博士論文

An Economic Analysis of the Effects of Small-Scale Pond Irrigation on Farm Income and Rural Development in Southern Provinces of Lao PDR

(ラオス南部における小規模溜池灌漑の農家所得と農村開発に

及ぼす効果の経済分析)

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ABSTRACT

This dissertation aims to gain an understanding of impacts of small-scale pond irrigation on rural poor farm households and poverty reduction linkages in lowland rice-based farming systems in rural southern areas of Lao PDR. Recently, Lao Government is trying to develop a rice policy for the country. One of the aspirations of the country is becoming a rice exporter (as the country has already attained self-sufficiency level). To achieve this goal, the Government of Lao PDR has been investing in intensify production support including irrigation for rice farmers during the dry season. However, construction of large irrigation scheme requires high investment and management. Laos has abundant sources of water during wet season but most of this will be gone as run-off water. A number of ponds or reservoirs are already used by farmers but their use and management are still an issue. To our knowledge, there is no empirical research examining the impacts of homestead ponds on production, farm income and market participation of the rural households in lowland rice-based farming systems in Lao PDR. Therefore, this dissertation intends to contribute to the empirical study of impact of small-scale pond irrigation on farm household income and poverty linkages in Southern parts of Laos. The research project by IRRI was initiated in 2011 through the ACIAR-funded project "Developing Improved Farming and Marketing Systems in Rainfed Regions of Southern Lao PDR" to help farmers improve the management of water in their farm ponds. The dissertation first used most of information obtained through a household survey of the ACIAR research project conducted in the four districts during August to September, 2012. In total 23 villages were selected to conduct a field survey, in 4 districts which are namely Outhoumphone, Champhone, Phonthong and Sukhuma districts due to their intensity of individual farm ponds in southern Laos

To achieve its objectives, the first research of this dissertation assesses the economic impact of farmstead pond irrigation on the decomposition of farm household income under rice-based farming systems, the comparative analysis of two groups from farm household survey 2012 (188 pond farms and 34 no-pond farms) is used to describe the potential benefits of pond irrigation for the farmers' annual incomes. The empirical models of crop annual incomes (mainly soybean, vegetable and total crops) and models for per capita incomes are developed to investigate the impacts and linkages. The

results from our research show that there are significant differences in household income from famers with a pond and that without a pond. The premise is that resource water can be developed on many homesteads by construction of ponds: this can support more sustainable production systems, higher productivity and income, and greater well being of the family.

However, the impact of pond irrigation on household income for poor famers in the southern also could be referred to the increase in agricultural commercialization due to water availability for enhancing production in both dry and wet season for pond farms. This increase in production encourages poor famers to participate in market by selling their products to local traders appointed at their village. The empirical study on the extent of pond irrigation and informal contact of sales for the rural Lao farmers, has provided some evidences of the impact of small scale irrigation on market participation of poor pond farmers in Southern Laos. This contact of sales created between the farmers and local traders affects significantly the smallholders' household income. In general, this kind of market arrangement is informal in many places of rural areas of Laos, where farmers are isolated from the infrastructure development. Only local small traders are their mean of market access and facilitate to sell out their farm outputs.

Finally, Based on these results, it is important to continue a research on the questions of what effectiveness of pond construction projects and what is the best choice of resource allocation in term of cropping land and water land on farmstead in the context of Southern Laos. Research on economic model of pond irrigation was studied. The empirical results show that small, medium and large ponds are profitable with positive NPVs, IRRs and BCRs. However, these economic indices are not so high as the potential benefits of ponds are not currently optimized. Overall, small and medium ponds show better profits than do large ponds (in term of BCR). By applying the BN model for pond modeling in different climatic scenarios and farming management styles, the simulation results show that the optimum size of the pond which appears to be around 0.03-0.09 of the farm area. However, it is important to note that the optimum pond size for the individual indicators (income, irrigation water or number of dry week) is not the same. Hence, here is a choice that the farmer should make: for his farm and the household, which indicator is the most important? Simulation can help oversee the consequences but the farmer should make the choice. The value of this optimum pond size (pond

model) is strongly related to the farming practice and not so much dependent on the relative pond size or rainfall.

The results of this dissertation provide the first source of evidence about the multiple-uses and benefits of ponds for agricultural production in Laos. Data strongly indicate the utility of ponds, suggesting the need for further research on methods to optimize their use in the Lao context. Additionally, an evidenced-based case arises for Government and development agencies in Laos to use the farm pond model within community development projects.

DEDICATION

This dissertation is dedicated to my beloved parents who loved and encouraged me to pursue this doctoral study. It is also dedicated to my beloved wife who loves and supported me with her patience to achieve my goal.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ADB	Asian Development Bank
APB	Agriculture Promotion Bank
BOL	Bank of the Lao PDR
DAFO	District Agricultural and Forestry Offices
DOI	Department of Irrigation
DOS	Department of Statistics
DS	Dry Season
FAO	Food and Agriculture Organization
FDI	Foreign Direct Investment
GDP	Gross Domestic Product
GOL	Government of Laos
JICA	Japan International Cooperation Agency
LAK	Lao Kip monetary currency
LECS	Laos Expenditure and Consumption Survey
MAF	Ministry of Agriculture and Forestry
MDGs	Millennium Development Goals
MPI	Ministry of Planning and Investment
NAFES	National Agriculture and Forestry Extension Service
NSC	National Statistics Center

NGPES	National Growth and Poverty Eradication Strategy
NSEDP	National Socio-Economic Development Plan
PAFO	Provincial Agriculture and Forestry Offices
SOE	State-Owned Enterprise
USD	United Nations Dollar
WS	Wet Season

1. INTRODUCTION

1.1. Background

Since the history of agriculture, farmers with access to affordable or supplemental irrigation can achieve higher yields and generate greater income than farmers who rely on rainfall conditions. Irrigation also helps smallholder farmers to produce more grain and fodder for their families and livestock in areas where households take part in subsistence agriculture. Higher yields enhance the supply of food and can also be helpful in reducing food prices in urban and rural markets. Thus, irrigation contributes to both the demand and supply components of efforts to achieve food security in developing countries.

The Green Revolution of the 1960s and 1970s gave rise to remarkable increases in grain yields being made possible by genetic improvements in rice and wheat (Turral et al., 2011; Tranh, and Kajisa, 2006). The higher yields depended also on much greater use of irrigation, fertilizer, and pesticides, all of which were essential components of the package of technological improvements of the Green Revolution (Borlaug, 2007; Dethier and Effenberger, 2012).

Large-scale irrigation development has a long history and a mixed record of successful and unsuccessful projects. Recent research evidence shows that the decline in performance and management in some of the large-scale irrigation schemes is correlated with the increasing use of small scale irrigation schemes (pumps and tube wells) allowing millions of farmers to gain access to surface water and groundwater in South Asia, China, India and Africa in recent decades (Huppert et al., 2003; Wang et al., 2005; and Kajisa et al., 2007). Shah et al. (2006) defined a small-scale irrigation as "noting that many farmers prefer the reliability and autonomy with which they access groundwater as individuals, while no longer relying on a centralized irrigation department or water purveyor to determine and implement a delivery schedule". Indeed, the increased availability of affordable small-scale pumps and tube wells, in conjunction with government subsidies in India and elsewhere, has transformed irrigated agriculture across a large portion of South and East Asia (Kajisa et al., 2007).

In rural Africa, many farmers also practice small, private irrigation in efforts to increase their production and to enhance their food security (Woltering et al., 2011; Burney and Naylor, 2012). Large-scale irrigation schemes are not common in Africa, and thus most farmers either rely on rainfall or they invest in efforts to have access to groundwater or surface water (Turral et al., 2011). While not as widely studied or publicized as the tube well revolution in South Asia and recently in India, the increase in small, private irrigation in Africa has improved the livelihood status of many households (You et al., 2011). To supplement their irrigation, they invest including the constructing of small ponds to capture and store rainfall for irrigation, and the purchase of treadle pumps and small motor pumps to access shallow groundwater (Giordano et al., 2012). Many farmers also have invested in drip irrigation kits, buckets, and pipes that enable them to capture, deliver and apply water on small plots of grains, fodder, and vegetables (Torkamani and Shajari, 2008; Vince, 2010). Much of the investment in small-scale water extraction devices, farm ponds, and irrigation equipment in Africa and South Asia has been made by individual farmers, without the involvement of a formal irrigation scheme or water user association. Farmers largely determine the investments they wish to make, and they seek information and technical support from local providers (Giordano et al., 2012). Donor organizations and extension agencies certainly have supported the introduction and dissemination of selected technologies, over time, but the farm-level investments largely have involved the farmers' own resources (Turral et al., 2011). Thus, we consider this phenomenon to represent small-scale and private irrigation such as pond irrigation systems for our research.

Investing in small-scale, private irrigation could bring challenges and opportunities that differ from those associated with large-scale irrigation schemes. The benefits of small, private irrigation (tank or farm pond irrigation) include the production and revenue gains made possible through reliable, timely access to surface water, groundwater, or rainfall that has been captured and stored (Pandey, 1991). The potential yields of grains, fodder, and vegetables generally are much higher with irrigation, than in rainfed settings. And much of the increase in crop yields is due to the timing of irrigation events. Water stress during reproduction can reduce yields substantially (Blum, 2009), such that the incremental value of irrigation water during reproduction is quite high.

Farmers operating in rainfed conditions have little, if any, control over water stress conditions during critical stages of the plant growth and reproductive cycle. By contrast, farmers with access to affordable and supplemental irrigation water can manage and produce crops more productively and they can ensure their food security and improve their livelihoods more adequate when the common irrigation schemes are not possible.

1.2. Research problem

Lao PDR is one of low-income developing countries that are trying to eradicate the population's poverty by 2020 and to develop its economy based on agricultural sector linked to regional and international markets. Recently, Lao Government is trying to develop a rice policy for the country. One of the aspirations of the country is becoming a rice exporter (as the country has already attained self-sufficiency level). To achieve this goal, the Government of Lao PDR has been investing in intensification of production including irrigation development for rice farmers during the dry season, mainly from the tributaries of the Mekong River. However, construction of large irrigation scheme requires high investment and management. Laos has abundant sources of water during wet season due to the climatic characteristics of the region (with a tropical monsoon) but most of this will be gone as run-off water. In many parts of rural areas, harvesting run-off water by constructing small-scale irrigation systems such as gibbon dams, reservoirs or on-farm private ponds for agricultural production are already adopted by the local development authorities but their use and management are still an issue in term of water use efficiency and economic impact on farm households' livelihood.

In Southern Laos, agricultural production is increasingly developed and the products are mainly exported to regional and international markets. Irrigated agriculture concentrates on extraction of water from surface and groundwater sources. However, water for agriculture in Southern Laos is scarce especially in the dry months from December to May although water is adequate during the rainy season. These prompted farmers in the region construct farm ponds/reservoirs to collect water during the rainy months and utilize the stored water to supplement insufficient water supply during the dry season. Water from the ponds can be used for irrigation of crops, fish culture, and drinking water for livestock in general but particularly for high value crops (vegetables and maize) and fish to generate an extra income for rural poor household (Ireson, 1995).

It is important to notice that the reservoir or pond irrigation is still less developed, particularly individual private pond irrigation is not considered as a priority of irrigation development for the rural remote farmers. The construction of farm ponds undoubtedly alleviates the persistent lack of water for agricultural production during the dry season. The research project by IRRI was initiated in 2011 through the ACIAR-funded project "Developing Improved Farming and Marketing Systems in Rainfed Regions of Southern Lao PDR" to help farmers improve the management of water in their farm ponds. However, improvement on the management of stored water may still be needed in order to further increase the productivity in these water scarce areas. Therefore, a model of pond water use will increase water use efficiency and as a result greatly contribute to the welfare of poor farmers to rural poverty reduction linkages, and to the development of the country's economy as a whole.

Though ponds have been used by farmers in rural areas of Laos in the past, a considerable amount of investment is required to make irrigation water available in this way, it is important to understand how effective such investments will prove to be. This is an especially important question where farmers with low levels of capital must allocate scarce agricultural resources for the establishment of farmstead ponds. A clear understanding of cost and benefits of pond investment will help the public authorities or other development agencies to provide an adequate supports (technical and financial) to potential farmers who wants to have pond on their farms. To our knowledge, there is no empirical research examining the impacts of homestead ponds on farm production, farm income and poverty linkages of the rural households in lowland rice-based farming systems in Lao PDR. Therefore, this dissertation intends to contribute to the empirical study of impact of pond irrigation in this regard.

1.3. Objectives and research questions

This dissertation aims to gain an understanding of impacts of small-scale pond irrigation on poor farm households and to provide a guideline of pond model as a tool for rural development in the context of lowland rice-based farming systems in rural southern areas of Lao PDR. In particular, the following four research questions will be addressed:

1. How does small-scale pond irrigation affect farm production and household income in southern Laos?
2. What is the impact of pond irrigation on market participation (agricultural commercialization and market-oriented production)?
3. What are the benefits and costs of farmstead ponds in rural southern Laos? (i.e. the effectiveness of farm pond investment)?
4. What are the suitable land-water resource ratios in different scenario of Lao farm management strategies in the context of southern Laos?

To fulfill the objectives and to address the research questions listed above, field survey and data collections were conducted in the study areas of two southern provinces of Lao PDR.

1.4. Methodology

1.4.1. The study sites

Southern Lao PDR has a tropical monsoon climate characterized by alternating wet season (April - November) and dry season (December - March). The annual rainfall average is 1000-1500 mm, and more than 85% of the rain falls during the months of May-September. Savannakhet and Champasak are the two provinces selected for the study. They are located on the left bank of the Mekong River. Extreme weather conditions of drought and flood are the major threats for the agricultural production in these provinces.

The study sites comprise 4 districts: namely Outhoumphone, Champhone, Phonthong and Sukhuma districts. Agriculture in these districts is characterized by small-scale subsistence rice-based farming systems. The diversity of dry season crops potentially generates an extra income for farmer household such as vegetable, maize, beans, and water melon. Since irrigation schemes have not been developed in our study sites, most farmers withdraw irrigation water from various sources including rainfall harvesting, based on the collection and concentration of surface run-off in a farm pond to irrigate crop production. Beside crop cultivation, farmers are also raising several types of livestock including cow, buffalo, goat, pig, and poultry as supplementary sources of household cash income, food and fertilizer. Many young residents have out-migrated to the capital cities as they do not perceive farming as an attractive occupation and local employment opportunities are very limited. Local farmers struggle to generate off-farm income through seasonal works and remittance from their children working in the cities or in the neighboring country (Thailand).

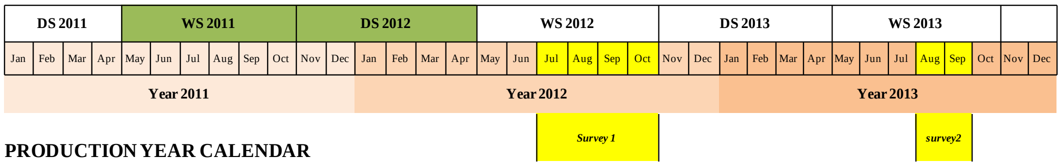
Poverty, however, is still prevalent, and its reduction is a pressing issue in the study sites. A multiple use of farm pond is expected to contribute to it since pond farmers can not only supplement irrigation water during the wet and dry season but also raise fish for their household consumption or even selling some surplus to the local market.

1.4.2. Field survey

Most of information for this dissertation was obtained through a household survey conducted in the four districts. There were two field surveys: 1st survey was carried out in July-September 2012 and the second survey was conducted in August-September 2013. We developed the questionnaire based on an informal presurvey conducted in February 2012 by IRRI using individual interviews and group discussions with farmers and key informants. The survey periods and production year calendar are shown in figure 1.1. As mentioned in the section 1.4.1, there are two cropping seasons in a year. The first survey covered the information of one production year from WS 2011 (May-October) to DS 2012 (November-April), thus, we used one production year including two cropping seasons: WS 2011 (May-October) and DS2012 (November-April).

For the subsequent analysis in the dissertation, we define a production year as consecutive two cropping seasons because the rainfall in the previous rain season is farm production in the following dry season.

Figure 1.1. Survey periods and production year calendar



The statistics of villages and pond numbers in each district were provided by the District Agriculture, Forestry, and Extension Offices (DAFEO). We selected to survey the poor villages listed provided by the village authorities (village head). Target farmers are predetermined as following criteria:

- Producing rice as main product
- Having an individual pond and actively use it in agricultural production (WS2011 and DS2012) such as crops (vegetables, maize, beans, and others), and fish raising

Interviewers who assisted the researcher in conducting the survey were trained in administering the questionnaire. The pond-specific survey contains, in particular, a series of questions, such as pond size, irrigation status, ownership, types of soil, soil fertility, distance from home, topography and slope, types of crops, yields, crop intensity, crop rotation and the occurrence of natural disasters. Village features include distance from the district centre and from capital city. In addition, we collected data describing total household income and income by source including crops (vegetables and beans), fish, livestock, off-farm, and other income. The questionnaire used for the survey 2012 was attached in Appendix.

In this study, net farm income from operations is obtained by subtracting gross farm expenses (paid-out costs for farm production) from the value of farm outputs (sales and home consumption) during the year of production (WS and DS). Each crop income refers to the value of output minus paid-out production costs, taking into account the market value of crops produced for home consumption. Off-farm income includes the wages of the household's agricultural and non-agricultural workers, income from self-run businesses, and migrant remittances. Livestock income comprises the net income generated from animal husbandry, including the byproducts. The remaining income is treated as 'other income' and may include retirement pensions, earnings from leasing or sales of assets and other unidentified sources. Additional supplementary information was collected through key informant interviews and observation. Selected village heads or leaders, elderly farmers and road/pond constructing companies were the key informants interviewed. Market prices for crops, pumping costs and labor costs are obtained from the survey and also from the Provincial Agricultural, Forestry Offices (PAFEO) and Provincial Industry and Commerce Offices (PICO) for years 2010/2011, 2011/2012, and 2012/2013.

The target farmers were obviously divided in two groups before the random sampling for the first survey 2012: pond farmers and no-pond farmers. These two groups were separately, randomly selected with the predetermined criteria cited in the section 1.4.2. According to the time schedule and budget constraint, only 256 farmers were randomly visited and interviewed on their farms (206 pond farmers and 50 no-pond farmers). Due to incomplete information and false results in some questionnaires, 222 valid questionnaires were taken in the end: pond-farm (188 households) and no-pond farm (34 households). For the second survey 2013, 100 pond farms were revisited for deeply detail on cost and benefits of irrigation pond construction.

