technologies, including saturated soil culture, alternate wetting and drying, and aerobic rice varieties, showed encouraging results. Further research on water-saving technologies has the potential to increase rice production, particularly in the dry season. More efforts in breeding and variety selection are needed to increase the yield of rice in aerobic soils.
- Build on indigenous knowledge of traditional farming systems and understand the interface between biophysical and socioeconomic circumstances of targeted communities for effective development and dissemination of technologies.
- Adoption of improved rice varieties is very low in upper catchments. A better understanding is needed to identify the factors that influence farmers' decisions on the adoption of improved rice varieties and component technologies. Adoption and impact studies of improved technologies help develop new technologies. More such studies should be carried out.
- The upper catchment is home to a large number of rice cultivars. Increased efforts are needed to collect, evaluate, and preserve native germplasm that is adapted to upland conditions. These materials constitute precious sources of diversity and adaptation and they are useful for current and future breeding programs.
- Small-scale farmer-managed irrigation schemes dominate upper catchments. These irrigation systems are used more efficiently in Thailand than in Lao PDR and Vietnam. Some opportunities exist to increase dry-season rice production through better management of hardware and software aspects of irrigation schemes in Lao PDR and Vietnam. Further studies on irrigation management systems and opportunities to improve their efficiency are warranted in Lao PDR and Vietnam.
- The hydrology model developed in this study quantified an important relationship between land use and water supply in the watershed. Nonetheless, two years of field hydrology data in small catchments established this relationship. More years of data collected over bigger watersheds are needed to derive generalized results over a larger geographical area.

2.4.2 Extension

- We validated a large number of technologies. However, returns to investment on these technologies are realized only when these technologies are adopted by beneficiaries. Therefore, we must put more efforts into disseminating these technologies over large geographical areas and promoting adoption by farmers. The extension approaches involving formal and informal channels and the multi-institutional platform developed need further strengthening to accelerate the process of technology dissemination.
- The informal extension sector (community organizations, NGOs, private firms, etc.) is a powerful agent of change and should be included in the supply of technologies and information. In many cases, agro-vet shopkeepers, NGO staff, community organizations, and village leaders serve as a major source of information for farmers. Therefore, the public-private partnership mode of extension service delivery should be explored.
- It is important to ensure that men and women farmers have equal access to new seeds as well as knowledge on crop management requirements specific to local areas.
- The technology recommendation domains identified could be used by national systems to target and disseminate improved technologies for greater efficiency.
- The use of diverse extension and communication means is effective to disseminate and outscale. Mass media proved to be effective in many cases.

2.4.3 Policy

- The incidence of poverty and food insecurity is higher in upper catchments. Upland areas were neglected in terms of investment in agricultural research and development. Substantial opportunities exist to overcome poverty, food insecurity, and environmental degradation problems through investment in agricultural research and development. Moreover, upper catchments provide various provisioning, protecting, and regulating environmental services—a public good. The stewards of environmental services need proper compensation for equity. One way to pay for environmental services is to invest to improve farmers' livelihoods. Investments in agricultural R&D and in rural infrastructure must be increased substantially.
- There is strong resource flow and other linkages between upstream and downstream. By intensifying favorable pockets in the uplands—including productive upland paddies where paddy rice can be grown—intensification pressure is reduced in the less favorable and more fragile areas such as sloping uplands. Therefore, a landscape management approach provides a good framework for designing agricultural development programs for uplands and should be used in the future design of interventions in uplands.
- The poverty impact of improved access to water is higher in market-oriented production systems and in areas with adoption of improved technologies. Along with investment in water resource development, investments are also needed to develop the required rural infrastructure and institutional mechanisms for generating a poverty impact.
- Irrigation water, though critical, is only one of the inputs or services essential to enhancing farm productivity and income. Therefore, we recommend strengthening support services such as rice varieties, crop management technologies, extension, seed supply, input availability, and financial services.
- Farmers' access to high-quality seeds of rice varieties with high yield and other acceptable traits is vital to increasing rice production. Policy support to multiply seeds of improved varieties rapidly is warranted.
- Most traditional irrigation systems in Lao PDR and Vietnam are based on temporary diversion from streams. They require a large amount of labor and other resources to convey water every crop season. A large amount of water is lost during conveyance. Although the efficiency of irrigation systems with a water users' association (WUA) is better, many irrigation systems do not have a WUA. Investment in hardware (repair and maintenance) and software (WUA and management) of traditional irrigation systems is needed to increase water access in terms of quantity, reliability, and timeliness.
- Access to paddies is an important factor that affects poverty and food security. Paddy construction in sloping areas with low gradient is economically viable. However, limited capital resources constrain the construction of terraces. Low-interest credit is needed to encourage farmers to construct terraces.
- The hydro-economic model results showed that conversion of upland crop area to forest increased the water supply in the watershed but this is not economically viable. The policy to convert upland crop area to forest will cause significant economic loss to the poor. Therefore, we recommend providing adequate compensation to households when the government pursues a policy to stop shifting cultivation to augment ecosystem services.