In the study sites, more than 16% of ponds were randomly surveyed in each village except Pha ding village, only one pond farm were interviewed (totally 10 pond farms in this village). On average, 49 % of total pond farms in Uthoumphone district, 64 % of pond farms in Champhone district, 38% of total pond farms in Sukhuma district, and 29% of total pond farms in Phoanthong district were randomly surveyed; respectively, but the total number of pond farms sampled are similar for both provinces. A summary of number of households and ponds was shown in Table A1.2 (Appendix to Chapter 1).

Moreover, additional information for pond modeling was obtained from the 7 pond observation stations regarding soil texture, pond water depth, cropping patterns and irrigation management in the areas under pond irrigation. 9 year climatic data were also collected from the Provincial Meteorology Offices in each province.

1.4.3. Data analysis

The cross-sectional data of 222 farm households' survey were used in our econometric analysis for this dissertation. The empirical estimations in Chapter 3 and 4 were conducted by using the STATA statistical package, version 12. The financial analysis in Chapter 5 was conducted by using the financial package in Excel 2010. Finally, the pond modeling work in Chapter 6 was conducted by adopting the BoNam model developed by Frits et al. (2010) and simulated by using SIMILE software version 5.96. The output results were displayed in Excel for interpretation.

1.5. Overview of the dissertation

This doctoral dissertation is divided into seven chapters. Chapters 1 and 2 provide general background on the brief review of small-scale irrigation development in the past, the research design and the research methodology. The literature review in Chapter 2 provides an overview of farming system and irrigation management in Lao PDR, the past and current research on small-scale pond irrigation and poverty linkages, and a brief description of poverty status in Lao PDR. The following 4 Chapters (Chapters 3 to 6) comprise the core of the dissertation addressing each of the research questions respectively: each chapter describes the research objective, methods, empirical results, conclusion, and policy implications. Finally, Chapter 7 concluded the dissertation. The focus of the core chapters in this dissertation is as follows.

Chapter 3 aims to answer the first research question. To understand the economic impact of farmstead pond irrigation on crop production and farm household income under rice-based farming systems, the comparative analysis of two groups from farm household survey 2012 (188 pond farms and 34 no-pond farms) is used to describe the potential benefits of pond irrigation for the farmers' annual incomes. The empirical models of crop yields (mainly soybean, vegetables and WS rice) and models for per capita income are developed to investigate the impacts. As pond farm (PONDFARM) is assumed to be endogenous, we examine the impact of pond irrigation on crop yields (soybean, vegetables, and rice) and on various sources of household income by using the Propensity Score Matching procedure (PSM). The nearest neighbor matching (NNM) methods with the common support program was applied. The results prove that pond irrigation has positive and significant impact on soybean and vegetables yields. The indirect effect of the pond irrigation on wet season rice yield reveals a difference in rice yield but not statistically significant. The PSM matching results on income shows per capita farm income and household income between famers with a pond and those without a pond.

Chapter 4 addresses the second research question and describes impacts of pond irrigation on market participation of the poor farmers in rural southern Laos. The concept of agricultural commercialization was studied in this chapter. In this section, two main empirical analyses are conducted by using the household survey dataset 2012. First, the regression analysis is to investigate the relationship between pond irrigation and degree of commercialization of a farm. The second analysis is to investigate the impact of pond irrigation on farmers' participation to informal sale contract. We extend the analysis on the impact of contract participation on per capita income and on agricultural commercialization. From the field survey, we observed that many farmers sell their products to local traders called middleman with whom they made a contract arrangement (informal contract). Pond farm and contract variables are endogenous in our research; the bivariate probit model is applied to determine the factors influencing the farm households' decision to produce crops under contract. Then, the effect of participation on income by using the propensity score matching method (PSM). The bivariate probit regression shows that rural farmers with larger land and wealthier farm assets (machinery and draft animal holding on farm) are more likely to have individual pond irrigation for enhancing their production outputs and to engage in inform sale contract arrangement with the local traders in the study areas. The empirical study of this chapter has provided some evidence of the positive impact of small scale pond irrigation on agricultural commercialization and participation in sale contract among farmers in Southern Laos. The PSM results show that farmers with contract earn more crop income per capita than farmers without contracts. But with respect to household income per capita, there is no significant difference between the two groups of farmers.

Chapter 5 answers to the third research question. The study aims to examine the effectiveness of pond construction investments as a guideline for rural development in small-scale pond irrigation in Lao PDR. The original contribution of this chapter is to evaluate the costs and benefits of multiple-purpose farmstead ponds in Southern Laos. 100 ponds (small, medium and large ponds) were selected at random to be interviewed for 4 districts to capture the variation relating to pond costs and benefits. Two scenarios of pond farm management strategies include self-sufficient farm and intensified farm. Cost-Benefit evaluation (CBA) of ponds is done by a comparison of the cost of construction with the potential benefits generated from a pond constructed on farm. The evaluation method is based on comparing the net present value (NPV), which is the discounted sum of all future benefits and costs associated with the ponds. The results show that all sizes of ponds are profitable with positive net present values and benefit-cost ratios (BCR) greater than 1. When the imputed cost of family labor is included, small and medium ponds justify investment. For the case of self-sufficient farms, small and medium ponds offer higher economic incomes than that of large pond in the rural context of Laos. But in case of intensifying farmers, medium and large ponds show better income than small ponds.

Chapter 6 deals with the fourth research question. The modeling research is to run the simulation by using a software program called Bonam model which is developed by Frits et al., 2010. The dataset from two provinces are used to calibrate the model including climatic data (9 consecutive years), soil characteristics and pond management data of the survey in Southern Laos, and the market prices 2010-2013. The research aims to determine the best land water ratio (pond ratio) for a particular farm (one farm for one location) by comparing the simulation results from varying the pond ratio variable. Two scenarios from Chapter 5 are used to run the simulation in order to design suitable model of pond irrigation in the areas. The simulation results show the different gross farm incomes with different sizes of pond (pond ratio) for these two scenarios. The results suggest that the optimum ratio of pond model in S outhern Laos is less than 0.09.

2. AGRICULTURE, IRRIGATION DEVELOPMENT AND POVERTY LINKAGES

2.1..Overview of Lao PDR

A landlocked country located in Southeast Asia (figure 2.1), Lao PDR has a total area of 236,800 square kilometers sharing borders with Cambodia, China, Burma (Myanmar), Thailand and Vietnam. The total population was estimated to be 6,520,000 in 2012 with a density of 26.7 people per square kilometers (World Bank, 2013) and a third of the country's population lives below the international poverty line which means living on less than US$1.25 per day (IMF, 2012). In 2013, Laos ranked the 138th place (tied with Cambodia) on the Human Development Index (HDI), indicating that Laos currently only has medium to low development (UNDP, 2013). The GDP per capita is estimated at 1,500 USD in 2012 (World Bank, 2013). About 85 per cent of total population lives in rural areas and the majority of the rural population resides in the lowland areas (50 per cent); about 30 per cent is located in the upland areas; and the remaining (20 per cent) is settled in the region combining upland and lowlands (MAF, 2010(a)). Lao PDR is a mountainous country with a warm tropical climate (a monsoon climate). The mean temperature is a range of 22 to 29 degrees Celsius with the mean maximum temperature of 32 degrees Celsius (Nieman and Kamp, 2009). The climate is divided into two seasons: the wet season (rainy season) is from May to September, and the dry season is from October to April. More that 90 per cent of precipitation is in the rainy season.

The Lao economy depends heavily on investment and from trade with its neighbors, Thailand, Vietnam, and China. Southern provinces have also experienced growth based on cross-border trade with Thailand and Vietnam, while northern region especially depends on China. The country receives development aid from the IMF, ADB, and other international sources; and also foreign direct investment for development of the society, industry, hydropower and mining (most notably of copper and gold) (IMF, 2013: WB, 2013). Agriculture still accounts for half of the GDP and provides 80% of employment. Rice dominates agriculture, with about 80% of the arable land area used for growing rice. Approximately 77% of Lao farm households are self-sufficient in rice (MAF, 2010a).

Laos is rich in mineral resources and imports petroleum and gas. Metallurgy is an important industry such as coal, gold, bauxite, tin, copper, and other valuable metals. In addition, the country's plentiful water resources and mountainous terrain enable it to produce and export large quantities of hydroelectric energy. Of the potential capacity of approximately 18,000 megawatts, around 8,000 megawatts have been committed for exporting to Thailand and Vietnam (MPI, 2012).

Figure 2.1. Map of the Lao PDR

2.2. Agriculture and irrigation development in Laos

2.2.1. Farming systems

Farming systems in Laos can be broadly categorized into two systems: lowland rain-fed and/or irrigated farming systems, mainly in the Central and Southern regions; and upland swidden farming systems, predominantly in the Northern mountainous areas. Most of the Lao population lives in rural areas and is engaged in subsistence agriculture. Subsistence rice cultivation is dominant and this employs about 80 per cent of the Lao workforce. Farmers practice small-scale farming, with an average land holding of about 1.6 hectares. It is estimated that 93 per cent of cultivated area is devoted to rice production, in particular, glutinous rice. This is used predominantly for household consumption (Bestari et al., 2006). Due to this small-scale farming system focusing on family consumption, only 6 per cent of farmers in Laos produce completely for markets by selling their total output; about one third (35 per cent) produce some surplus for commercial purposes, while meeting their own subsistence is their priority; and the remaining 59 per cent cultivate solely for household consumption (FAO, 2008). This glutinous rice cultivation is mostly supplemented by animal raising (namely, chickens, ducks, pigs, goats, cattle, and buffaloes), vegetable gardens, and fruit trees (mangoes, coconuts or bananas). It is expected that the demand for rice is growing rapidly due to the population growth rate of 2.5 per cent (Bestari et al., 2006).

2.2.2. Traditional irrigation for rural poor farmers in Laos

Rice-based farming farmers throughout Laos have been building traditional weirs and canals for centuries to provide supplementary irrigation to their wet-season rice crops. A typical traditional scheme would include a weir made of logs, stones, and sometimes bamboo and earth, with small hand-dug canals (Ireson, 1995). The command area of these traditional irrigation schemes has varied from a few hectares to about 100 ha, governed mostly by the limited areas of flat land within the mountainous watersheds. These small diversion schemes irrigate terraced or valley-floor paddy fields. As of 2002, thousands of these small weir and canal systems were still in operation in Laos (MAF, 2010b).

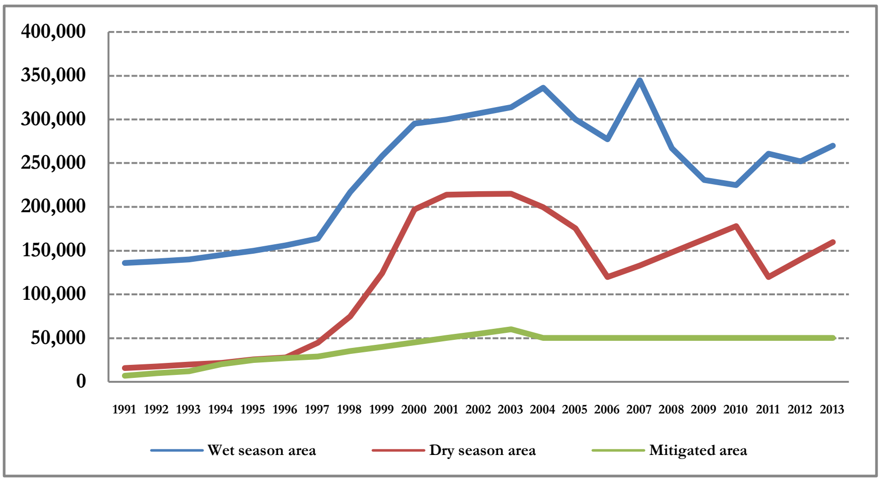
Although theses traditional schemes mainly focus on wet-season rice production, some also produce limited dry-season crops in areas where the streams have a significant dry-season flow, and where farmers have seen the potential for producing additional crops. However, on account of low efficiency levels and high labor demand for frequent repairs of the traditional weirs, over the past 25 years, hundreds of traditional systems have been replaced by more permanent and larger scale structures. However, this traditional irrigation is still being practiced by poor farmers in remote areas of the rural part of Laos where the irrigation schemes are difficult to be developed.

2.2.3. Agricultural and irrigation development in Laos

Agricultural development has been a priority for the Lao government since the establishment of Lao PDR in 1975 and irrigation has been given an important role in this process. Two years after the establishment of Lao PDR in 1975, the Government concentrated on the expansion of irrigated rice cultivation to achieve food self-sufficiency, which basically means self-sufficiency in rice. A number of large irrigation schemes were developed in the 1970s and these schemes were mostly located on the floodplain of the Mekong River close to Vientiane (Schiller et al., 2006).

The agricultural sector is very significant in economic development in Laos and will continue to be in the coming decades. It contributes to more than 40 per cent of the gross domestic product (ADB, 2012). The Government's development goals include "gradual introduction and increased application of modernized lowland market-oriented agricultural production adapted to climate change and focused on smallholder farmers; and conservation of upland ecosystems, ensuring food security and improving the livelihoods of rural communities" (MAF, 2010a). This is to serve the Government's general policy of alleviating poverty. In the early 1990s, a decision was made to expand the area of rice under irrigated production in order to accelerate improvements in rice production to achieve the joint goals of national rice self-sufficiency and greater production stability. However, it was also recognized that the proposed schemes had the potential for wet-season supplementary irrigation use as well.

Figure 2.2. Development of irrigated production areas in Laos (in hectare), 1991-2013.



Source: MAF, 2014. Author's calculation.

Figure 2.1 shows the development of irrigated production land from 1991 to 2013. The dry-season irrigated areas increased more than 750%, from 16,000 to 160,000 ha (MAF, 2010b). Around 50,000 ha were mitigated from flood.

An important increase in irrigation expansion areas was from 1997 to 2001. Most (94.5%) of the expansion in irrigated area took place in the central (70,816 ha) and southern (25,578 ha) agricultural regions. In 2001, still only about 5,600 ha were developed for irrigation in the northern agricultural region. Most of this expansion in irrigated capacity during the 1990s depended on pumping water directly from the Mekong River and, to a lesser extent, from tributaries of the Mekong. In 2013, it was estimated that Laos had 21,249 irrigation systems, with a capacity to serve about 270,000 ha in the wet season, or about 34% of the country's 800,000 ha of annually cultivated land. Irrigated land accounted for about 65% of total agricultural production.

In Laos, a total of 21,249 irrigation schemes were developed by the Lao Government supports since 1991. The capacity to irrigate is estimated to 336,305 ha. However, most of irrigation schemes were classified as tradition small scale irrigations accounting for 13,351 schemes with the capacity to irrigate the potential land in dry season accounting for about 55% of the total irrigable area (Table 2.1). If we compare the irrigated production area in wet season shown in figure 2.2 to the potential irrigated area in wet season, all irrigation schemes are not still used as their capacities could do.

Table 2.1. Irrigation schemes and irrigation capacity (potential irrigated area in 2010)

Type of irrigation system	**Number**	**Irrigable area (ha)[1]**	
		Wet season	**Dry season**
Weir	940	66,092	29,590
Reservoir	233	34,200	15,313
Pump	1,203	162,323	126,278
Gate and Dike	73	9,938	2,827
Gabions	193	5,307	10,000
Temporary weir	10,709	31,997	1,000
Community irrigation schemes	3,841	11,560	3,346
Small scale pumping schemes	4,057	14,888	10,870
Total	***21,249***	***336,305***	***199,224***

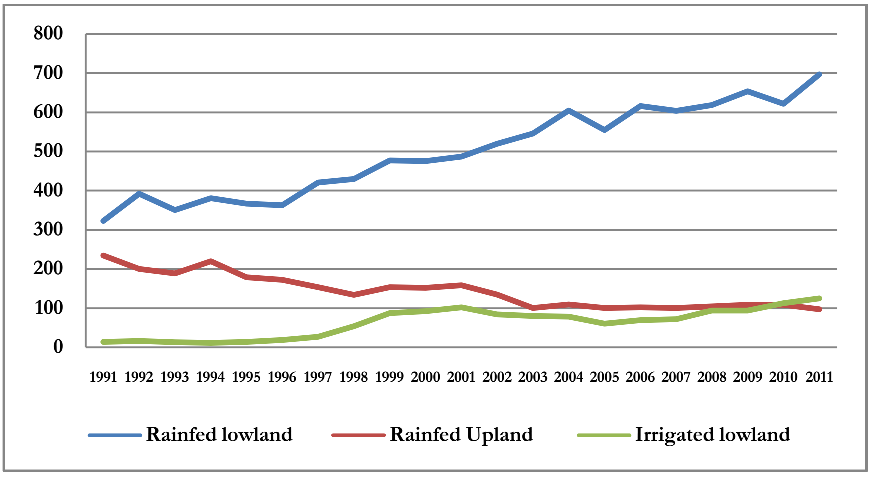
Note: [1]Irrigable land in wet season is s total potential irrigated area because it can be also used for dry season production. Source: MAF, 2010(b).

Regarding to private small-scale pond irrigation, it can be classified in reservoir scheme but it is not considered in this table because up to now, none of pond received financial support from the Lao Government. All existing ponds were constructed by farmers' themselves.

Since 1975, various agencies have been involved in programs of assistance to improve irrigation capacity within Laos. These agencies are the European Unions, United Nations Development Program (UNDP), United Nations Capital Development Fund (UNCDF), Mekong River Commission (MRC), the Japanese Government, Organization of Petroleum Exporting Countries (OPEC), World Bank, the Swedish Government, the Australian Government, and many NGOs.

As rice is the staple food for Lao people, it is cultivated in all regions of the country. Half of the rice area (51 per cent) is located in the Central Region, accounting for more than half of rice production (55 per cent). Savannakhet Province, which is included in this region, covers over 20 per cent of the rice farming area in the Central Region and contributes more than 20 per cent of national rice production. The remaining 45 per cent of rice production comes from the Southern (24 per cent) and the Northern (25 per cent) regions (Bestari et al., 2006).

Figure 2.3. Evolution of irrigated rice cultivation, 1991-2011 (a thousand hactares).



Source: MAF Agricultural Statistics Books, 2006-2012. Author's compilation 1991-2011.