2.4.4 Institutions

- Upland livelihoods are highly diverse and complex due to large variations in social and biophysical features. This makes designing technologies that suit farmers' requirements challenging. This is one reason why technologies developed through customary processes are not adopted in smallholder farming systems. We recommend institutionalization of the every participatory technology evaluation and dissemination approach. Moreover, we strongly recommend multilevel stakeholder participation in every step of the testing-delivery pathway. The method used in this study required participation from different stakeholders (from farmers to local authorities and policymakers) in every step from site selection to outscaling. The information and feedback gathered from farmers, both men and women, during evaluation should be carefully considered during the process of commercial release of varieties. The endorsements from local authorities, who were also involved in every step from site selection to community evaluation, were crucial in the formulation of a cohesive program from local to provincial levels to disseminate the new cropping systems and technologies.
- The project recommends ensuring the participation of household members, particularly women, who are actually involved in the farming activities, in training, and in technology evaluation. This is crucial to avoid the usual mistake that "the ones who attend meetings and training (usually men) are not the ones who actually make decisions and do farming activities at home."
- On-farm workshops (farmer field days and farmer exchange visits) and farmer-to-farmer extension were very effective in creating an environment for lively discussions, participants contributing ideas and inputs, farmers reporting first-hand experiences on technologies, convincing fellow farmers to adopt technologies, technology dissemination, technology evaluation, and getting feedback to scientists. We recommend institutionalization of such farmer participatory activities in the technology testing-delivery pathway.
- For farmers to play a larger role in collaborative research and in managing and evaluating on-farm trials, more action is needed in training farmers in data collection, encouraging systematic farmer documentation, and organizing seed fairs and conferences for farmers.
- National programs lack the critical mass of scientists and research facilities to undertake focused research and development activities in unfavorable areas. We recommend investment to develop the required research facilities, and to strengthen human capacity in research and delivery, including degree and nondegree training, as well as capacity for participatory and adaptive research.
- National programs have severe shortages of social scientists. We recommend more investment to train social scientists who can work with other disciplines to underpin the process of technology development and validation.
- National programs should be encouraged toward intra-institutional interdisciplinary research, with scientists representing different disciplines but addressing common problems. More important, there is a dire need for inter-institutional linkages for sharing of resources to develop technologies and for dissemination of technologies.
- The multi-institution partnership model followed in this project provided mutual benefits to all institutions in terms of sharing germplasm, component technologies, and knowledge. A number of institutional linkages and R&D partnerships—at national and international levels—have been established among institutions that have not previously worked together. These institutional linkages provided a foundation for future collaboration. In areas with limited institutional capacity, the project strategy of pursuing multiple channels for dissemination proved to be effective for rapidly scaling out validated technologies. We strongly recommend the multi-institutional partnership model for project implementation.
- Initiatives in poverty reduction and rural development should not just focus on technology development, but also on methodological innovations such as farmer participatory research and participatory research planning and management that are simple and cost-effective, and produce greater impact.
- One of the most important problems that farmers faced is a lack of markets or inefficiency of available markets. Special organizational, operational, legal, and regulatory mechanisms that enhance the development and functioning of markets are needed.
- For sustained dissemination of improved varieties, "farmer seed production groups" are essential, and they provide opportunities for establishing commercial and profitable rural enterprises. The innovative seed multiplication mechanisms developed and used by the project could serve as models for other projects and programs that support local production of high-quality seed.