As shown in figure 2.3, the rainfed area of lowland rice system steadily increases, representing 77 percent of total paddy production area in Lao PDR in 2011. The area of the upland rice system decrease which was particularly strong between 1991 and 2003 due to some extent government policies (decreasing area in the "slash-and-burn" system in the upland). On other side, the irrigated area of lowland rice system strongly increased from 1995 until 2001, followed quickly by a pronounced decrease. Then, from 2005 onwards, growth was to reach around 120,000 ha in 2011. If we compared to the irrigated production area in dry season shown in figure 2.2, this irrigated rice area covers the majority of the irrigated production area. However, despite the significant investments in irrigation, the rice area expansion in Lao PDR during the period 1991-2011 took place mainly in the area in the wet season lowland production system, increasing from around 320 000 ha in 1991 to 690 000 ha in 2011.

2.3. Irrigation management and problems in Lao PDR.

The Government of Laos has been trying hard to achieve its goals of reducing poverty and improving livelihoods and food security by promoting self-sufficiency, eradicating slash-and-burn agriculture to protect the environment, increasing income generating opportunities, and providing education for all (Bestari et al., 2006; MAF, 2010a).

To achieve this goal, the Lao Government provided special support to irrigation development. There were two key support measures: (i) reduced tariffs for power supply to pump irrigation projects; and (ii) subsidies on inputs in form of no-payment for pump equipment and installation (MAF, 2010b). A number of large irrigation schemes were developed in the 1970s and mostly located on the floodplain of the Mekong River close to Vientiane. These irrigation schemes, in particular, large lowland irrigation schemes, were managed by government agencies mainly Provincial Agricultural Forestry Extension Offices and District Agricultural Forestry extension Offices (Schiller et al., 2006).

Similar to many countries, the Government of Laos is facing operational and management issues and the management at present day is focusing on improving management and control in order to facilitate high-valued crop production by increased water productivity (Jusi & Virtanen, 2005). The new irrigation management strategies – Irrigation management transfer (IMT) and Participatory irrigation management (PIM), known as community-managed approaches – have been adopted as well in Lao PDR in 2000 (Jusi & Virtanen, 2005).

In the last five years, the Government has invested more money in irrigation infrastructure with the purpose of expanding the irrigation area and rehabilitating the existing irrigation systems. In 2009-2010, about 2,866 irrigation schemes were registered across the country. Water user associations (WUAs) have been established in 68 schemes and water user groups (WUGs) in 933 schemes. WUGs were established upon completion of a scheme and generally involved village-based organization and administration; a relatively few WUGs have been institutionalized under the regulatory framework as WUAs (MAF, 2009b). In the remaining 1,865 schemes, no WUGs have been set up as they are very small irrigation projects (MAF, 2010b).

Souvannavong (2011) conducted a research on irrigation management in Laos and concluded that the implementing IMT in Laos was facing some difficulties including: weak capacity building of the public agencies (human resources, knowledge, capability to deliver irrigation service), inadequate water management skills at farm level; lack of access to rural credit for agricultural production inputs for farmers; and limited sound agricultural advice from extension service. Moreover, there is no leader in water resource management since there is no strong coordination among water resource management agencies (ADB, 2006). This basically means there is no particular ministry responsible for administering the WUA development or implementing water laws (Jusi & Virtanen, 2005). This is identified to be the major issue in water resource management in Lao PDR since communication and coordination among provincial agricultural departments and the key central authorities are weak and inadequate (Jusi, 2010).

As reported by the Government of Laos, IMT has not been successfully implemented since local communities cannot sustainably manage irrigation facilities as WUAs are very weak. Water fees cannot be collected and do not cover operating costs, resulting in large debts (MAF, 2008b). The debt at April 2012 amounted to approximately USD 11.9 million, up from USD 8.1 million in 2011 (Eliste and Santos, 2012). There is also significant deferred maintenance, which has led to the deterioration of many systems built in the 1990s (MAF, 2010b).

2.4. Small-scale irrigation, farm pond, and livelihoods

2.4.1. Multiple function of small-scale irrigation schemes

Investments in small-scale, individual/or private irrigation are consistent with the goal of reducing the variance and increasing the mean of crop yields, by modifying soil moisture availability to enhance crop growth (Torkamani and Shajari, 2008; Takeshima and Yamauchi, 2012). Farmers who capture rain-water in a small pond for irrigation, or pump groundwater from a shallow aquifer, can manage the amount of soil moisture available during crop growth and reproductive stages.

Table 2.2. Impact of irrigation by type of system

Impact	Large-scale public, dry zone	Large-scale public, paddy-based	Small- or medium-size community-managed	Private, commercial	Smallholder, individual
Economic					
Production	Low positive	Low positive	Low positive	High positive	High positive
Food security	High positive	High positive	High positive	Low positive	High positive
Rural employment	High positive	High positive	High positive	Low positive	High positive
Social					
Settlement strategies	Mixed	Mixed	High positive	None	None
Social capital	None	Low positive	High positive	None	None
Health	Mixed	Mixed	Mixed	Low negative	Mixed
Environmental					
Biological diversity	Mixed	Mixed	Mixed	Mixed	None
Soil and water conservation	Mixed	Mixed	Mixed	Mixed	None
Water quality	High negative	Mixed	Mixed	High negative	Low negative
Cultural					
Religious ceremonies	Low negative	None	Low positive	None	None
Landscape, aesthetics	Mixed	High positive	High positive	Low negative	None
Cultural heritage	Mixed	Mixed	High positive	None	None

Source: IWMI, 2007. Note: Mixed indicated a large variability of local situations.

Many researchers conduct economic assessments of irrigation projects (large or small scales) typically based on the internal rate of return, which compares the costs and benefits of irrigation development. But this approach rarely takes into account multiple uses of irrigation water. In addition, the intangible benefits associated with irrigation are not captured (Tiffen, 1987). Irrigation development is usually associated with intensive agriculture and the forces of modernization, but it has a long history and in some places is closely linked to local culture and tradition, acting as a stable agro-ecosystem. As economies develop, the relationships among food production, food consumption, and food security become more complex. Irrigation affects the material and the cultural life of society and the environment in four main ways: economic, social, environmental, and cultural. The impact in each area varies with the type of irrigation system, and the magnitude (positive or negative) is subjective, but there is value in highlighting the complex and diverse roles of irrigation. From Table 2.2, the small or medium community-managed irrigation systems provide a wider range of high positive impacts for the farmers and beneficial communities but low impact on production. Regarding to this dissertation, pond irrigation is classified in the category of smallholder, individual irrigation system In term of economic impact, this irrigation system has high positive impact on production, food security and rural employment.

2.4.2. Farm ponds and farmers' livelihoods in rural Laos

- Pond and aquaculture in rural areas

Lao farm ponds add value to other farming activities: water from ponds can serve domestic and livestock water supplies as well as irrigation for high-value crops and vegetables. Lao farm ponds typically range from 400 m^2 to 1000 m^2; size depends on the resources of the farmer and larger natural 'small water bodies', like small lakes, can also be considered as farm ponds (Funge-Smith, 2000). Ponds offer the opportunity to rear fish and other aquatic organisms providing for diversification of food resources and income generation for the poor farmers. At smallholder farm level, there are two common types of pond systems in rural Laos.

Runoff ponds: The ponds are commonly practiced by farmers in remote areas. Runoff ponds are built in the watershed and receive water from rainfall. The sites for the pond are often chosen at the head of a shallow valley or between two small hills. Such ponds receive varying quantities of runoff depending on the ground cover. Such ponds play multiple roles in fish raising, and water harvesting for cropping.

Ground water ponds: In lowland areas of Laos, these ponds are dug in lowland areas where the water table is near the surface. Flooding is a threat and can be avoided by building a canal around the pond to divert water. Many farmers in rural Southern Laos convert their land to construct this type of pond for water harvesting and fish raising.

- *Benefits to the household*

Food security and nutrition: First benefit of pond for farmers. Water from ponds can provide irrigation for various crops productions and water for livestock. This can have a positive effect on family nutrition, making crop and livestock production less risky and allowing families to have more farm products to consume. Fish can also be produced, providing for yet another important 'nutrient' in the family diet. Pond fish is an important source of protein for the family.

Cash income generation: Water from ponds can increase the surplus of farm production. Improved production techniques and better management practice can increase the production of crops and fish from small farm ponds. With higher yields, supply to local markets can become an income generating activity for the household (Funge-Smith, 1998; Funge-Smith, 2000).

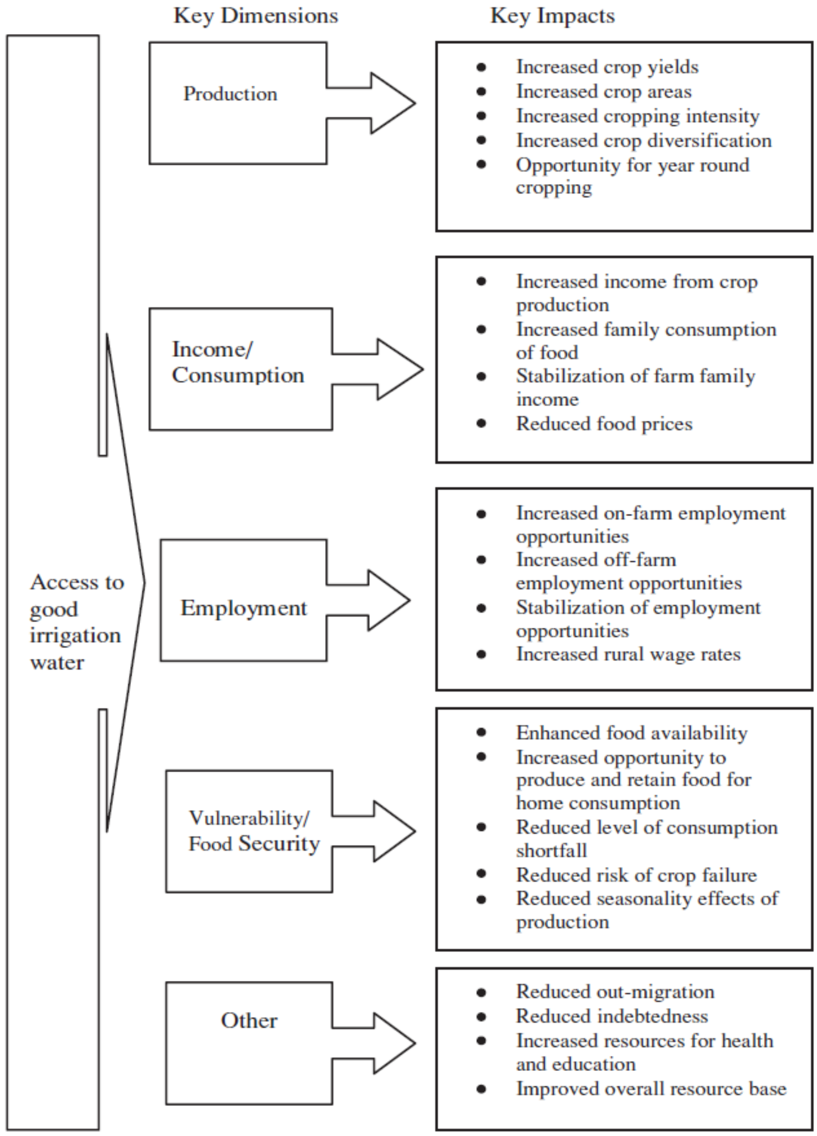
Diversification of the farming systems: Having a small pond also assists in diversification of other parts of the farm, providing opportunities for vegetable growing as well as leafy water plants. It also provides water for livestock. Pond fish also provides an excellent opportunity for diversification of rural households' farming systems. It is relatively low-cost and less liable to losses from disease compared to raising livestock, providing a relative low risk diversification of the livestock production base (Funge-Smith, 1998; Garaway, 1999).

2.5. Irrigation water and poverty linkages

Poverty is an outcome of several complex institutional factors, processes, actions and policies and often affects various households differently, depending upon their entitlements and endowments of natural and human capital resources (Hussain et al., 2000). Over the last 25 years, the understanding of poverty has advanced and become more holistic. Once understood almost exclusively as inadequacy of income, consumption and wealth, many dimensions of poverty and their complex interactions are now widely recognized (Smith, 2004). These include isolation, deprivation of political and social rights, lack of empowerment to make or influence choices, inadequate assets, poor health and mobility, poor access to services and infrastructure, and vulnerability to natural hazards such as droughts and floods.

Hussain and Hanjra (2003) conceptualized the linkages between irrigation and poverty reduction. There are five key dimensions of how access to irrigation water can contribute to poverty reduction as shown in Figure 2.4. These are (1) increased production/productivity, (2) income/consumption, (3) employment, (4) reduced vulnerability/food insecurity and (5) higher overall growth and improved welfare.

Figure 2.4. Irrigation water and poverty linkages



Source: Hussain and Hanjra, 2003.

In this dissertation, all empirical analysis attempts to provide some insights of impact of small scale pond irrigation and poverty reduction linkages for the tow key dimensions: Production and income of rural households in southern Laos.

In case of small scale individual irrigation system such as pond in Lao PDR, rural households may use water from pond irrigation for agricultural or domestic use in many ways, such as for drinking, sanitation, homestead gardens, trees, livestock, urban water supply, rural industries, artisanal fishing and aquaculture (Nguyen-Kao et al., 2005). Having water available for agriculture can encourage farmers to produce more total farm output for their own consumption and for sales and increases farm income by improving yields and cropping intensity. Reliable access to water also enhances the use of complementary inputs, such as high-yielding varieties and agrochemicals, which also increase output levels, improve farm income and contribute to reduce poverty (Smith, 2004).

2.6. Agriculture and rural poverty in Lao PDR

2.6.1. Poverty trends in Laos

Poverty Analyses of Lao PDR are based on the Lao Expenditure and Consumption Surveys (LECS), which are sample surveys to show situations of households in the country for very five years since 1992/93 by the Department of Statistics (DOS) under the Ministry of Planning and Investment (MPI). Poverty is estimated a poverty headcount ratio. At the national level, poverty incidence reduced in the decade between 1992/93 and 2002/03, from 46 % to 33.5% (Table 2.3). The population below the absolute poverty line also decreased from more than 2 million to less than 1.85 million people. The poor population decreased by 10% during the decade.

Table 2.3. Poverty incidence, % headcount of total population

Survey year	Poverty incidence(in per cent)		
	National	Urban	Rural
Year 1992/93	46	26.5	51.8
Year 1997/98	39.1	22.1	42.5
Year 2002/03	33.5	19.7	37.6
Year 2007/2008	27.6	17	32

Source: MPI, 2010.

It has been observed that poverty decreased in both urban and rural areas as well. Urban poverty incidence declined to less than 20% in 2007/08 from 26.5% in 1992/93. The reduction of poverty in rural areas was more dramatic. The incidence of poverty in rural areas decreased from 51.8% to 32% for the same period. Rural poverty remains higher than the national average because a significant share of rural population still live in the remote areas without road access for all season and lack of appropriate facilities for production.

2.6.2. Rural income and agricultural commercialization

Rural livelihoods in Laos depend mostly on subsistence farming operating small plots of farm without irrigation, and rural poverty incidence is strongly correlated with geography and the natural environment that determine agricultural production conditions. According to LECS 3, only 23% of grain production in rural areas was sold at market. It suggests that the most agriculture productions are consumed by rural households for their food subsistence. Therefore, such rural subsistence households those are partly or fully engaged in crop production, are more likely to be below the poverty line because their limited crop production results in limited income.

Table 2.4. Rural households' cash income (in percent), 2002/2003.

Region	Share of Households Earning Cash Income
Rural Laos	39
Vientiane Plain	67
Mekong Corridor	42
Central-South highland	39
North lowland	38
North highland	23

Source: MPI, 2004 (LECS III).

The level of income diversification of rural households remains low, and the ability to generate cash income from employment and/or self-employment remains limited. In 2002/03, only 39 percent of rural households were able to generate such cash income, scarcely more than half the level of Vientiane Plain's households (Table 2.4).

Moreover, the level of commercialization of agricultural products by households is quite low. Rural households participate in markets for sales of livestock more than for rice, reaching above half of households in the North (Table 2.5). Rice marketing is considerably lower, particularly in the Central-Southern highlands, but scarcely above a third of households with the exception of households in the Vientiane Plain.

Table 2.5. Rural households' rice and livestock sales (in percent), 2002/2003.

Region	Share of rural households' selling	
	Rice	Livestock
Vientiane Plain	48	40
Mekong Corridor	37	50
Central-South highland	16	47
North lowland	24	55
North highland	28	57

Source: MIP, 2004 (LECS III).

Additional marketing activities engaged by rural households are non-timber forest products (NTFP). Separate studies show that NTFPs can often be a more important source of cash income for families – as much as 50 percent or more of total cash income – than livestock of crops. These NTFP activities are the main source of cash income for households who live in the upland and northern parts of Lao PDR. But in the study site of our research, rice and livestock are the main activities generating cash income for rural households. In addition, rural women often supplement household cash income through production and marketing of handicrafts (Foppes, 2003).

2.7. Conclusion

Agricultural development has been a priority for the Lao government since the establishment of Lao PDR in 1975 and irrigation has been given an important role in this process in order to accelerate improvements in rice production to achieve the joint goals of national rice self-sufficiency and greater production stability. Lowland rainfed and irrigated farming systems are predominant. Irrigation water is withdrawn from large irrigation schemes mainly the Mekong River and its tributaries for agricultural production. To achieve its goals of reducing poverty and improving livelihoods and food security, the Lao Government provided special support to irrigation development. The irrigated production land increased from 1991 to 2013 more than 750%, from

16,000 to 160,000 ha (MAF, 2010b). Farmers who live in the command areas of these schemes produce mainly for commercial purpose, particularly in the southern provinces where the larger plains of flat lands are located. However, despite the significant investments in irrigation, the rice area expansion in Lao PDR during the period 1991–2011 took place mainly in the area in the wet season lowland production system, increasing from around 320 000 ha in 1991 to 690 000 ha in 2011.

Despite of introduction and implementation of the new irrigation management strategies, the Government of Laos was still facing some difficulties in managing these irrigation schemes due to weak capacity building of the public agencies (ADB, 2006) and due to inadequate communication and coordination among the local authorities and the key central counterparts (Jusi, 2010). Therefore, there is also significant deferred maintenance, which has led to the deterioration of many systems built in the 1990s (MAF, 2010b).

In rural parts of Lao PDR, farmers practice traditional irrigations to provide supplemental irrigation mainly for wet-season rice and some irrigated crops. Even though many of these traditional schemes have been replaced by more permanent and larger scale structures over the past 25 years, they are still being practiced by poor farmers in remote areas of the rural part of Laos where the irrigation schemes are difficult to be developed. In southern Laos, some farmers who rely on rainfall for irrigating their crops, they construct a farm pond for capture rainfall and use it for multiple purposes within the farm household. This kind of small scale and individual irrigation scheme (pond irrigation) is the key focused issue of subsequent analysis on impact of pond irrigation for the following chapters in this dissertation.