2.5 Publications

2.5.1 Referred journal articles

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2. Kitchaicharoen J, Ekasingh B, Dithaprayon S, Chaiwinit W. 2008. Linkages between access to irrigated water and livelihood strategies using sustainable livelihood framework. The 4th National Symposium on "Agricultural Systems," Chiang Mai, Thailand. 27-28 May 2008.

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9. Bhandari H, Keonakhone T. 2009. Training for junior staff of socioeconomic division of NAFReC, Lao PDR. 12-13 May 2009.

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2.5.11 Videos

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Appendix A

Basic structure of the linear programming matrix, Luang Prabang Province, Lao PDR

Objective function and constraints	Row	Farm activities $X_{1..X_{23}}$	Labor buy $X_{24..X_{29}}$	Rice buy $X_{30..X_{35}}$	Rice consume $X_{36..X_{41}}$	Labor sell $X_{42..X_{47}}$	Rice sell $X_{48..X_{53}}$	Crop sell $X_{54..X_{131}}$	Rice transfer $X_{132..X_{137}}$	Cash borrow $X_{138..X_{143}}$	Cash transfer $X_{144..X_{149}}$	Living expense X_{150}	Net cash income	Type of constraint	RHS value
Objective function													1		
Land	$R_{1..R_4}$	1												\leq	b_i
Water	R_5, R_6	a_{ij}												\leq	b_i
Market access	$R_7..R_{11}$	1												\leq	b_i
Household labor	$R_{12..R_{17}}$	a_{ij}	-1			1								\leq	b_i
Hired labor	$R_{18..R_{23}}$		1											\leq	b_i
Sold labor	$R_{24..R_{29}}$					1								\leq	b_i
Production	$R_{30..R_{107}}$	y_{ij}					1	1						\leq	b_i
Rice buy	$R_{108..R_{113}}$	1		1	-1									\leq	b_i
Rice sell	$R_{114..R_{118}}$	1					1							\leq	b_i
Rice consume	$R_{119..R_{124}}$	1		-1	1									\geq	b_i
Rice balance	$R_{125..R_{130}}$	y_{ij}			1		1		1					$=$	0
Crop balance	$R_{131..R_{136}}$	y_{ij}						1						$=$	0
Capital	$R_{137..R_{142}}$	a_{ij}								-1	1			\leq	b_i
Cash borrow	$R_{143..R_{148}}$									1				\leq	b_i
Living expenditure	$R_{149..R_{154}}$													$=$	b_i
Cash balance	$R_{155..R_{160}}$	c_i	c_i	c_i		p_i	p_i	p_i	c_i	c_i		c_i	1	$=$	0

Appendix B

Validated uplands technologies and extrapolation domain, Lao PDR and Vietnam.