3. IMPACTS OF SMALL-SCALE POND IRRIGATION ON FARM PRODUCTION IN DRY SEASON AND HOUSEHOLD INCOME IN RURAL SOUTHERN LAOS

3.1. Introduction

Recent reviews suggest there are strong linkages between irrigation and poverty (Hussain and Hanjra, 2003; Smith, 2004). Although irrigation variables are defined differently, many of the microeconomic and econometric studies show that irrigation is a positive determinant of income and a negative determinant of poverty in Asia (Freebairn, 1995; Kishore, 2002). However, few studies examine the impacts of irrigation on production and poverty in Lao PDR. Using household survey data from the irrigation schemes in Savannakheth province, Lorenzen et al. (2000) demonstrate positive relations between irrigation and rice yields and farmers' income in the irrigated areas. In rural areas, most irrigation schemes are small scale and village or community-based and only farmers living near to the command areas of these schemes are beneficial. Some farmers construct a small reservoir or pond to capture rainfall during rainy season for irrigating rice seedbed preparation and dry season vegetables for self-consumption.

In Southern Laos, agricultural production is increasingly developed and mainly exported to regional and international markets. Irrigated agriculture concentrates on extraction of water from surface and groundwater sources. However, water for agriculture in Southern Laos is scarce especially in the dry months from December to May although water is adequate during the rainy season. Traditionally, these prompted farmers in the region construct farm ponds/reservoirs to collect water during the rainy months and utilize the stored water to augment insufficient water supply during the dry season.

Practicing farmstead pond irrigation is supposed to provide multiple benefits for farm households in many rural parts of Southern Laos. However, an important question remains to be investigated:

what impact have the farmstead ponds had on crop production as well as farm household income? This is the main motivation of this Chapter. In our study sites where a record of farm pond irrigation system is absent at the local authorities' offices and farmers hold small and fragmented land, either the studies of farmstead ponds or the numbers used in irrigating crops at the farm level is difficult to obtain.

Up to now, there is no research investigating the impact of small-scale farm pond irrigation on farm production and household's income in Laos. Ponds are small reservoirs that allow farmers to capture rainfall, and to store surplus water for agricultural activities such as cropping and animal husbandry (Mushtaq, et al., 2000). A research on farmstead pond and pond irrigation system was conducted in Northeast Thailand; this pond irrigation system is mainly used to irrigate rice during the late monsoon to early dry seasons from September through December. Integrating a farm pond in a Thai farm was strongly promoted by the New Theory of the King Bhumibol Adulyadej of Thailand on Sufficiency Economy was introduced in 1987. But this research focused mainly on farm pond modeling under climatic situations in Notheast Thailand, the economic aspect was not inclusively studied (Penning de Vries, et al., 2005; Penning de Vries & Rouaysoongnern, 2010).

To provide some empirical evidences on the importance of farm pond irrigation in Lao PDR, it is important to investigate the economic impact of small-scale irrigation pond on farm households under rice-based farming systems. Drawing on household surveys conducted by the author in two lowland rice-based farming provinces in 2012/2013, the objective of this chapter is to evaluate the impact of pond irrigation on crop production and farm household income.

3.2. Farmstead pond and household income in Southern Laos

3.2.1. Farm household and pond characteristics

Pond is commonly used within rural farms in many parts of Southern Laos. In general, ponds are natural built by making soil and/or stone dikes surrounding a reservoir or a submerged area within a paddy land in which rainfall or run-on water straggles. Many farmers use these ponds for the main purposes of collecting rainfall in rainy season for irrigating an earlier preparation of rice seedbed and of producing food such as vegetables and pond fish for home consumption, particularly for the poor farmers. For richer farmers, they construct a pond within their farms mainly for raising fishes for sales and for irrigating rice seedbed in rainy season and crops (i.e. vegetables, maize and beans). The research on pond irrigation was conducted in 4 districts which are namely Outhoumphone, Champhone, Phonthong and Sukhuma districts. Agriculture in the areas is characterized by small-scale subsistence rice-based farming systems. Most of villages visited were located in the rural areas and classified as poor village by the local authorities (lists provided by the heads of the village)

From our survey, ponds were newly constructed within farmers' land when the Government constructed access roads and lanes through the districts and villages. These pond farms obtained ponds by giving their soils to the road constructors for digging a pond on their farm land. In Table 3.1, 73 percent of ponds sampled have age between 1 and 5 years old; many of them were constructed in 2009. 10 percent of the pond sampled aged between 6 and 10 years. 10 percent of them aged between 11 and 15 years. Only 5 percent of total surveyed ponds were constructed in 1991s.

Table 3.1. Age of 188 ponds in the study sites (in percentage)

Ages of ponds	1-5 (Year 2006-2011)[1]	6-10 (Year 2001-2005)	11-15 (Year 1996-2000)	16-20 (Year 1991-1995)
Percentage	73	10	12	5

Notes: [1]Figures in parenthesis are the period of pond's construction.

Source: Field survey of 188 ponds in Southern Laos, 2012.

As shown in Table 3.2, the average farm size of the samples is 2.5 ha per household, which is higher than the national average of 1.6 ha (MAF, 2012a). The Average farm size of pond farms is much higher than those of no-pond farm. The averages of farm size are 3.38 ha and 1.7 ha for pond farms and for no-pond farms, respectively. In our samples, pond farmers are wealthier than no-pond farmers in terms of land asset and livestock asset.

The household size varies around 6 to 7 members per household. For our research, active member aging 15 to 60 years old is considered as an important to analyze the impact of pond irrigation on per capita income. This active number is significant higher in the group of pond farm than that in the group of no-pond farm.

Table 3.2. Averages of characteristics of the farms in our survey[1]

Case/feature	Pond farms in Phonthong	Pond farms in Sukhuma	Pond Farms in Champhone	Pond farms in Uthoumphone	Pond farms	No-pond Farms
Total farm size (ha)[2]	3.0 (2.1)	2.1 (1.1)	4.1 (3.4)	4.5 (2.5)	3.35(0.8)	1.7(1.4)
Paddy land (ha)	2.7 (1.7)	1.9 (0.9)	3.1 (1.9)	3.7 (2.1)	2.78(1.0)	1.6 (1.0)
Pond area (m^2)	1325 (1044)	1039 (1551)	2442 (8265)	2014 (2577)	1397 (4421)	--
Pond depth (m)	2.3(1.2)	1.9(0.7)	1.8(0.6)	2.1(1.0)	2.1(0.9)	--
Water Storage Capacity (m^3)[3]	3265 (3324)	1798 (2790)	4422 (14267)	4282 (6332)	3431(8084)	--
Pond ratio (index)[4]	0.09(0.15)	0.05(0.06)	0.06(0.10)	0.05(0.06)	0.05(0.09)	--
Pond category[5]	medium	medium	medium	medium	medium	--
Household size (heads)	6.2 (1.7)	6.5 (1.4)	6.2 (1.5)	6.9 (1.9)	6.4 (1.7)	6.4 (1.9)
Number of active members (15-60 years old)	4.2 (2.1)	4.7 (1.7)	4.3 (1.3)	5.2 (1.6)	4.6 (1.7)	3.9 (1.9)
WS Rice yield (tons/ha)	1.7 (1.0)	2.5 (2.0)	1.9 (0.8)	2.0 (0.9)	2.2 (0.7)	1.9 (0.7)
No. of rice farmers[6]	52	40	44	48	184	29
DS Soybean (kg/ha)	1123 (652)	1350 (334)	1301 (231)	1050 (211)	1220 (732)	982 (221)
No. of soybean farmers	15	13	11	15	54	31
DS Vegetable (tons/ha)	8.3 (11.1)	4.1 (5.7)	6.9 (7.7)	6.7 (13.9)	6.6 (5.3)	2.7 (3.9)
No. of vegetable farmers	27	10	21	22	80	24
WS Vegetable (tons/ha)	10.2 (3.1)	7.4 (4.7)	8.4 (8.7)	9.6 (4.4)	8.9 (11.3)	6.4 (4.3)
No. of vegetable farmers	42	40	44	42	168	34
Pond fish (kg/year)	90.3 (74.4)	107.9 (178.4)	264.8 (725.4)	156.3 (409.4)	153.2 (414.2)	--
No. of fish farmers	52	42	45	49	188	--
Livestock asset[7] (millions LAK)	3.5 (8.7)	8.2 (8.2)	7.9 (8.5)	13.9 (10.5)	8.1 (8.9)	3.4 (6.3)
Produce	Vegetable, rice, beans, fish	Rice, beans, vegetable, fish	Rice, Vegetable, fish	Vegetable, rice, beans, fish	Rice, beans, Vegetable, fish	Rice, beans, vegetable
Farm income[8] (% of total without livestock)	64	47	59	58	57	39
Number of samples	52	42	45	49	188	34

Notes:

[1] Standard deviation is in the parenthesis. [2] Total certificated land hold by a farmer. [3] This is equivalent to the dimension of pond (water volume is equal to surface area multiplied by depth). [4] Pond ratio is equivalent to a pond surface (pond surface) allocated over a total farm land. [5] Classification of pond capacity: small pond has a storage capacity is less than 1,000 m^3, medium pond has a storage capacity between 1,000 and 10,000 m^3, while large pond has more than 10,000 m^3 (Muzhtaq, et al., 2007).

[6] 9 households were excluded due to flooded paddy land. [7] Draft animal holding by household expressed in total monetary value, based on market price 2010/2012, and LAK is a Lao currency, 1US$ is equal 8,000 LAK (exchange rate provided by the Lao Exterior Commercial Bank, September, 2012). [8] Farm income is a sum of net incomes from rice, beans, vegetable and other crops including fish for pond farms.

Source: Author's calculation based on survey in 2012.

The surface size of pond differs from district to district with an average ranging from 1,324 m^2 to 2,442 m^2, which is much larger than the average size of Lao farm pond between 400 m^2 to 1,000 m^2 observed by Fung-Smith (2000). The average depth of pond is about 2.1 m. In term of pond dimension, this indicates its capacity of water storage and its capacity of water availability on a farm, particularly on dry season crop production. The average capacity of water storage of the studied ponds is 3,431 m^3 per farm. According to the classification of water storage capacity of a pond by Muzhtaq, et al. (2007), the capacity of ponds surveyed in 4 districts is between 1,000 m^3 and 10,000 m^3, classified as 'medium' size. The pond ratio is an index of water-land resource allocation ratio on a farm. The average ratio is the ratio of pond surface area in total farm size, indicating water-land resource allocation on a farm. The average ratio 0.05 which means only 5 % of total farm land is allocated to pond for a farm in Southern Laos.

Paddy land varies from district to district. The smallest area per household is found in Sukhuma district, 1.9 ha. The national average is 1.6 ha per farmer (MAF, 2012a), which is corresponds to the average area for no-pond farms. From the field survey, both farmers grow crops principally in rainy season such as WS rice, DS and WS vegetables, and DS soybeans for home consumption as well as for sales.

In our study sites, rice from our survey is produced in rain-fed system and relies on climatic conditions, particularly rainfall. Rice is the main source of income with average yields of 2.2 tons per ha and 1.9 tons per ha for pond and no-pond farms, respectively. The highest yield is in Sukhuma district, 2.5 tons per ha. In addition, beans and vegetable are also considered as main cash crops for the farmers surveyed in the study areas. Soybean is commonly produced on paddy field by both types of farmers (pond and no-pond famers) after harvesting rice in December. From the survey, 38% of the samples grow soybean in dry season, from later December until February. Soybean yields fluctuate from one to other farm, the average yields are 1,220 kg for pond farm and 982 kg for no-pond farm. These yields are lower than the national average of 1,640 kg per hectare (MAF, 2012b).

Vegetable is another common cash crop produced in both seasons (wet and dry season). In general, most of farmers (more than 90 per cent of farmers surveyed) produce vegetable in rainy season for home consumption and for income in case of surplus production. Some farmers grow vegetable in dry season for those who have access to water for irrigation such as groundwater pumping or pond irrigation. From the field visit and interview, both groups of farmers produce with similar techniques.

Compost or manure is used for crop fertilization but chemical products[1] are also applied by farmers. The average yields of vegetable (WS and DS) are different between pond famers and no-pond farmers. Pond farmers significantly produce much higher DS vegetables that no-pond farmers do. The average yields of DS vegetables are 6.6 tons and 2.7 tons per has for pond farmers and no-pond farmers, respectively. Theses yields are lower than the national average yield of DS vegetable, which is 8.69 tons per ha (MAF, 2012b). The average yields of WS vegetables are 8.9 tons for pond farmers and 6.4 tons per ha per no-pond farmers. However, the yields of WS vegetables for both groups are lower than the national average (9.47 tons per ha (MAF, 2012b)), due to low techniques of production and lack of irrigation water in the study sites.

One of the main benefits of irrigation farm pond is a possibility of on-farm aquaculture. From our survey, most of pond farmers raise fish from June to December (rainy season). Pond fish is traditionally consumed by family members for poor and small farms, but sold out to the local market for bigger pond farms. According to Fung-Smith (2000), pond fish is considered as an important source of protein and has an effect on family nutrition and food security of household.

As shown in table 3.3, farm income without livestock accounts for more than 40% of total household income for interviewed farmers. Livestock (poultry, goat and some cattle) is considered important due to its capital saving. Farmers sell out their animals only for the special events or the emergency case. We describe more in detail the various sources of household income in section 3.2.2.

3.2.2. Multiple purpose of farm pond and household income

At farm level, on-farm pond has a multiple function for farm production and also for household's livelihoods. In the studied areas, most of farmers are rice-based farming producers of rainfed rice system and their farm outputs depend largely on climatic conditions. Due to their limited sources of agricultural water, all pond farmers use water available from their ponds for various purposes, particularly for irrigating crops and raising fish.

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[1] Chemical products are mainly urea (46-00-00) and NPK compound (15-15-15, 16-20-00). These products are promoted by the local traders (sometimes in form of credit in the beginning of season and credit payment at harvesting period.

As presented in Table 3.3, Pond farms use their water mainly for fish raising (88%) and growing crops in dry season (69%). Some of them use pond as a source of water for their animals. Water withdrawn from pond is also used as a supplemental irrigation in wet seasons, particularly when there is no rain during the cropping season. Particularly for rice cultivation, 64% of pond farms use pond water to prepare early seedbeds for rice seedlings' plots, usually located near the pond. This is a very important benefit for rice-based farming farmers with rainfed rice system.

Table 3.3. A multiple use of farm pond irrigation in Southern Laos, 2012.

irrigation of crops in dry season	supplemental water in wet season	earlier preparation of seedbeds for rice	fish raising	Domestic uses	water sources for animals
69.1	43.6	63.8	88.8	16.0	40.4

Source: Author's calculation from survey 2012. 188 pond-farms surveyed.

In some rural remote villages, pond water is for domestically used such as washing clothes, bathing, or even drinking. For many farmers (about 40%), pond water is considered as an important source of drinking water for their herds within their farms.

In terms of pond benefits on household income, it is interesting to present them by sources as shown in Table 3.4. In terms of the share in household income, income from wet season rice production is an important activity for both types of farms surveyed. In many households, rice is considered as a staple food and also a main source of cash income especially in emergency case. Rice represents an important proportion of total income (20-30%) among farmers regardless of the pond status

Table 3.4. Decomposition of 2012 household income (Pond and non-pond farms)

Farm type	% Rice income	% Livestock income	% Agricultural income[1] other than rice	% Fish culture	% Off-farn income[2]
Pond farmers	25	5	22	10	38
Non-pond Farmers	26	8	13	--	53

Notes: [1] Agricultural income is comprised net income of crops (i.e. vegetable, soybeans, and other crops) produced on farm. [2] It is comprised mainly remittance and salary earned from off-farm activities.

Source: Author's calculation from the survey 2012.

The percent contribution of agricultural income (excluding rice) to total income of farmers with pond was 22% on average, while fish culture income contribution was about 10% on average. From the field survey, off-farm income was mostly derived from remittances from children working outside the district. For non-pond farms, off-farm income is a main source of income (59%), and the share of agricultural income other than rice accounts for 13 % of their total household income. In addition, the percent contribution of livestock income to total household income is relatively small, only 5 % and 8% for pond farmers, and for no-pond farmers, respectively.

The overall objective of this Chapter is to analyze the impact of pond irrigation on per capita income. It is interesting to differentiate sources of per capita income for pond farms and no-pond farms. We distinguished 9 sources of household income for the sampled households in the rural southern Laos as shown in Table 3.5.

Table 3.5. Per capita incomes of pond-farms and of no-pond farms, in millions LAK.

Sources of income	Pond farm		No-Pond farm		*T-test of difference*[1]
	mean	St. dev	mean	St. dev	
1. WS rice income	0.80	0.63	0.62	0.48	-1.92*
2. Off-farm income	1.53	1.63	1.52	1.79	-0.01
3. Livestock income	0.21	0.38	0.27	1.33	0.26
4. DS soybeans income	0.05	0.07	0.02	0.05	-2.74***
5. Vegetable income	0.67	1.15	0.25	0.36	-4.03***
WS vegetables	*0.16*	*0.45*	*0.08*	*0.19*	*-1.80**
DS vegetable	*0.51*	*0.84*	*0.17*	*0.31*	*-4.13****
6. Fish income (pond)	0.24	0.75	0.00	0.00	NA
7. Income depending on pond (4+5+6)	0.96	1.31	0.28	0.37	-5.98***
8. Income independent of pond (1+2+3)	2.54	1.80	2.42	2.70	-0.26
9. Total household income (7+8)	3.50	2.20	2.69	2.74	-1.36*

Notes: [1] Two samples t-test with unequal variance. ***Significance at 1%, **Significance at 5% and *Significance at 10%.

Source: Author's calculation based on survey in 2012.

Rice income is commonly important for both groups of farmers because rice is produced in rainy season and relying on climatic conditions (rainfall and production inputs). Per capita rice income of pond farms is 0.80 million LAK (US$100) higher than that of no-pond farms (0.62 million LAK or about USD 77.5). There is significant difference in per capita rice income between pond farms and no-pond farms (significantly at 10 %). From our survey, most of farmers (pond farm and no-pond farms) have income from off-farm activities such as remittance and salaries from children who are working outside of the village. Livestock income is from cow, goat, poultry and pig production. There are no significant differences of per capita livestock and off-farm incomes between pond farms and no-pond farms. For pond farms, incomes from DS vegetables, DS soybeans, and pond fish represent significant proportions in household income. Per capita DS soybeans income of pond farm is significantly higher than that of no-pond farms. Pond farmer earn more per capita vegetables income than no-pond farm do (significant at 1%). From Table 3.5, the per capita income depending on pond irrigation (DS soybeans, vegetable and fish) is significantly different between farm having pond irrigation and a farm having no pond irrigation on farm (significant at 1%).

Total household income of pond farms is higher compared to non-pond farms (significantly different at 10 per cent level). In average, per capita household incomes are 3.50 million LAK (USD437.5) for pond farmer and 2.69 million LAK (USD336.25) for no-pond farmer. Pond farms can have more various sources of incomes and greater diversity of agricultural production. This is consistent with the view that integrated farms have more opportunities for agricultural production due to their larger water availability (Ruaysoonnern and Penning de Vries, 2010).

3.3. Empirical framework and model specifications

3.3.1. Data source

The main set of data for our research in this chapter is from our field survey of 222 farmers, and the key variables for the subsequent analysis are shown in table 3.6. The survey intentionally selected more pond farmers than non-pond farmers. Pond farmers and no-pond farmers were randomly and separately interviewed. 188 pond farmers (85% of the sample households) were randomly selected, while 34 no-pond farmers were randomly selected. Most of them practice rainfed rice-based farming for home consumption and for sales. In general, the crop structure in this area is very simple and rather similar, especially within a household and a village as described in section 3.2. Because beans and vegetables are the major cash crops irrigated with pond water, they are shown in Table 3.1.

Table 3.6. A summary of main variables of 222 households in Southern Laos, 2012.

Variable	Description	Pond farms (N=188)			No-pond farm (N=34)			*T*-test[1]
		Obs.	Mean	Std.dev	Obs.	Mean	Std.dev.	
BEANYD	Dry season soybeans yield, tons.ha^{-1}	54	1.17	0.61	31	0.92	0.40	-3.12***
DSVEGYD	Dry season vegetable yield, tons.ha-1	80	5.76	4.54	24	3.16	4.72	-2.31**
WSRICEYD	Wet season rice yield, tons.ha-1	184	2.25	1.04	29	1.96	1.06	-1.93*
PONDFARM	Dummy (1 if a pond farm, 0 otherwise)	188	1	0	34	0	0	
FARMLAND	Farm land per household, ha	188	3.35	2.31	34	1.80	1.32	0.56**
HHMB	Household size, person	188	6.44	1.66	34	6.44	1.91	0.01
ADULTS	Number of active members aging 15-60, persons	188	4.57	1.74	34	3.85	1.88	-2.07**
AGE	Average age of adult members, years	188	42.04	10.99	34	43.79	10.39	-0.64
SCHYRS	Average schooling years of adult members, years	188	7.35	3.49	34	7.06	3.38	-0.46
DROUGHT	Drought occurred for crops in 2010, (dummy, 1)	188	40%		34	94%		16.78***
RICEINC	Wet season rice income per capita, million LAK	184	0.80	0.63	29	0.62	0.48	-1.92*
OFFFARMINC	Off-farm income per capote, million LAK	158	1.78	1.63	30	1.72	1.81	-2.56
LIVESINC	Livestock income per capita, million LAK	153	0.35	0.39	30	0.31	0.35	0.39
BEANINC	DS soybean income per capita, million LAK	54	0.06	0.07	31	0.02	0.05	-5.51***
VEGINC	Total vegetables income per capita, million LAK	168	0.67	1.15	34	0.25	0.36	-4.03***
FARMINC	Agricultural (farm) income per capita, million LAK	184	1.76	1.49	29	0.90	0.56	-5.55***
TOTALINC	Total household income per capita, million LAK	188	3.50	2.20	34	2.69	2.74	-1.63*
AGRMACH	Value of farm machinery per capita, million LAK	188	0.86	1.20	34	0.19	0.78	-4.17***
DRAFT	Value of draft animals per capita, million LAK	188	1.30	1.47	34	0.62	1.12	-3.13***
EXTENSION	Dummy, 1 if a farmer received a training	188	78%		34	38%		-4.38***
DISTTOWN	Distance from the district centre, km	188	7.53	5.59	34	6.71	5.32	-0.82
DISTCITY	Distance from the provincial capital, km	188	50.78	16.18	34	48.06	18.32	-0.81

Notes: [1] Two samples t-test with unequal variance. [2] Exchange rage USD 1 = 8,000 Lao kips (LAK) (August, 2012 at the time of the survey). ***Significance at 1%, **Significance at 5% and *Significance at 10%.

Source: Author's calculation based on survey in 2012.

According to our pond farms survey, their cropping plots for beans and vegetables are small and usually located next to the pond. By using only the main plots near the pond, this proximity seems to make irrigation effective.

Our data were collected after construction of farmstead private individual ponds in the study sites that motivates this research. This may cause concern that we have not adequately described the situation of pond utilization. However, the number of pond farms in these study sites id relatively small. In addition, most pond farmers and no-pond farmers have one or more small plots that are irrigated by pond irrigation. For this present research, it is not feasible to track and record only those farms affected by pond irrigation (which are subject to change) and provide panel data for the 'before and after' analysis. In our view, a comparison between pond farms and no-pond farms provides a sound basis for projecting the likely impacts of pond irrigation on crop production and income.

3.3.2. Crop choices and determinations of key variables

- ***Dependent variables:***

As discussed in section 3.2, soybean and vegetables are main cash crops depending on pond irrigation in the study areas. Due to their importance as a source of household income, soybean and DS vegetable are chosen in the subsequent empirical analysis in this chapter. The main dependent variables are DS soybean yield, DS vegetable yield, and income per capita from those crops.

For each source of income, net income is obtained by subtracting gross farm expenses (all paid-out costs of farm production) from gross farm revenue (sales and home-used production) during the year (Edwards, 2008). In our empirical analysis, the goal is to examine the contribution of pond irrigation to poverty reduction linkages in rural areas of Lao PDR. Per capita household income is applied in the subsequent empirical analysis of this dissertation.

- ***Independent variables:***

The key variable as a proxy of the effect of pond irrigation is PONDFARM (a farm having a pond for irrigation). In our analysis, PONDFARM variable is assumed to be an endogenous variable for the following reasons. First, pond farms are minority, about 19 % of total farms in the 22 villages visited in our study sites (shown in Table A1.2). Second, we could observe from our survey, that pond farmers have more farm assets compared to no-pond farmers in terms of land, livestock and farm machinery. Third, due to the limited resources (farm land) and the constraint of rice farming as for household's staple food, a farmer must keep an adequate land for a paddy area in wet season and production some crops in dry season (if possible). So, allocating a farm land for a pond surface requires a farmer to have a good decision to make as a private, individual irrigation system. As mention in section 3.2, many pond farms selected are newly constructed since 2009 due the Government's infrastructure development projects (national roads and access roads construction), some farmers decided to have ponds constructed on their farms by giving their soils to the road constructors.

Other variables are household characteristics and village's features (distance from town and city, rainfall, experiences in drought...)

3.3.3. Model specifications

For rural farmers in the studied areas, cash crops such as beans and vegetable are put as a priority and suitable to grow under small-scale pond irrigation according to our interviews with farmers and to our field observation. Although they are not the primary staple food, vegetable and beans plays an essential role in satisfying food needs, and in generating income for most of farm households.

In general, pond irrigation contributes to agricultural production in two ways: (1) to increasing the crops yields, and (2) to enabling farmers to diversify crops and switch to high-value crops such as vegetable and beans. Increased yield is theoretically produced for satisfying family consumption and for earning extra income by selling it in the local markets. In our empirical analyzes of impact of pond irrigation on farm household, two steps of study include firstly examining the effect of pond irrigation on crop yields (soybean and vegetable), and secondly the impact on crop income as well as on total household's income.

Due to lack of data or research on impact of pond irrigation on farm production in Lao PDR, the main variable used in all empirical studies in this Chapter is a dummy variable as a proxy for the effect of pond irrigation: PONDFARM (a farm having pond irrigation).

Empirical models examining the effect of pond irrigation on crop yields

To examine the effect of pond irrigation on agricultural production, we develop an empirical model that accounts for pond-specific characteristics and household features. The observed variation in yields issued from using pond within a farm could be largely attributed to household features and pond-plot characteristics. Moreover, this variation is also influenced by the external factors including climate conditions, market prices, availability of agricultural infrastructure, and accessibility to market and technology (Mushtaq et al., 2007). However, the external factors such as village features do not directly influenced on crop yield but indirectly for some farmers in term of easy access to local market[2] for production inputs mainly seed and fertilizers.

[2] Local market means a market located in the centre of each district, which is usually smaller, with lower prices, and less demand compared to the markets located in the Provincial Capital.

We hold constant many of many of the pond-specific factors that could be affecting yields and which could be potentially correlated with a plots' irrigation status (such as, soil quality, water quality). We also observed some non-plot varying factors that could be affecting yields (such as off-farm employment opportunities and village location). For example, households in proximity of or near the cities (Center of Province) have more opportunity to work off-farm and, ceteris paribus, they will almost certainly allocate less family labor to farming activities than households living far from the border that do not have as convenient access to off-farm jobs.

To measure the effect of irrigation on yields while holding other factors constant, we could start from the basic model to explain the yield function of a farmer. For soybean and vegetable irrigated by pond irrigation in dry season, the yield estimation function is specified as follows:

$$Y_i = a + \beta P_i + \gamma H_i + \varrho V_i + e_i \qquad i = 1,2,\ldots 222 \qquad (Eq.1)$$

Where Y_i denotes the crop yield produced on farm of i^{th} household. P_i refers to the proxy of effect of pond irrigation including a farm with pond irrigation (PONDFARM). This variable is treated as an endogenous for the models as mentioned previously. H_i represents a vector of characteristics including farm size, household size, adults (15-60), average age of household members, and average years of adult education. This average level of education in the household has proven to be a better explanatory variable of farm production and household income than education of the household head (Jolliffe, 1997; Onphandala, 2009). Other household characteristics are experiences in drought for crops (at least one) during the past three years, the values of farm machinery, the value of draft animals[3], and received at least one extension training during the last three years (from 2009 to 2011). V_i describes a village's features (distance from capital city and distance from local market). e_i is the usual well-behaved error terms, which is uncorrelated with the vector of independent variables. α, β, γ and ϱ are the coefficients to be estimated.

[3] These variables are estimated in monetary in order to indicate the level of capital assets of a farm. As described in section 3.2, livestock is considered as a capital for a household and used only for special cases such as scholar expenses, marriage events, new investments (production…), etc… Value of farm machinery is an indicator of the degree of farm mechanization. In our survey, this includes a hand tractor, small equipments, pumping set, and pumping motor.

The empirical model is in a linear form as follows:

Y(YIELD) = *F*(PONDFARM, FARMLAND, HHSIZE, ADULTS, AGE, SCHYRS , DROUGHT, AGRMACH, DRAFT, EXTENSION, DISTTOWN, DISTCITY)

(Eq.2)

As PONDFARM is assumed to be endogenous, we examine the impact of pond irrigation on crop yields (soybean, vegetables, and rice) by using the Propensity Score Matching procedure (PSM). PONDFARM is a treatment variable taking 1 if a farmer has a pond. The matched controls (no-pond farmer) for each treatment are calculated by using the select matching algorithm over the estimated probability as propensity scores. For this analysis, we use the nearest neighbor matching (NNM) methods with the common support program.

Empirical model examining the impact of pond irrigation on household income.

Household income is a function of many determinants including both household and locational characteristics (De Janvry and Sadoulet, 2001). To study the importance of irrigation on household income, we need to control for other factors affecting the household income: land assets, human capital, other household asset and village characteristics (Yuan et al., 2009; De Janvry and Sadoulet, 2001). Then, we follow the same empirical framework as the crop yield estimation function (Eq.1 above).

The empirical model of per capita net income function is specified as follows:

Y(INCOME *of various sources*) = *F* (PONDFARM, FARMLAND, HHSIZE, ADULTS, AGE, SCHYRS , DROUGHT, AGRMACH, DRAFT, EXTENSION, DISTTOWN, DISTCITY)

(Eq.3)

The impact of pond irrigation on various sources of per capita household income is determined by using the PSM method due to the endogeneity of PONDFARM variable within the income models. The NNM method with common support is applied to Eq.3.

3.4. Result and discussion

3.4.1. Impact of pond irrigation on crop yields

The effect of pond irrigation on dry season vegetable yield is evidently seen by having the availability of water to continue cropping their paddy land after harvesting rice in dry season. The pond irrigation on farm's production is explained by comparing the difference in crop yield produced by pond-farmer and no-pond farmers.

Table 3.7 shows the results before and after matching the control of using the PSM procedure with the nearest neighbor matching (NNM) method. The number of the sample and the results of the test of balancing were presented in Appendix (Table 3A.1).

The difference in soybean yield between pond farmer and no-pond farmer is 0.481 ton per hectare on average (significant at 1 per cent), which is higher that the difference in soybean yield before matching for both groups of farmers (0.252 ton per hectare significant at 5 per cent).

Table 3.7. Average Treatment Effect on Treatment on crop yields by NNM

Crop yield		Effect of having pond irrigation on yield in ton.ha-1	S.E	T-test[1]	*Pr(|T|>|t|)*
Soybean	Unmatched	0.252**	0.118	-3.12**	0.036
	Matched by PSM	0.481***	0.065	-4.15***	0.003
DS vegetable	Unmatched	2.416**	0.586	-2.13**	0.013
	Matched by PSM	2.871***	0.965	-5.32***	0.000
WS Rice	Unmatched	0.296*	0.199	-1.93*	0.072
	Matched by PSM	0.317	0.472	-1.96	0.157

Notes: [1] Two samples t-test with unequal variance. ***Significance at 1% level, **Significance at 5% level, and *Significance at 10% level.

Source: Author's calculation based the field survey, 2012.

As described in the previous section, the average of DS vegetable yield of pond farmer is higher than that of no-pond farmer. Before matching, the difference in DS vegetable yield between pond farmer and no-pond farmer is 2.416 ton per hectare (significant at 5 per cent). The results after matching the control show that the difference in yield is 2.871 ton per hectare (significant at 1 per cent).

For our research, the analysis also attempts to investigate the impact of pond irrigation on rainfed rice yield. Even though pond water could not be possible to ensure crop development for a whole season but at least it could contribute to prepare good seedlings for transplantation and supplement irrigation in case of no rainfall in a month in rainy season. Before matching, the difference in rice yield between pond farmer and no-pond farmer is 0.296 ton per hectare (significant at 10 per cent). NNM procedure estimated the average rice yield of control was 2.001 ton per hectare, so that the average farm with pond irrigation increases wet season rice yield by nearly 16 per cent. However, this impact is not statistically significant.

3.4.2. Impact of pond irrigation on per capita household incomes

The impact of pond irrigation on household income was estimated with seven models. The results before and after matching the control are shown in Table 3.8. The numbers of sample used in the PSM method and the test of balancing PSC were presented in Appendix (Table A3.2).

Table 3.8. Average Treatment Effect on Treatment on per capita household income by NNM

Source of income		Effect of having pond irrigation on per capita income in million LAK	S.E	T-test[1]	*Pr(|T|>|t|)*
Rice	Unmatched	0.190*	0.099	-1.92*	0.078
	Matched by PSM	0.068**	0.121	-2.48**	0.017
Livestock	Unmatched	0.028	0.072	-0.39	0.689
	Matched by PSM	0.029	0.223	-0.05	0.957
Off-farm	Unmatched	0.091	0.355	-2.56	0.7995
	Matched by PSM	-0.306	1.356	0.43	0.761
Soybean	Unmatched	0.033***	0.006	-5.51***	0.000
	Matched by PSM	0.039	0.004	-10.12***	0.000
Vegetable	Unmatched	0.421***	0.053	-4.03***	0.000
	Matched by PSM	0.872***	0.099	-8.00***	0.000
Agricultural (farm) income	Unmatched	0.866***	0.261	-5.55***	0.000
	Matched by PSM	0.797***	0.328	-6.77***	0.000
Household income	Unmatched	0.810*	0.427	-1.63*	0.094
	Matched by PSM	0.824**	1.967	-0.83**	0.047

Note: [1] Two samples t-test with unequal variance. ***Significance at 1% level, **Significance at 5% level and *Significance at 10% level.

Source: Author's calculation from survey 2012.

The differences in various sources of per capita incomes are statistically significant except livestock and off-farm incomes. Per capita income from rice for the treatment group is higher than the control group by 0.068 million LAK or $US8.5), significant at 5 % level. However, this difference in rice income before matching is higher.

Livestock production is considered as asset or capital accumulation for rural farmers in the studied areas. However, it is sold out each year to get cash money for paying schooling fees of their children and for health care. The results before matching show that the difference in per capita livestock income for pond farmers is higher than those of no-pond farmers by 0.028 million LAK ($US3.50). After matching by the Nearest Neighbor Matching, the per capita livestock income of pond farmer is higher than that of no-pond farmer by 0.029 million LAK ($US3.625). However, these differences are not statistically significant.

In the study areas, off-farm income (i.e. non-agricultural activities) represents an important share of rural household income, for example remittance from family member engaging in non-agricultural work or working outside of the village during dry season. The research work done by Manivong et al, 2010 shows some evidences on rice intensification and rural remittance in Southern Laos. Rural poor farm households' members usually go to the capital cities or to Thailand for finding a job during dry season and come back to the farm with some money to pay for production inputs in rainy season. The present study also trends to show the impact of pond irrigation on employment development on a farm in rural areas. To examine this effect, the result after matching show that the per capita off-farm income of pond farmer is lower that no-pond farmer by 0.106 million LAK ($US13.25). This indicates that production activities related to pond irrigation require more labor from particularly family members, particularly during the dry season. These family members cannot go out of the farm to find an off-farm income in the Capital cities or even in the neighboring countries (e.g. Thailand).

Pond irrigation could help to create extra activities/on-farm job opportunities for household members such as pond fish culture or high value-added DS/WS crops such as vegetable. From our interviews, pond farmers require more labors to run on-farm production activities during a year. For example, a pond farm needs to cure and clean the pond for each rainy season in order to prepare a pond for fish production. Fish harvest requires some important labors, particularly bigger pond farms. So, family members are priority labor and required to stay on farm during production season.

For no-pond farms, most of sample households had active members who went illegally to Thailand for hunting jobs, particularly in dry season.