S.N.	Country	Technology group	Crop	Variety and technology description	Extrapolation domain
1	Laos	Variety	Rice	B-6144F-MR-6 (non glutinous)	Northern Lao uplands grown to upland rice under farmer practice or with little to recommended fertilizer dosage.
2	Laos	Variety	Rice	Chao Laosuong (glutinous)	Northern Lao uplands grown to upland rice under farmer practice or with little fertilizer.
3	Laos	Variety	Rice	Chao Mad (glutinous)	1. Northern Lao uplands grown to upland rice under farmer practice or with little fertilizer. 2. Two-three years of continuous cropping on sloping uplands with none or little fertilizer.
4	Laos	Variety	Rice	Dodeng (glutinous)	Northern Lao uplands grown to upland rice under farmer practice or with little fertilizer.
5	Laos	Variety	Rice	Dok Dou (glutinous)	Northern Lao uplands grown to upland rice under farmer practice or with little fertilizer.
6	Laos	Variety	Rice	IR55423-1 (non glutinous)	Northern Lao uplands grown to upland rice under farmer practice or with little to recommended fertilizer dosage.
7	Laos	Variety	Rice	IR60080-60A (non glutinous)	Northern Lao uplands grown to upland rice under farmer practice or with little to recommended fertilizer dosage.
8	Laos	Variety	Rice	IR71525-18-1 (non glutinous)	Northern Lao uplands grown to upland rice under farmer practice or with little to recommended fertilizer dosage.
9	Laos	Variety	Rice	IRAT70 (non glutinous)	Northern Lao uplands grown to upland rice under farmer practice or with little to recommended fertilizer dosage
10	Laos	Variety	Rice	Laboun (glutinous)	1. Northern Lao uplands grown to upland rice under farmer practice or with little fertilizer. 2. Two-three years of continuous cropping on sloping uplands under farmer practice or with none to little fertilizer.
11	Laos	Variety	Rice	Maisang (glutinous)	Northern Lao uplands grown to upland rice under farmer practice or with little fertilizer.
12	Laos	Variety	Rice	Makhinsoung (glutinous)	Northern Lao uplands grown to upland rice under farmer practice or with little fertilizer.
13	Laos	Variety	Rice	Makthoua (glutinous)	Northern Lao uplands grown to upland rice under farmer practice or with little fertilizer.
14	Laos	Variety	Rice	Nok (glutinous)	Northern Lao uplands grown to upland rice under farmer practice or with little fertilizer
15	Laos	Variety	Rice	Non (glutinous)	1. Northern Lao uplands grown to upland rice under farmer practice or with little fertilizer. 2. Two-three years of continuous cropping on sloping uplands under farmer practice or with none to little fertilizer.

S.N.	Country	Technology group	Crop	Variety and technology description	Extrapolation domain
16	Laos	Variety	Rice	Pongseng (glutinous)	Northern Lao uplands grown to upland rice under farmer practice or with little fertilizer.
17	Laos	Variety	Rice	Yunlu58 (non-glutinous)	Northern Lao uplands grown to upland rice under farmer practice or with little to recommended fertilizer dose.
18	Laos	Variety	Rice	Yunlu69 (non-glutinous)	Northern Lao uplands grown to upland rice under farmer practice or with little to recommended fertilizer dose.
19	Laos	Management	Rice	<u>Imperata infested field reclamation:</u> Glyphosate + Pigeon peas to reclaim imperata-infested sloping lands	Imperata infested upland rice fields in northern Laos.
20	Laos	Management	Rice	<u>Optimal seeding time:</u> Optimum time of sowing rice to obtain highest yield	Northern Lao uplands grown to upland rice.
21	Laos	Management	Rice	<u>Optimal seeding rate:</u> Optimum number of seed per hill to obtain maximum rice yield	Northern Lao uplands grown to upland rice.
22	Laos	Management	Rice	<u>Soil fertility management:</u> Effect of land preparation practices (slash-and-burn and slash-and-mulch) on soil fertility and rice yield	Northern Lao uplands grown to upland rice.
23	Laos	Management	Rice	<u>Soil fertility management:</u> Upland rice grown to different rate of nitrogen fertilizer application	Northern Lao uplands grown to upland rice.
24	Laos	Management	Rice	<u>Weed management:</u> Effect of different frequency of manual weeding on rice yield	Northern Lao uplands grown to upland rice
25	Laos	Crop system	Maize	<u>Maize intercropped with upland rice:</u> Upland rice + Maize (var. LVN10)	Northern Lao uplands grown to upland rice.
26	Laos	Crop system	Stylo	<u>Stylosanthes intercropped with upland rice:</u> Upland rice + stylosanthes broadcast	Northern Lao uplands grown to upland rice.
27	Laos	Crop system	Rice	<u>Soil improvement:</u> Pigeon pea (sticklac insect may be inoculated on pigeon peas to produce sticklac resin which is sold for cash)	Northern Lao uplands grown to upland rice.
28	Vietnam	Variety	Rice	Bao Dam	Northern Vietnam sloping uplands grown to upland rice under farmer practice or with none to little fertilizer.
29	Vietnam	Variety	Rice	CIRAD 141	Northern Vietnam sloping uplands grown to upland rice under farmer practice or with little to recommended fertilizer dosage.
30	Vietnam	Variety	Rice	IR74371-3-1-1	Northern Vietnam sloping uplands grown to upland rice under farmer practice or with little to recommended fertilizer dosage.
31	Vietnam	Variety	Rice	IR74371-54-1	Northern Vietnam sloping uplands grown to upland rice under farmer practice or with little to recommended fertilizer dosage.