The effect of pond irrigation on per capita agricultural income is illustrated by the diversity of crop production such as DS soybean, vegetables (WS and DS), and aquaculture (i.e. pond fish). The results after matching shows that the difference in per capita income of soybean, vegetable between pond farmer and no-pond farmers are 0.039 million LAK ($US4.875) and 0.872 million LAK ($US109), respectively. These differences are statistically significant at 1% level. Per capita farm income of pond farmer is significantly higher than that of no-pond farmer (significant at 1 % level). The results after matching show that the difference in per capita agricultural income between pond farmer and no-pond farmers is 0.797 million LAK ($US99.625). This difference is slightly lower compared to the results before matching.

Finally, the effect of having pond irrigation on total household per capita income is examined by the propensity score matching. The results before and after matching are shown in Table 3.8. After matching, the difference in per capita household income between pond farmer and no-pond farmer is 0.824 million LAK ($US103), statistically significant at 5% level. This illustrates that a pond farmer can earn more income than no-pond farmers.

3.5. Conclusion

Small-scale pond is commonly used within a Lao farm but still minority in many rural parts of southern Laos due to an important investment in constructing a pond on farm. In studied sites, most of pond farmers could only have a farmstead pond by giving their soil to the road construction projects. The multiple purposes of pond irrigation are well known in term of supplemental irrigation and food supply (pond fish) at home consumption. However, the impact of pond irrigation on poverty reduction has not been rigorously examined in Lao PDR. That is the motivation of this chapter.

The analysis results in this chapter constitute a pioneer evidences on the effect of pond irrigation on agricultural production in dry season and on per capita household income. By using the propensity score matching (PSM) method with the common support program, the results show that there are significant differences in crop yields (DS soybean, DS vegetable and WS rice), per capita farm income and household income between famers with a pond and those without a pond.

The premise is that resource water can be developed on many homesteads by construction of ponds: this can increase the productivity of dry season cash crop, enhance household income, and consequently reduce rural poverty. However, even if pond has a positive impact on agricultural production, it is not yet known if farmers efficiently manage the pond since. Utilizations and management of pond have not been empirically studied a farm level. Research on modeling of water use efficiency from pond irrigation concept is needed in order to bear some hints for policy making.

4. POND IRRIGATION, MARKET PARTICIPATION AND AGRICULTURAL COMMERCIALIZATION OF POOR HOUSEHOLDS

4.1. Introduction

Agriculture continues to play a critical role in the economies of most developing countries. The importance of agricultural development bears more significance in the case of most backward countries like Laos where nearly 80 percent of the total population is engaged in agriculture, which is contributing 32 percent of GDP (MAF, 2012a). Promotion of agricultural production and commercialization to poor famers entails investment of substantial amounts of resources, including cash and labor, on the part of farmers. Commercialization is indispensable for agricultural development, which, besides other things, entails mechanization of agriculture for reducing the cost of production and increasing crop yield, eventually increase profit margin of farmers (Nepal and Thapa, 2009). It is plausible to ask questions to what extent its stated objective of particularly agricultural commercialization and market participation concepts has been achieved and what are the factors significantly influencing commercialization and market participation in the approach of rural development in Lao PDR.

The success of farm commercialization can be determined by factors external to small-scale farmers, including infrastructure, level of urbanization, technological change, and demand for the product as well as farm-level factors including size of landholding, extent of land use diversification, level of input use, and intensity of management. Thus, the commercialization of a product can be stimulated or deterred by factors ranging from household characteristics to broader institutional and policy environments.

In rural Lao PDR, ponds, small reservoirs, allow farmers in rainfed lowland rice-based farming systems to capture rainfall, conserve water from other sources and then use it for supplementing irrigation for short duration dry season crop production or aquaculture, destined either for commercialization in local markets or for home consumption. Many farmers construct a farmstead pond and develop it as a small-scale irrigation for farm production. Harvesting rainwater in ponds for agricultural production is commonly practiced to support food security and to enhance commercialization to generate extra income for poor farmers.

Small farm pond irrigation of agriculture contributes to market participation of poor smallholder farms in two ways. First, it helps to increase the yield of existing crops by supplementing irrigation water in rainy season and the surplus of production is sold to the local market. Some pond farmers decide to produce high value added such beans and vegetable for selling to the Capital cities like farmers in Phonthong and Outhoumphone districts, where road conditions and market access are easier for them. Second, pond irrigation farmers have more water available to ensure the crop development and production. This availability of water encourages farmers to produce for commercial purpose such as cash crops and engage in marketing.

This chapter aims to examine the important contribution of pond irrigation on market participation of poor rural households in southern Laos. First the research analyzes the effect of pond irrigation on agricultural commercialization of farmers in the study areas. Second, we extend our research on the importance of having farm pond on market participation (engagement in sale contract). Lastly, we examine the effect of contract participation on agricultural commercialization of poor households, and then on per capita household income of rural farmers in the study areas. To study the market participation of a poor farmer, we adopt two concepts of market participation namely (1) degree of agricultural commercialization and participation in sale contract (informal contract in our case study).

Up to now, no research was done yet examining the impacts of small farm pond irrigation on rural commercialization and farmers' participation in agricultural commercialization in the rural areas of Lao PDR. This chapter of the dissertation aims to empirically investigate the impact of pond irrigation on market participation of the rural poor farmers by analyzing (1) the extent of pond on agricultural commercialization (defined as a degree of commercialization), (2) the extent of contract engagement (participation in contract production), and (3) the effect of contract participation on various sources of household income.

4.2. Agricultural commercialization and market participation for poor

Promotion of agricultural commercial production has been adopted as agricultural-led growth development strategy to enhance food security and to alleviate rural poverty (von Braun, 1995; Poole et al., 2013). Agricultural production promotion entails investment of substantial amounts of resources, including cash and labor. Von Braun (1995) explained that rural farmers have no incentive for making investments in areas where there is little opportunity for marketing their products, or the profit accruing from the sales of agricultural products does not reflect the opportunity cost of investment. As a result, most farmers in rural and poor areas with few marketing opportunities are engaged primarily in subsistence agriculture, which has constrained improvement in their quality of life.

Agricultural commercialization as a process and a characteristic of agricultural change is more than whether or not a "cash crop" is present to a certain extent in a production system. The research evidence shows that commercialization of subsistence agriculture can take many different forms. It can occur on the output side of production with increased marketable surplus, but it can also occur on the input side with increased use of purchased inputs (Pingali & Rosegrant, 1995; von Braun, 1995). Commercialization is not restricted to just "cash crops": the so-called traditional food crops are frequently marketed to a considerable extent, and the so-called cash crops are retained, to a substantial extent, on the farm for home consumption (von Braun, 1995).

Commercialization is essential for poor farm household in term of livelihood's improvement and poverty reduction, which, amongst other things, entails some investment in intensification of farm and in increase in market participation. In rural Laos, intensification of a rice-based farm is common since 1995 by having a hand-tractor (diesel motor system) and applying production inputs such as improved varieties and chemical products. For farm households, the hand tractor helps to reduce the costs of production (labor hiring costs) and to facilitate irrigation for rice seedbed preparation (pumping water from a pond for irrigation). The research on mechanization of rice-based farming system in Laos show that tractor-owning farmers have increasing return to scale while non-tractor owing farmers have a constant return to scale (Latmany et al., 2008). In rural areas, tractor-owing farmers can generate extra paddy (1,300 kg per household per year) from hiring out their tractor to non-tractor farmers (Latmany et al., 2008). Another factor also encourages the agricultural production promotion that is facilitating the access to information and markets for farmers (Phanthavong et al., 1994).

As we have seen in the chapter 2, the level of participation in markets for the commercialization of agricultural products by Lao farm households is quite low. Rural households participate in markets for livestock more than for rice. Rice marketing is considerably lower, particularly in the Southern highlands, but scarcely above a third of households with the exception of households in the Vientiane Plain (MPI, 2008). In Laos, some poor and rural farmers increase their sales of farm outcomes by engaging in marketing in several means: by making an informal contract with local trader, usually called 'a middleman' [4] and by signing contract with some local agro-industrial companies such as rice milling factories. Such kind of market participation helps rural farmers to sell out huge quantities of their products each year. Contracting production is considered as a key determinant of rural trade in Lao PDR, and there has been a rapid rise in contract farming during the past decade. This kind of contract agriculture has been carried out in the north part of Laos since late 1990s when the Chinese investor began supplying Lao farmers with seed and inputs for commercial production of sugarcane and tree crops (e.g. rubber) as part of hoping for the eradication of opium production and opium trade in the region - Laos-China border (Setboonsarng et al., 2008). A contract farming producing various crops for exporting mainly to Chinese markets for example tea, maize, soybean, sugarcane, sweet corn, horticulture and rubber.

For smallholder farmers, agricultural commercialization demonstrates the shift from subsistence production to an increasingly commercial production and consumption system based on the market (Goletti, 2005). Apart from marketing of agricultural outputs, it includes product choice and input

[4] This local trader or middleman is known as a Hyundai trader in many rural parts of Laos. They come to the village and make a contract, called 'production arrangement with farmer'.

use decisions based on the principles of profit maximization (Pingali and Rosegrant, 1995). Commercialization can occur on the output side of production with increased marketable surplus, as well as on the input side with increased use of purchased inputs (von Braun, Bouis, & Kennedy, 1994). A low degree of commercialization involves farm production essentially for subsistence purposes, with very little surplus to be sold in the market. Farmers under a high degree of commercialization produce only for the market and are integrated with dynamic markets (Poole et al., 2013). In the latter case, production is specialized and based on farm mechanization and technology (tractor, chemical fertilizers uses, pump-sets for small-scale irrigation), and income stabilization and profit making are among the major concerns of farmers rather than such issues as food security (Goletti, 2005).

In rural areas, farmers are confronted with many unpredictable uncertainties ranging from climatic vagaries to market price fluctuation. This phenomenon is more accentuated in case of rural poor farmers in the areas where infrastructure development is still low. The degree of uncertainty is greater in developing countries where the farmers do not have access to basic information on demand, supply, prices and alternative opportunities (Anderson, 2003). These uncertainties make farmers vulnerable to various risks including loss of assets and income. Therefore, they find it difficult to shift entirely from self-sufficient to commercial agriculture for many rural poor farmers of Lao PDR.

Farmers' decisions on adoption of technologies such as pond irrigation or commercialization are also considerably influenced by their experiences about soils, plants, animals, and machines (tractors or small diesel pump). Poor farmers find it difficult to procure improved seeds, fertilizers and irrigation required for commercial agriculture, owing to some structural constraints imposed by limited resources and capital. Mechanization (tractorization) and small irrigation pump-sets are key factors of farm commercialization for rural poor farmers in many parts of Laos (Latmany et al.2008). Farmers' decision making is not determined by one particular factor. Rather it is a function of several biophysical, and socioeconomic factors.

4.3. Selected variables and data source

4.3.1. Dependent and independent variables

To examine the effect of pond irrigation on market participation for rural farmers, we define the dependent and independent variables as follows:

Degree of agricultural commercialization:. In the literature, Nepal et al. (2009) studied about factors associated with commercialization and mechanization of rural farmers in Nepal by using the concept of 'commercialization' defined as cash earning from the crops aggregated and considered as an indicator of 'degree of commercialization' of a farm. We found that firstly this variable cannot solely answer our first objective on the effect of pond irrigation on market participation for the poor because this indicator varies in function of prices of crops and location where the crops are sold. Secondly, cash earning from crops provides only information on farm revenue but cannot explain the extent of farm commercialization and farmer's engagement in marketing process in our study areas. This dependent variable, the degree of agricultural commercialization is defined as the average of total productions sold of each season for a household over the total farm production in each season, expressed in percentage

Participation in sale contract: dependent variable, a dummy variable takes a value 1 if a farmer engages to sells their farm products with contract to the local traders or the middlemen at the harvest period. This contract is an informal type, commonly practiced in rural areas of Laos. The contract is withdrawn verbally between the farmers and local traders (usually local middlemen from the village or neighbor villages who run business). In most cases, the contract is done between two parties before harvesting products (mainly vegetable, beans and rice if possible). Farmers know well about their counterparts (traders) because they have been doing business with them for many years[5].

Per capita income: As mentionned in the Chapter 3, rice, bean and vegetables mainly sold to the local traders under on-farm sale contract. Per capita of rice income, soybean income, vegetable

[5] From the survey, 83% of farmers with sale contract (120 farmers contracted) reported that they have sold their crops to the same buyers (local traders) for at least 3 years and they are confident and willing to sell to them.

income, farm income and total household income are used in the subsequent analysis on the effect of participation in sale contract on household income.

In term of explanatory variables, the **'PONDFARM'** is an endogenous variable used as a key proxy to examine the effect of pond irrigation on agricultural commercialization and on market participation under sale contract. Household characteristics and village features are used as factors affecting the agricultural commercialization and contract participation.

4.3.2. Data source

The dataset were summarized from the field survey in 2012 and presented in Tables 4.1, 4.2 and 4.3 below. Information on the nature of contract was also collected during the field survey in 2012.

Table 4.1. Summary statistics of the main variables for the empirical study.

Variables	Description	Pond farm (N=188)		No-Pond farm (N=34)		*T*-test[1]
		Mean	St.dev	Mean	St.dev	
PONDFARM	Dummy, 1 if a pond farm, 0 otherwise.	1		0		
AGRICOM	Degree of agricultural commercialization, per cent	47.29	14.39	36.91	16.00	-3.53***
CONTRACT	Dummy, 1 if a farmer engages to sell crops to a trader, 0 otherwise.	55%		53%		
RICESOLD	Percentage of rice sold, per cent.	35.02	16.47	27.01	15.65	-3.45**
LIVESTSOLD	Percentage of livestock sold, in per cent.	39.35	19.61	34.92	19.78	-2.87
CROPSOLD	Percentage of crop (other than rice sold, in per cent)	61.8	14.7	57.1	5.8	-3.12***
FARMLAND	Farm land per household, ha.	3.35	0.80	1.70	1.40	0.56**
HHMB	Household size, person.	6.44	1.66	6.44	1.91	0.01
ADULTS	Family member aging 15-60, person.	4.57	1.74	3.85	1.88	-2.07**
AGE	Average age of adult member aging 15-60, years.	42.04	10.99	4.39	10.39	-0.64
SCHYRS	Average schooling years of adult members, years.	7.35	3.49	7.06	3.38	-0.46
HHMB	Household size, person	6.44	1.66	6.44	1.91	0.01
DROUGHT	Drought occurred for crops in 2010, (dummy, 1)	40%		94%		16.78***
RICEINC	Rice income per capita, million LAK[2]	0.8	0.6	0.6	0.5	-1.92*
BEANINC	Bean income per capita, million LAK	0.1	0.1	0.0	0.0	-2.74***
VEGINC	Vegetable income per capita, million LAK	0.7	1.1	0.3	0.4	-4.03***
LIVESINC	Livestock income per capita, million LAK	0.35	0.39	0.31	0.35	-0.39
FARMINC	Agricultural (farm) income per capita, million LAK	1.76	1.49	0.90	0.56	-5.55
TOTALINC	Total household income per capita, million LAK	3.5	2.2	2.7	1.0	-1.63*
AGRMACH	Value of farm machinery per person, million LAK	0.86	1.20	0.19	0.78	-4.17***
DRAFT	Value of draft animal per person, million LAK	1.30	1.47	0.62	1.12	-3.13***
DISTTOWN	Distance from the district centre, km	7.53	5.59	6.71	5.32	-0.82
DISTCITY	Distance from the city, km	50.78	16.18	48.06	18.32	-0.81
EXTENSION	Dummy, 1 if a farmer receive a training	78%		38%		-4.38***

Note: [1] Two samples t-test with unequal variance. [2] Exchange rage USD 1 = 8,000 Lao kips (LAK) (August, 2012 at the time of the survey). ***Significance at 1%, **Significance at 5% and *Significance at 10%.

Source: Author's calculation based the field survey of 222 farmers, 2012.

In our study area, farmers are still self-sufficient rice-based ones, growing different type of crops, such as rice, maize, beans, vegetables, water melon, and raising pond fish for household consumption as well as for sale. Main crops are rice, beans, and vegetables. From our interviews, farmers reported that they did not sell any products in some season due to poor production because they need to keep them for family consumption and for seed provision for next season. This is a typical characteristic of poor smallholder agriculture in developing countries where farmers are confronted with several risks, including food shortage and economic loss arising from natural disasters (drought and flooding), and market price fluctuation (Anderson, 2003; Nepal and Thapa., 2009). Despite possessing small landholdings, most farmers in the study area are selling crops, though the amount of crops sold and the income accruing from it varies from one household to another.

From the field survey, we interviewed about the commercialization of farm outputs and the existing type of trader and type of contract. Many pond farms sell their products to local traders or called 'middle man' with informal sale contract. The 'informal contract' is identified between farmer and local trader. This informal contract type is common in the studied areas, usually described as 'production arrangement between farmer and trader'. Rice, beans and vegetable are traded under this type of contract. For rice, the traders or middle men were local rice millers (rice milling factory) located near by the village. They usually know each other and they come to the village to make verbal contract with farmers (usually an agreement to sell) at the beginning of rice production season. According to our field discussion, farmers are willing to sell some part of their production on paddy field with the proposed price because they do not need to carry their paddy rice to the millers. The millers come to collect or buy paddy rice at the harvest period (in December) with their threshing truck[6]. In case of beans and vegetable, it is different from rice. The engagement between farmers and traders are usually done before the production seasons begin. The traders or middlemen are local traders from the same villages or neighbor villages. According to our interviews, many farmers reported that these local traders were very helpful for them to buy some or total productions from each season. They come to the villages at the beginning of the season and ask farmers about the crops planted and ask farmers to sell to them. The risk of this type of informal contract is that rural

[6]It is quite common that rice milling factory's owner provides a service as a thresher during the harvesting period for poor farmers in the village. The service fee is based on the amount of rice's bags produced by each farmer. For example, for every 100 paddy rice bags (50 kg per bag), the thresher takes 7 bags. In our survey, 88% of farmers sell their rice to these millers.

farmers are not able to negotiate the prices very much but have to accept the prices proposed by the traders if the prices seem to be reasonable. However, many farmers can verify the prices by cell phone in case of their doubts in price differences, particularly vegetable. In our survey (219 farmers[7]), among the sample of 185 pond farms, 104 pond farmers sell their products under contract with local traders and 81 pond farmers who do not sell their products to the local traders under sale contract. For no-pond farmers, 16 of total 34 farmers surveyed sell their crops under sale contracts with local traders. Table 4.2 presents the characteristics of pond famers and no-pond farmers who sell and do not sell their products to the local traders in the study area.

Table 4.2. Summary statistics of participated and non- participated in sale contract.