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32	Vietnam	Variety	Rice	IR78875-1-3-1	Northern Vietnam sloping uplands grown to upland rice under farmer practice or with little to recommended fertilizer dosage.
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S.N.	Country	Technology group	Crop	Variety and technology description	Extrapolation domain
33	Vietnam	Variety	Rice	Luyin 46	Northern Vietnam sloping uplands grown to upland rice under farmer practice or with little to recommended fertilizer dosage.
34	Vietnam	Variety	Rice	Nep Suoi Giang	Northern Vietnam sloping uplands grown to upland rice under farmer practice or with none to little fertilizer.
35	Vietnam	Variety	Rice	Yunlu 100	Northern Vietnam sloping uplands grown to upland rice under farmer practice or with little to recommended fertilizer dosage.
36	Vietnam	Variety	Rice	Yunlu 105	Northern Vietnam sloping uplands grown to upland rice under farmer practice or with little to recommended fertilizer dosage.
37	Vietnam	Variety	Rice	ARHY 1	Northern Vietnam sloping uplands grown to upland rice under farmer practice or with little to recommended fertilizer dosage.
38	Vietnam	Variety	Rice	ARHY 3	Northern Vietnam sloping uplands grown to upland rice under farmer practice or with little to recommended fertilizer dosage.
39	Vietnam	Management	Rice	<u>Weed management:</u> Optimum number of manual weeding to obtain higher rice yield	Upland rice grown in northern Vietnam.
40	Vietnam	Management	Rice	<u>Soil mulching:</u> Mulching (plastic films, rice straw, crotolaria, and other plant materials) technologies for weed control and moisture conservation	Upland rice grown in northern Vietnam.
41	Vietnam	Crop system	Legume	<u>Crop rotation:</u> Introduce legume crops in the spring season in mono-cropped upland rice system	Spring legume - Upland rice rotation in northern Vietnam.
42	Vietnam	Crop system	Peanut	<u>Crop rotation:</u> Peanut varieties L12, L14, L15, L23, L24, MD7, MD9 for upland rice-based crop rotation	Spring legume - Upland rice rotation in northern Vietnam.
43	Vietnam	Crop system	Soybean	<u>Crop rotation:</u> Soybean varieties DT12, DT84, DT2004, VX93 for upland rice-based crop rotation	Spring legume - Upland rice rotation in northern Vietnam.
44	Vietnam	Crop system	Fodder	<u>Livestock fodder:</u> Food grass (Guatemala grass and Elephant grass) for livestock	Livestock raising areas in northern Vietnam.

Appendix C

Validated lowland technologies and extrapolation domain, Lao PDR and Vietnam

S.N.	Country	Technology group	Crop	Variety and technology description	Extrapolation domain
1	Laos	Variety	Rice	B-6144F-MR-6 (non glutinous)	Northern Lao montane lowlands for lowland rice culture in dry and wet seasons under farmer practice or with none to recommended fertilizer dosage.
2	Laos	Variety	Rice	Gall midge tolerant variety: Mueang Nga	Northern Lao paddies infested with gall midge.
3	Laos	Variety	Rice	IR5423-1 (non glutinous)	Northern Lao montane lowlands for lowland rice culture in dry and wet seasons under farmer practice or with none to recommended fertilizer dosage.
4	Laos	Variety	Rice	KDML 105 (non-glutinous)	Northern Lao lowlands grown to lowland rice in dry and wet seasons under farmer practice or with little to recommended.
5	Laos	Variety	Rice	NTN1 (glutinous)	Northern Lao lowlands grown to lowland rice in dry and wet seasons under farmer practice or with little to recommended.
6	Laos	Variety	Rice	PSBRc68	Northern Lao lowlands grown to lowland rice in dry and wet seasons under farmer practice or with little to recommended.
7	Laos	Variety	Rice	TDK1 (glutinous)	Northern Lao lowlands grown to lowland rice in dry and wet seasons under farmer practice or with little to recommended.
8	Laos	Variety	Rice	TDK5 (glutinous)	Northern Lao lowlands grown to lowland rice in dry and wet seasons under farmer practice or with little to recommended.
9	Laos	Variety	Rice	TDK6 (glutinous)	Northern Lao lowlands grown to lowland rice in dry and wet seasons under farmer practice or with little to recommended
10	Laos	Variety	Rice	TDK7 (glutinous)	Northern Lao lowlands grown to lowland rice in dry and wet seasons under farmer practice or with little to recommended.
11	Laos	Variety	Rice	TDK9	Northern Lao lowlands grown to lowland rice in dry and wet seasons under farmer practice or with little to recommended fertilizer dosage.
12	Laos	Variety	Rice	TSN1 (glutinous)	Northern Lao lowlands grown to lowland rice in dry and wet seasons under farmer practice or with little to recommended fertilizer dosage.
13	Laos	Management	Rice	<u>Nutrient management:</u> Effect of different dosages of NPK fertilizer application on lowland rice yield	Northern Lao lowlands grown to lowland rice in dry and wet seasons.
14	Laos	Management	Rice	<u>Nutrient management:</u> Effect of different sources of nutrient (<i>Chromolaena odorata</i> , pig manure, and inorganic fertilizer) on rice yield	Northern Lao lowlands grown to lowland rice in dry and wet seasons.
15	Laos	Management	Rice	<u>Non-chemical weed control:</u> Optimum number of weeding to obtain high rice yield	Northern Lao lowlands grown to lowland rice.