Farm type	Key dependent variables	Participated farmers	Non Participated farmers	t-test of difference	
				T-test	*Pr(|T|>|t|)*
Pond farms	Degree of commercialization (in %)	37.8	34.1	3.06**	0.04
	Rice income per person (million LAK)	0.79	0.76	1.92	0.17
	Soybean income per person (million LAK)	0.14	0.09	2.28***	0.00
	Vegetable income per person (million LAK)	0.85	0.76	3.22*	0.09
	Livestock income per person (million LAK)	0.42	0.39	1.39	0.52
	Farm income per person (million LAK)	1.89	1.71	2.67*	0.07
	Household income per person (million LAK)	3.21	2.91	1.34*	0.08
	Observations	104	81		
No-pond farms	Degree of commercialization (in %)	36.42	38.21	-0.35	0.73
	Rice income per person (million LAK)	0.79	0.65	1.96**	0.03
	Soybean income per person (million LAK)	0.14	0.09	2.28	0.67
	Vegetable income per person (million LAK)	0.25	0.36	-1.22***	0.00
	Livestock income per person (million LAK)	0.30	0.34	-1.87	0.79
	Farm income per person (million LAK)	0.94	0.83	2.54*	0.08
	Total income per person (million LAK)	2.16	2.51	-1.34	0.72
	Observations	16	18		
Total		*120*	*99*		

Note: [1] Two samples t-test with unequal variance. [2] Exchange rage USD 1 = 8,000 Lao kips (LAK) (August, 2012 at the time of the survey). ***Significance at 1%, **Significance at 5% and *Significance at 10%.

Source: Author's calculation based the field survey, 2012.

From table 4.2, there is significant difference of total farm commercialization between pond farmers who participate and do not participate in the sale contract (significant at 10 per cent level), but no significant difference for no-pond farmers even they participate or do not participate in sale contract. For vegetable income per capita, the difference is seen in both cases (participated and non-

[7] 3 farmers of total 222 farmers sample are excluded from the analysis due to their paddy land partially flooded.

participated contract) for two groups of farmers interviewed. Per capita livestock incomes are not statistically different for both groups of famers even they participate or not in sale contract. In term of farm income and total household incomes per capita, we notice significant differences between pond farms who participated in sale contract with those who did not participate in contract (significantly at 10 per cent). For no-pond farmers, farm and household incomes are not statistically different for contracted and non-contracted farmers.

Table 4.3 shows the patterns of farm outputs' commercialization in Southern Laos. Households living near the capital cities are selling about 72.9% of the dry season vegetable produced and 84% of fish on average. This is primarily attributed to the proximity to the city, plain topography with fertile soil and availability of pond water for irrigation. However, only a small percentage of the paddy is sold in the outer zone, primarily because the overall amount of production in this zone is very small due to unavailability of paddy land and rice production is usually for home consumption.

According to our survey, all farmers reported that livestock is considered as a capital for family and they will sell it out only for some special events such as traditional festivals, schooling fees for children and for the emergency cases of health care. Percentage of livestock sold in the capital was mainly poultry, pork and goats because there is high demand in the city.

Table 4.3. Proportion of farm's products sold out, in percentage[1].

	Proximity		Pond irrigation	
	Near capital	Outer Capital	Pond farm	No-pond farm
DS crops (vegetable and soybean)	72.9	42.0	68.0	0.0
WS crops (vegetable)	59.4	38.2	69.0	36.8
Fish	84.1	43.6	73.5	0.0
WS rice	26.3	34.9	33.2	14.4
Livestock	43.7	12.0	52.6	42.3

Note: [1] It is a percentage of share of total products sold. DS and WS correspond to dry season and wet season.

Source: Author's calculation from survey data, 2012

For pond farms, high agricultural commercialization is primarily attributed to the cultivation of high value crop such as vegetable and bean that account for 68% of total household production. By pond farm type, pond farmers sell more DS vegetable and pond fish which are the high proportion of total income.

4.3.3. Empirical framework and Model specifications

Impact of pond irrigation on agricultural commercialization

In this chapter, the impact of pond on agricultural commercialization is evaluated by estimating the regression model specified as follows:

$$Y_i = a + \beta P_i + \gamma H_i + \sigma V_i + e_i \qquad i = 1,2,\ldots 222 \qquad (Eq.1)$$

Where Y_i denotes the degree of agricultural commercialization of i^{th} household. P_i refers to a farm having pond irrigation on i^{th} household. H_i represents a vector of household factors including landholding size per household, average age of adult member, average schooling years of adults, total household member, and experience in extension training on farm. ***Vi*** are village features (distance from the district centre and from the capital cities). e_i is the usual well-behaved error terms, which is uncorrelated with the vector of independent variables. α, β, γ and σ are the coefficients to be estimated. The empirical model can be written as follows:

Y(AGRICOM) = *F*(PONDFARM, FARMLAND, HHSIZE, ADULTS, AGE, SCHYRS , DROUGHT, AGRMACH, DRAFT, EXTENSION, DISTTOWN, DISTCITY) *(Eq.2)*

As specified in the chapter3, PONDFARM is an endogenous variable within the commercialization model. To investigate the effect of pond irrigation on farm's commercialization, the propensity score matching (PSM) procedure is applied to estimate the models. The PONDFARM variable is a treatment variable taking value 1 if a pond farmer. The nearest neighbor matching (NNM) with common support is used to estimate the differences in percentage of WS rice, crops (other than rice), and livestock sold between pond and no-pond farmers.

Factors influencing the adoption of pond irrigation and contract engagement of farmers

To examine the extent of pond irrigation and participation in on-farm sale contract simultaneously, A bivariate probit model was developed. Discrete outcome modeling techniques were utilized as the dependent variables consist of binary indicator variables (i.e., having pond/no-pond farm and contracted/non-contracted farmer). The dependent variables for the models are PONDFARM (a farm having pond irrigation) and CONTRACT (participation in on-farm sale contract), each coded as a binary indicator taking the value of either 1 or 0. The bivariate probit model was utilized in order to control for the common unobserved factors that affect the decision-making process regarding constructing a farmstead pond and participation in sale contract. The bivariate probit model is designed to model binary dependent variables that may be simultaneously determined (Greene, 2003). The generic form of a bivariate probit model is written as follows:

$$y_{1i}^* = \beta_1 X_{1i} + \varepsilon_{1i}$$
$$y_{2i}^* = \beta_2 X_{2i} + \varepsilon_{2i} \qquad \text{(Eq.3)}$$

where:

y_{1i}^* y_{2i}^*: latent (not directly observed) dependent variables;

β: vector of estimable parameters;

X: vector of explanatory variables;

ε_1,ε_2: disturbance terms assumed to be normally distributed with zero mean and variance of 1. ϱ is the tetrachoric correlation coefficient between y_1 and y_2. In our study, the correlation coefficient ϱ measures the correlation between having a farm pond and participation in sale contract arrangement of farmers after the effects of the explanatory variables included in the model have been accounted for. The dependent variables y1 and y2 are observed if the latent variables y_1^* y_2^* are greater than zero:

$$y1 = 1 \text{ if } y_1^* > 0, 0 \text{ otherwise}$$
$$y2 = 1 \text{ if } y_2^* > 0, 0 \text{ otherwise} \qquad \text{(Eq.4)}$$

By following the same logic as in the equation 1 described above, the empirical models can be written as follows:

Y_1(PONDFARM) = F(FARMLAND, HHSIZE, ADULTS, AGE, SCHYRS , DROUGHT, AGRMACH, DRAFT, EXTENSION, DISTTOWN, DISTCITY)

(Eq.5)

Y_2(CONTRACT) = F(FARMLAND, HHSIZE, ADULTS, AGE, SCHYRS , DROUGHT, AGRMACH, DRAFT, EXTENSION, DISTTOWN, DISTCITY)

(Eq.6)

The explanatory variables were selected based on data availability, which are similar to those used for the model specification in the chapter 3. In order to ascertain the magnitude of the effects of the independent variables on a farmer‘s choice to have pond irrigation and his decision to participate in contract arrangement, the Marginal Effects (MEs) are calculated for the case of join probability of variables of interest (i.e. when PONDFARM =1 and CONTRACT=1). The marginal effects can be interpreted as the change (increase or decrease) in the expected value of a dependent variable associated with changing an independent variable.

Impact of market participation on farm commercialization and per capita incomes

This empirical analysis focused on the household characteristics associated with participation in a sale contract (market participation) and the impact of sale contract participation on per capita incomes. If informal contract draws labour and land away from other activities, focusing on crop income of the contracted pond farmers may overstate the impact on household well-being.

All sources of household incomes are rice, beans, vegetables, farm income, and total household incomes. The empirical models for per capita income function are described as follows:

Y(source of income) = *F*(CONTRACT, FARMLAND, HHSIZE, ADULTS, AGE, SCHYRS , DROUGHT, AGRMACH, DRAFT, EXTENSION, DISTTOWN, DISTCITY)

(Eq.7)

To examine the effect of contract participation on per capita household income as defined in function of household (Eq.7), the CONTRACT variable is endogenous within the income model. To account for this endogeneity, the equation 7 is treated by using the propensity score matching (PSM) method. This PSM method first proposed by Rosenbaum and Rubin (1983) is a treatment effect correction model used to reduce bias when estimating the effect of treatments. The contact variable is a treatment variable taking value 1 if a farmer participates in sale contract. To do a PSM procedure, it needs to estimate first the probability of participation of all sample through either probit or logit model. The next steps, the matched controls for each treatment are explored using selected matching algorithm over the estimated probability as a propensity score. For this study, the matching algorithm is Nearest-neighbour matching with replacement due to the nature of the dataset. NNM method is the most straight forward matching method. It involves finding, for each individual in the treatment sample, the observation in the non-participant sample that has the closest propensity score. The empirical estimations were conducted by using the STATA statistical package, version 12.

In addition, we also examine the effect of contract participation on agricultural commercialization by following the same procedure as for the effect of contract participation on per capita income.

4.4. Empirical results and discussion

4.4.1. Impact of pond irrigation on farmer's commercialization

The econometric analysis uses the propensity score matching method to examine the effect of pond irrigation on agricultural commercialization as a function of various characteristics of household. The results before and after matching the control are shown in table 4.4. The numbers of sample used in the test of balancing PSC and the predicted propensity score ranges were presented in Appendix (Table A4.1).

Table 4.4. Average Treatment Effect on Treatment on agricultural commercialization

Products sold		Effect of having pond irrigation on commercialization in percentage (%)	S.E	T-test[1]	*Pr(|T|>|t|)*
Agricultural commercialization	Unmatched	8.242	4.318	-3.52***	0.006
	Matched by PSM	8.481	3.116	-5.15***	0.000
%Rice	Unmatched	7.116	3.586	-3.52**	0.033
	Matched by PSM	8.287	1.965	-5.32	0.415
%Crops (other than rice)	Unmatched	4.296	9.129	-3.13***	0.002
	Matched by PSM	13.317	3.472	-2.96***	0.157
%Livestock	Unmatched	4.316	3.786	-2.83	0.713
	Matched by PSM	5.117	3.577	-2.32*	0.078

Note: [1] The standard errors are in the parenthesis. ***Significance at 1%, **Significance at 5% and *Significance at 10%.

Source: Author's calculation based the field survey data, 2012.

Before and after matching, the difference in agricultural commercialization between pond and no-pond farmers is statistically significant at 1 percent level. PSM after matching results show that pond farms have degree of commercialization higher about 8.48 per cent compared to no-pond farm (significant at 1 per cent level). This means, in average 41.7% of total farm production were sold out to the market for all pond farm. However, this share of household's products sold is still low compared to the percentage of market-oriented farming systems, 50% of production sold (Manivong et al., 2012).

Rice is considered as a staple food for most of farmers in the study areas. More than one third of paddy rice production is sold out after harvesting. The rest of production is kept for home consumption including seed provision for the next production season. After matching, the difference in percentage of rice sold to the market between pond farmer and no-pond farmer is 8.29%, statistically insignificant. This means that pond farmers tend to sell more paddy rice out to the market compared to no-pond farmers. From our interviews, two third of pond farmers reported that rice is a staple food but not principle because they eat less rice than before in their food diet and consume more vegetable and fish.

Crops (other than rice) are commonly sold out for cash income for all farmers. Its percentage of commercialization is the highest compared to other products for pond and no-pond farmers. The PSM shows that the difference in degree of commercialization of crops between the treatment group and the control group is 13.32%, statistically significant at 1 percent level. This difference after matching is much higher than that before matching due to reduced number of control groups in the PSM procedure. This result shows that there is significant effect of having pond irrigation on degree of commercialization of crops (other than rice), mainly soybean and vegetables (WS and DS).

In terms of livestock commercialization, the difference in percentage of livestock sold between pond farmer and no-pond farmer before matching is 4.32, not statistically significant. After PSM matching, the result shows that the difference in livestock sold between two groups is 5.12%, statistically significant at 10 percent level. However, these percentages of livestock sold are relatively lower compared to other farm's products due to its importance of capital asset accumulation for many farmers in the study areas. Selling out the livestock asset (particularly cattle and goats) requires a good consideration of farmer's strategies regarding to production system and to the well-being of household.

4.4.2. The extent of pond irrigation on sale contract participation in rural areas

The study applies the bivariate probit model includes a total of 11 model parameters. The results are presented in table 4.5. The parameters estimates are highly significant with a Log-livelihood value of -167. Moreover, the observed value of the dependent variables is predicted correctly 74.7% and 67.5% of the times in the PONDFARM and CONTRACT equations, respectively. For the joint distribution of two variables, the percentage of correct predictions is 53.2%. In addition, the rho (ϱ) coefficient is positive (0.875) and statistically significant at the 5 percent level, indicating that the disturbance terms of the two equations are correlated. The positive correlation parameter indicates that a famer having pond was more likely to participate in sale contract arrangement and vice versa.

Table 4.5. Results of the bivariate probit model[1].

Variables	PONDFARM			CONTRACT		
	Estimate(β)	S.E	t-Statistic	Estimate(β)	S.E	t-Statistic
FARMSIZE	0.1995	*0.0857*	2.33***	0.1101	*0.0478*	2.30**
HHMB	-0.1796	*0.0986*	-1.82	-0.2656	*0.0856*	-3.10**
ADULTS	0.2824	*0.1014*	2.78***	-0.1216	*0.0788*	-1.54
AGE	-0.0068	*0.0127*	-0.53*	0.0066	*0.0106*	0.62
SCHYRS	0.0348	*0.0360*	0.97	0.0165	*0.0306*	0.54
AGRMACH	0.4398	*0.1609*	2.73***	0.1999	*0.0954*	2.10**
DRAFT	0.1161	*0.0994*	1.17	0.1542	*0.0788*	1.96*
DROUGHT	0.7447	*0.2815*	2.65***	-0.9948	*0.3010*	-3.31
DISTTOWN	-0.0078	*0.0258*	-0.31	0.0084	*0.0214*	0.39*
DISTCITY	0.0051	*0.0083*	0.61	0.0096	*0.0071*	1.37
EXTENSION	0.0213	*0.0145*	1.27**	2.4489	*0.3261*	7.51
Constant	0.5649	*0.8554*	0.66	-2.1241	*0.7536*	-2.82***
Log-likelihoods	-167.08					
Rho(ϱ)	0.875**					
Observation	219					

Percent of correct predictions of PONDFARM and CONTRACT	
Pond irrigation	74.67%
Contract participation	67.53%
Joint having pond irrigation and contract participation	53.16%

Notes: [1] Robust standard errors (in italic) are used to correct heteroscedasticity. * Significant at the 10 per cent level; ** Significant at the 5 per cent level, *** Significant at the 1 per cent level.

Source: Author's calculation from the field survey, 2012.

In the PONDFARM equation, six coefficients (out of 11) are significant at the 10% or better. FARMSIZE, ADULTS, AGRMACH, DROUGHT (a binary variable capturing the drought occurred at least one time on farm since 2009) and EXTENSION which measure farm size, family labor, farm size, value of farm machinery, experiences in drought and receiving training from extension service (DAFEO), respectively, all have a positive and significant effect on the likelihood of having pond irrigation. These results indicate that larger farm land and higher machinery asset of household trend to have a pond constructed on their farm. Experience in drought and in receiving training for agricultural production also influence farmers' choice to have a pond constructed on their farm. In contrast, AGE (average age of family member), has a negative and significant influence on having a pond on farm (at 10 percent level).

In the CONTRACT equation, five coefficients (out of 11) are significant at least at the 10% level. FARMLAND, AGRMACH (value of machinery), DRAFT (value of draft animals), and DISTTOWN (distance from the District centre) have a positive and significant influence in participating in sale contract arrangement. In contrast, HHBN has a negative and significant influence on farmer's participation in sale contract arrangement.

The variables FARMLAND and AGRMACH represent farm household assets at the farm level. As expected, the parameters for these variables are positive and significant in both the PONDFARM and CONTRACT equations, suggesting that families with larger and mechanized farms are more likely to have pond irrigation for increasing their production and joining sale contract.

Table 4.6 shows marginal effects (MEs) for the case of joint probability (i.e., when PONDFARM and CONTRACT are both equal to 1). Following Greene (1996), the values reported are percent changes. The marginal effects (ME) for farm assets are low (i.e. FARMLAND, AGRMACH and DRAFT), 0.039, 0.075 and 0.054, respectively. The ME for FARMLAND is 0.039 suggesting that a 10% increase in the unit of farm land increases the probability of having a pond and participating in sale contract arrangement by 3.9%. For other farm assets, increases of one unit of AGRMACH and DRAFT imply increase the probabilities of having pond irrigation and participation in sale contract by 7.5% and 5.4%, respectively.

The parameter for HHNB is negative in both equations but significant only in the CONTRACT model. This result suggests that farmers with larger number of family members have a lower probability of having pond irrigation and participating in sale contract. The ME for this variable is 0.115, implying that farmers with larger number of family members are 11.5% less likely to construct farm pond and selling under contract than farmers with smaller family members. From the field interviews, farmers reported that they preferred to keep some part of their production outputs for home consumption. The parameters for SCHYRS are not significant although this variable is expected to have a positive effect on adopting pond irrigation on farm while the same lack of significance is found for AGE.