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S.N.	Country	Technology group	Crop	Variety and technology description	Extrapolation domain
16	Laos	Management	Rice	<u>Non-chemical weed control:</u> Effect of hill spacing and number of seeds per hill on weed control	Northern Lao lowlands grown to lowland rice.
17	Laos	Management	Rice	<u>Seedling age and plant density:</u> Effect of optimum age of seeding and optimum plant density on rice yield	Northern Lao lowlands grown to lowland rice.
18	Laos	Management	Rice	<u>Crop establishment methods:</u> Effect of crop establishment methods (transplanting, direct seeding, line seeding, and broadcasting) on weed control and rice yield	Northern Lao lowlands grown to lowland rice.
19	Laos	Crop system	Legume	<u>Crop rotation:</u> Legume crops are grown in post wet season rice using soil moisture conserving practices	Northern Lao lowlands grown to lowland rice.
20	Laos	Water saving	Rice	<u>Alternate wetting and drying:</u> Effect of alternate wetting and drying practices on water saving and rice yield	Northern Lao lowlands grown to lowland rice in the dry season.
21	Laos	Water saving	Rice	<u>Saturated and flooded soil culture:</u> Effect of saturated and flooded soil culture practices on water saving and rice yield	Northern Lao lowlands grown to lowland rice in the dry season.
22	Vietnam	Variety	Rice	AYT01	1. Northern Vietnam spring season lowland rice under farmer practice or with little to recommended fertilizer dosage. 2. Northern Vietnam summer season lowland rice under farmer practice or with little to recommended fertilizer dosage.
23	Vietnam	Variety	Rice	AYT77	1. Northern Vietnam spring season lowland rice under farmer practice or with little to recommended fertilizer dosage. 2. Northern Vietnam summer season lowland rice (under farmer practice or with little to recommended fertilizer dosage) followed by winter legume.
24	Vietnam	Variety	Rice	BT13	1. Northern Vietnam spring season lowland rice under farmer practice or with little to recommended fertilizer dosage. 2. Northern Vietnam summer season lowland rice (under farmer practice or with little to recommended fertilizer dosage) followed by winter legume.
25	Vietnam	Variety	Rice	BTR01	1. Northern Vietnam spring season lowland rice under farmer practice or with little to recommended fertilizer dosage. 2. Northern Vietnam summer season lowland rice under farmer practice or with little to recommended fertilizer dosage.
26	Vietnam	Variety	Rice	CIRAD141	Northern Vietnam lowlands under farmer practice or with little to recommended fertilizer dosage.

S.N.	Country	Technology group	Crop	Variety and technology description	Extrapolation domain
27	Vietnam	Variety	Rice	HYT100 (hybrid variety)	1. Northern Vietnam spring season lowland rice with fertilizer. 2. Northern Vietnam summer season lowland rice with fertilizer.
28	Vietnam	Variety	Rice	HYT183 (hybrid variety)	1. Northern Vietnam spring season lowland rice with fertilizer. 2. Northern Vietnam summer season lowland rice with fertilizer.
29	Vietnam	Variety	Rice	IR74371-3-1-1	1. Northern Vietnam spring season lowland rice under farmer practice or with little to recommended fertilizer dosage. 2. Northern Vietnam summer season lowland rice under farmer practice or with little to recommended fertilizer dosage.
30	Vietnam	Variety	Rice	IR74371-54-1	1. Northern Vietnam spring season lowland rice under farmer practice or with little to recommended fertilizer dosage. 2. Northern Vietnam summer season lowland rice under farmer practice or with little to recommended fertilizer dosage.
31	Vietnam	Variety	Rice	LCV9	1. Northern Vietnam spring season lowland rice under farmer practice or with little to recommended fertilizer dosage. 2. Northern Vietnam summer season lowland rice under farmer practice or with little to recommended fertilizer dosage.
32	Vietnam	Variety	Rice	N46	1. Northern Vietnam spring season lowland rice under farmer practice or with little to recommended fertilizer dosage. 2. Northern Vietnam summer season lowland rice (under farmer practice or with little to recommended fertilizer dosage) followed by winter legume.
33	Vietnam	Variety	Rice	T10	1. Northern Vietnam spring season lowland rice under farmer practice or with little to recommended fertilizer dosage. 2. Northern Vietnam summer season lowland rice under farmer practice or with little to recommended fertilizer dosage.
34	Vietnam	Variety	Rice	VD8	1. Northern Vietnam spring season lowland rice under farmer practice or with little to recommended fertilizer dosage. 2. Northern Vietnam summer season lowland rice under farmer practice or with little to recommended fertilizer dosage.
35	Vietnam	Variety	Rice	Nhi Uu 838	1. Northern Vietnam spring season lowland rice with fertilizer. 2. Northern Vietnam summer season lowland rice with fertilizer.

S.N.	Country	Technology group	Crop	Variety and technology description	Extrapolation domain
36	Vietnam	Variety	Rice	KD 18	Northern Vietnam lowlands under farmer practice or with little to recommended fertilizer dosage.
37	Vietnam	Variety	Rice	Chiem Huong	Northern Vietnam lowlands under farmer practice or with little to recommended fertilizer dosage.
38	Vietnam	Management	Rice	<u>Fertilizer dose for lowland rice:</u> Different combination of NPK fertilizer to obtain optimum yield of lowland inbred rice variety	1. Northern Vietnam spring season lowland rice. 2. Northern Vietnam summer season lowland rice.
39	Vietnam	Management	Rice	<u>Fertilizer dose for popular hybrid rice variety Nhi Uu 838:</u> Different combination of NPK fertilizer to obtain optimum yield of lowland hybrid rice variety	1. Northern Vietnam spring season lowland rice. 2. Northern Vietnam summer season lowland rice.
40	Vietnam	Management	Rice	<u>Optimum rice seedling density:</u> Optimum number of seedling per hill to obtain maximum rice yield	Northern Vietnam summer season lowland rice growing paddies.
41	Vietnam	Management	Rice	<u>Crop establishment method:</u> Rice yield under direct seeding and transplanting methods of crop establishment	1. Northern Vietnam spring season lowland rice. 2. Northern Vietnam summer season lowland rice.
42	Vietnam	Management	Rice	<u>Weed management:</u> Optimum number of weeding to obtain high rice yield	1. Northern Vietnam spring season lowland rice. 2. Northern Vietnam summer season lowland rice.
43	Vietnam	Crop system	Legume	<u>Crop rotation:</u> Introduce legume crops (peanut or soybean) in the spring season in mono-cropped summer season lowland rice system	Northern Vietnam lowlands grown to rainfed lowland rice in the summer season.
44	Vietnam	Crop system	Legume	<u>Crop rotation:</u> Introduce legume crops (soybean and peanut) as third crop after summer season rice crop in double-cropped lowland rice system	Northern Vietnam lowlands grown to irrigated lowland rice.
45	Vietnam	Crop system	Legume	<u>Crop rotation:</u> Introduce maize as third crop after summer rice crop in double cropped lowland rice system	Northern Vietnam lowlands grown to irrigated lowland rice.
46	Vietnam	Crop system	Peanut	<u>Crop rotation:</u> Peanut varieties L12, L14, L15, L23, L24, MD7, MD9 for lowland rice-based crop rotation	1. Spring legume - Lowland rice rotation in northern Vietnam. 2. Lowland rice - Winter legume rotation in northern Vietnam.
47	Vietnam	Crop system	Soybean	<u>Crop rotation:</u> Soybean varieties DT12, DT84, DT2004, VX93 for lowland rice-based crop rotation	1. Spring legume - Lowland rice rotation in northern Vietnam. 2. Lowland rice - Winter legume rotation in northern Vietnam.
48	Vietnam	Water saving	Rice	<u>Saturated soil culture:</u> Saturated soil culture with vegetal and plastic mulch to save water in lowland rice cultivation in the spring season	Northern Vietnam lowlands grown to lowland rice in the spring season.
49	Vietnam	Water saving	Rice	<u>Furrow and raised bed irrigation system:</u> Furrow and raised bed irrigation system to save water in the spring season in lowland rice	Northern Vietnam lowlands grown to lowland rice in the spring season.
50	Vietnam	Water saving	Rice	<u>Aerobic rice varieties:</u> To test the feasibility of growing aerobic rice varieties in the spring and summer season in lowlands	Northern Vietnam lowlands grown to lowland rice in the spring season.

Appendix D

1. Annual reports
2. Project data and documentation of database
3. Electronic copy of publications
4. Completion workshop presentation slides
5. Project Video for Lao PDR and Vietnam