Table 4.6. Marginal effects (MEs) from the PONDFARM and CONTRACT equations[1]

Variables	Marginal effects	S.E	t-Statistics
FARMSIZE	0.0395	*0.0265*	1.49**
HHMB	-0.1150	*0.1052*	-1.09*
ADULTS	-0.0539	*0.0681*	-0.79
AGE	0.0028	*0.0046*	0.61
SCHYRS	0.0080	*0.0147*	0.54
AGRMACH	0.0747	*0.0383*	1.95**
DRAFT	0.0537	*0.0538*	1.12*
DROUGHT	-0.2942	*0.3003*	-0.98
DISTTOWN	0.0212	*0.0086*	0.24*
DISTCITY	0.0032	*0.0044*	0.72
EXTENSION	0.8125	*1.0067*	0.81

Notes: [1] Robust standard errors (in italic) are used to correct heteroscedasticity. * Significant at the 10 per cent level; ** Significant at the 5 per cent level.

Source: Author's calculation from the field survey, 2012.

The parameter for DISTTOWN is positive and significant at the 10% level in the CONTRACT equation and negative but not significant in the PONDFARM equation. The ME indicates that an increase in the unit of distance from the District centre (km) leads to a 2.1% rise in the probability of a pond farmer participating in sale contract. We observed that the farmers who live in rural areas with the bad road conditions (particularly during rainy season) prefer to sell out their products to the local traders (from the same village or from neighbor villages) during wet season production. The marginal effect for DISTCITY is a positive sign but not significant influence on pond irrigation adoption and participation in contract.

Moreover, the highest marginal effect is found for EXTENSION but not statistically significant. This result implies that farmers received training from extension service are more likely to have a farm pond and to participate in contract arrangement.

4.4.3. Impact of contract participation on agricultural commercialization

The impact of participating in sales contract on agricultural commercialization computed using the matching algorithms of the nearest neighbor matching (NNM). Propensity scores were estimated for all 219 farmers including 99 non-participated in sale contract (control) and 120 contracted farmers (treatment). Among the participants, pond farmers (185) and no-pond farmers (34) are separately analyzed. The number of sample in the common support and the balancing test are presented in Appendix (table A4.2).

Table 4.7. Average Treatment Effect on Treatment on agricultural commercialization by NNM

		Effect of contract participation (in per cent)	S.E	T-test	P(T=<t)
Pond farm	Unmatched	3.59*	2.028	1.77	0.078
	Matched by PSM	6.09***	2.412	3.08	0.007
No-pond farm	Unmatched	-2.19	1.008	-0.37	0.783
	Matched by PSM	-1.94	2.012	-0.41	0.875

Note: * Significant at the 10 per cent level; ** Significant at the 5 per cent level;*** Significant at the 1 per cent level.

Source: Author's calculation based field survey with 219 farmers, 2012.

Table 4.7 shows the results before and after matching the control for pond farm and no-pond farms. The total agricultural commercialization difference between participated and non-participated pond farms is 6.09% (significant at 1 per cent level). This explains that the informal sale contract practiced in the study areas has a positive impact on agricultural commercialization in the study areas.

For no-pond farmers, the after matching results indicate that the difference in agricultural commercialization between participant and non-participant farmers is -1.94% but not statistically significant. This means that informal sale contract has a negative impact on agricultural commercialization for no-pond farmers. From our field interviews, many no-pond farmers were not really interested to sell to the local traders due to their small production.

4.4.4. Impact of contract participation on per capita household incomes

The impact of participating in sales contract on per capita income computed using the matching algorithms of the nearest neighbor matching (NNM). Propensity scores were estimated for all the 219 farmers including 99 non-participated in sale contract (control) and 120 contracted farmers (treatment). Among participants (pond farmers and no-pond farmers), the predicted propensity score ranges and the balancing tests are presented in Appendix (tableA4.3 and A4.4).

Table 4.8 shows the results before and after matching the control for pond farmers. The difference in total household income per capita between participated and non-participated pond farms is 1.078 million LAK or US$134.75 on average, which is computed as average treatment effect on treatment (ATT). NNM procedure estimated the average per capita household income of control after matching was 2.839 million LAK or US$354.9, so that the average contract participation increases per capita household income by nearly 38 per cent. For per capita farm income, the matching results show that the difference in farm (agricultural) income per capita between participated and non-participated pond farms is 0.193 million LAK or UD$24.125 on average, significant at 1 % level. The average per capita farm income after matching is estimated by 1.834 million LAK or US$229.25 (an increase by 11.2% if a pond farmer participated in sale contract).

Table 4.8. Average Treatment Effect on Treatment on per capita income of pond farms by NNM

Source of income		Effect of contract participation on per capita income (million LAK)	S.E	T-test	Pr(|T|>|t|)
Rice	Unmatched	0.556**	0.115	2.224**	0.029
	Matched by PSM	0.665*	0.410	3.080*	0.080
Soybean	Unmatched	0.027*	0.014	1.876*	0.067
	Matched by PSM	0.015***	0.027	0.551***	0.007
Vegetable	Unmatched	0.957***	0.235	4.070***	0.000
	Matched by PSM	1.112***	0.266	4.187***	0.000
Livestock	Unmatched	0.377	0.230	1.640	0.103
	Matched by PSM	0.393	0.270	1.454	0.134
Farm income (agricultural)	Unmatched	0.211*	0.130	2.640*	0.068
	Matched by PSM	0.193***	0.091	2.541***	0.001
Total household income	Unmatched	1.016	1.316	1.413	0.159
	Matched by PSM	1.078	1.518	1.367	0.525

Note: [1]Exchange rage USD 1 = 8,000 Lao kips (LAK) (August, 2012 at the time of the survey). * Significant at the 10 per cent level; ** Significant at the 5 per cent level;*** Significant at the 1 per cent level.

Source: Author's calculation based field survey of 185 pond farms, 2012.

In short term, the informal contract of sales revealed a positive impact on the income from cash crops like rice, soybean, and vegetables since the sale contract directly deals with such products among rural poor farms in Southern provinces of Laos. Since vegetables are the most common traded under sale contract on farm, they have the largest impact on per capita income. However, the participation in informal sale contract does not increase total household income per capita probably because the farmers with sale contract have lower off-farm income per capita. As described in chapter 3, off-farm income such as remittance or wage from outside of farm represents an important proportion of total household income for most of farmers in the study areas.

The before and after matching results for no-pond farmers were presented in table 4.9. After matching, the difference in total household income per capita between participated and non-participated no-pond farms is -0.278 million LAK or US$34.75 on average but not significant, which is computed as average treatment effect on treatment (ATT). The no-pond farmers with informal sale contract have lower total household per capita income than those with no contract. From the survey, under contract no-pond farmers engage to produce for the traders and less opportunity for work outside of the farm for off-farm income generation. However, the contract participation has a positive impact on per capita farm income for no-pond farm. The difference in farm income per capita between participated and non-participated farmers is 0.113 million LAK or US$14.125.

Table 4.9. Average Treatment Effect on Treatment on per capita income of no-pond farms by NNM

Source of income		Effect of contract participation on per capita income (million LAK)	S.E	T-test	Pr(|T|>|t|)
Rice	Unmatched	0.116*	0.125	1.957**	0.029
	Matched by PSM	0.125	0.221	1.780	0.800
Soybean	Unmatched	0.034*	0.044	2.276*	0.087
	Matched by PSM	0.035	0.037	1.951	0.571
Vegetable	Unmatched	-0.095***	0.435	-1.218***	0.000
	Matched by PSM	-0.012***	0.346	-2.117***	0.000
Livestock	Unmatched	-0.036	0.330	-1.874	0.793
	Matched by PSM	-0.039	0.447	-1.854	0.634
Farm income (agricultural)	Unmatched	0.109*	0.223	2.540*	0.082
	Matched by PSM	0.113*	0.391	2.141*	0.061
Total household income	Unmatched	-0.346	0.416	-1.343	0.719
	Matched by PSM	-0.278	0.518	-2.167	0.825

Note: [1]Exchange rage USD 1 = 8,000 Lao kips (LAK) (August, 2012 at the time of the survey). * Significant at the 10 per cent level; ** Significant at the 5 per cent level;*** Significant at the 1 per cent level.

Source: Author's calculation based field survey of 34 no- farms, 2012.

Before matching, the difference in per capita income for vegetable between participated and no-participated no-pond farmers is -0.095 million LAK or US$11.875. After matching by PSM, this difference is -0.012 million LAK or US$1.5, statistically significant at 1% level. This result implies that the informal sale contract participation has a negative impact on per capita vegetable income for no-pond farmers due to its small production and lower prices proposed by the traders.

4.5. Conclusion

Based on the findings of this study that revealed the major proportion of the land being used for growing crops for household consumption as well as sale, it is concluded that a farm with pond irrigation can increase their income by selling some surplus of farm production. Rural farmers with larger land and wealthier farm assets (machinery and draft animal holding on farm) are more likely to have individual pond irrigation for enhancing their production outputs and to engage in inform sale contract arrangement with the local traders in the study areas.

In terms of pond irrigation impact on market participation of rural farmers, This contact of sales created between the farmers and local traders enhances significantly the smallholders' per capita income from the crop under the contract. In general, this kind of market arrangement is informal in many places of rural areas of Laos, where farmers are isolated from the infrastructure development. Only local small traders are their mean of market access and facilitate to sell out their farm outputs. Per capita household income of farmers under sale contract is 38 per cent higher than that of farmers who prefer to sell their product by themselves to the markets. However, the difference is not statistically significant.

Therefore, we conclude that the informal sale contract observed in rural Southern Laos does not have positive or negative impact on the alleviation of poverty. Future research is needed to reveal such impact of pond irrigation on poverty reduction linkage in the case of Laos.

5. ECONOMIC EVALUATION OF SMALL-SCALE IRRIGATION PONDS FOR RURAL DEVELOPMENT IN RURAL AREAS OF LAO PDR.

5.1. Introduction

Laos has surface water resources such as rivers in abundance but the extraction of this water for domestic use and agricultural production requires an enormous investment. Investment in irrigation development started in 1990 and currently only 15% of all paddy rice fields are irrigated by pump system during the dry season. 59% of total rural villages lack irrigation facilities (MAF, 2012a). Investment in irrigation is still limited in many remote areas throughout Laos. Farmers in these areas rely exclusively on rainfall to grow their crops. Some construct a pond on their farmstead to capture rainfall in order to supplement irrigation for crops during the dry season (Ireson, 1995).

Though ponds have been used in many rural areas of Laos in the past, a recent increase in the number of new ponds has led the Lao government's intention to invest in pond construction such as small-scale reservoirs or weirs for poor communities. As a considerable amount of investment is required to make irrigation water available in this way, it is important to understand how effective such investments will prove to be. This is an especially important issue in the study site where farmers with low levels of capital must allocate scarce agricultural resources for the establishment of farmstead ponds. To our knowledge, there is no research examining the effectiveness of pond construction investment in Laos. Thus, drawing on household surveys in 2012, the original contribution of this chapter is to evaluate the costs and benefits of multiple-purpose farmstead ponds as a decision-making tool for rural Lao farmers and other actors who are interested in small-scale pond irrigation development.

5.2. Costs-benefits approach and Pond irrigation investment

The benefit-cost approach is simply rational decision-making. People use it every day, and it is older than written history. The costs-benefits analysis is always seen as a simple way to assess the effectiveness of an investment, particularly in public goods such as hydropower or water irrigation projects.

At large scale irrigation projects, the benefits-costs analysis is indispensible and needed to be provided before allocating the budget. Shoengold and Zilberman (2007) distinguish the benefits and costs of water irrigation project development as follows: benefits of irrigation include increase of productivity and food production on farm, employment opportunities and increase off-farm non-agricultural income for household, stabilization of irrigation water supply and risk aversion of farmers, and flood control. Costs of irrigation are namely: (1) Capital cost of construction and maintenance of irrigation schemes, these costs are commonly expressed in monetary unit and possible to be estimated. (2) Environmental costs and (3) social concerns are often sees as impact of irrigation construction such as deforestation, habitat destruction, blocking migration of native species (fish), disease contamination of water, salinization and water logging et environmental problems. These costs are required to be studied deeply and minimized in order to satisfy the return of such investment.

For small-scale irrigation project, particularly individual or private pond construction, the benefits-costs analysis is applied at household level. The results help farmer to prioritize his decision making (choices) on farm resource allocation and production systems such as (1) land allocation: how optimum land-water ration on a farm (which area for each crop, pond surface), production farming management styles (what crops should be irrigated, for home consumption or for commercialization), and what type of irrigation system used (small traditional or modern pumping systems, etc). The benefits of pond irrigation have been described in chapter 2 including outputs generated from pond irrigation. In this section of this chapter, the costs of pond irrigation in rainfall harvesting systems are identified mainly: economic costs (capital costs) and opportunity costs (Tian et al., 2002; Wang et al., 2007). For our research, the opportunity costs including land used for pond and off-farm activities for family labors (adults) were used in the analysis.

There are few researches on benefit-costs analysis on small-scale individual irrigation such as farm pond irrigation. The similar empirical researches on rainfall harvesting irrigation schemes focused on benefits and costs of community reservoir (tank) at village or community level (Liang and van Dijik, 2011).

5.3. Empirical framework and model specifications

5.3.1. Data sources

The data used for the empirical study in this chapter were partially summarized from the households' survey conducted in two southern provinces of Lao PDR, namely Savannakheth and Champasack provinces within 4 districts, namely Outhoumphone, Champhone, Phonthong and Sukhuma districts, where numerous ponds are located.

As described in chapter 1, two sets of questionnaires were developed. The first was for use at the household level. The second was for key informants at the village level including village heads; heads of "*Kum Ban*"[8]; and the district authorities. Our objective was to gain a quantifiable overview of pond characteristics and use. Data were sought on the following details: water and crop management, sources of finance for pond construction; operation and maintenance costs; and the benefits of pond irrigation. The field survey was conducted in 23 rural villages in the survey area from August to September 2012. To realize our empirical studies, 100 ponds were additionally selected at random from the 2012 survey to be interviewed in 2013 to capture the variation relating to pond costs and benefits.

5.3.2. Analytic framework: Benefit-Cost Analysis

The economic evaluation of ponds was performed by comparing the costs and benefits of pond construction. As costs and benefits accrue at different points in time, our study is based on comparing their respective net present value (NPV), which is the discounted sum of all future benefits and costs associated with the ponds (Liang and van Dijik, 2011). The benefits in the case of

[8] *Kum Ban* is a village Cluster, an administrative group of villages gathered within a district.

ponds comprise the incremental net return due to ponds in comparison with rain-fed agriculture. The benefits depend on the nature of crop production with and without ponds (Mushtaq, et al. 2007; Pandey, 1991).

To analyze the costs and benefits of the ponds, two economic indicators are used: financial net present value (NPV) and financial internal rate of return (IRR). The NPV was estimated by the equation 1 shown below.

$$NPV = GB_p - NB_{RF} - TC \qquad \text{(Eq.1)}$$

Where GB_p is the NPV of gross benefits from ponds, TC is the net present value of total costs associated with ponds and NB_{RF} is the NPV of net benefits from rain-fed agriculture. However, $NB_{RF} = 0$ if there is no rainfed crops on farm.

$$GBp = \frac{\sum_{t=1}^{n} Bt}{(1+i)^t} \qquad \text{(Eq.2)}$$

$$TC = \sum_{t=0}^{m} \frac{C_{1t}}{(1+i)^t} + \sum_{t=0}^{m} \frac{C_{2t}}{(1+i)^t} + \sum_{t=1}^{n} \frac{C_{3t}}{(1+i)^t} + \sum_{t=1}^{n} \frac{C_{CM}}{(1+i)^t} \dots\dots\dots\dots\dots \qquad \text{(Eq.3)}$$

$$NB_{RF} = \sum_{t=1}^{n} \frac{GB_{RF(t)}}{(1+i)^t} - \sum_{t=1}^{n} \frac{C_{RF}}{(1+i)^t} \qquad \text{(Eq.4)}$$

Where B_t is the gross benefit in year t; C_1 is the total cost of pond construction; C_2 is the cost of irrigation equipment and pipes; C_3 is the fixed investment of pump replacement, or pond expansion in year t; C_{CM} is the cost of cleaning and maintenance; GB_{RF} and C_{RF} are the gross benefits and costs from rain-fed agriculture, respectively. i is the discount rate. Feasible scenarios will give NPV > 0. The internal rate of return (IRR) was computed by the equation 5.

$$IRR_{RF} = \sum_{t=1}^{n} \frac{B_t}{(1+IRR)^t} - [(\sum_{t=0}^{m} \frac{C_{1t}}{(1+IRR)^t} + \sum_{t=0}^{m} \frac{C_{2t}}{(1+IRR)^t} + \sum_{t=1}^{m} \frac{C_{3t}}{(1+IRR)^t} + \sum_{t=1}^{m} \frac{C_{CM}}{(1+IRR)^t}) +$$

$$(\sum_{t=1}^{n} \frac{GB_{RF(t)}}{(1+IRR)^t} - \sum_{t=1}^{n} \frac{C_{RF}}{(1+IRR)^t})] \qquad \text{(Eq.5)}$$

The IRR is accepted if it is greater than the minimum expected interest rate. We used the financial analysis package in Excel, 2010 to compute the equations for the analysis.

5.3.3. Estimation of model parameters

Pond area estimates: the surface irrigated by a pond depends on the pond's size; the volume of available pond water; and the farmer's cropping strategies. Pond dimensions were measured as part of the field survey and farm owners were asked to describe their cropping patterns and related activities.

Yield estimates: irrigated and rain-fed yields of rice and vegetables were reported from farmers' estimates. Rice is mainly irrigated by rainfall. Only beans and vegetables are irrigated by pond water. Vegetable is leafy vegetable (lettuce and Chinese kale)[9] selected for our analysis. 75% of ponds were used for raising fish, with yield measured as the amount of fish produced per year.

Price estimates: the investment values are adjusted to reflect the calendar year 2010-2011. Farm-level prices collected at different times during this period were used to calculate the average prices received by farmers. The distribution of prices is assumed to be stationary (constant prices).

Profit estimates: the net returns of various crops were calculated as gross returns minus the costs of all relevant inputs, including the cost of irrigation and labor. The average household size is 6.4 members. Considering this fact, combined with increasing growing agro-industrial farms, we assume that household labor may have opportunity costs. Therefore, the imputed cost of family labor is included when calculating the net return from crops and fish raising. Due to increasing opportunities for off-farm economic activity in nearby cities, the daily wage rates for labor in the study area are used as the opportunity costs of family labor. The current market rate for 8 hours is between 35,000 Lao Kip (LAK) or US$3.75 and 40,000 LAK or US$5.00 per day depending on the nature of work. The average is used in our analysis, 37,000 Lao Kip or US$4.69.

Cost estimates: the costs of using ponds for multiple purposes are divided into two components: 'use' and opportunity. 'Use' costs are associated with construction, maintenance and replacement of pumps and equipment. Opportunity costs relate to alternative uses of land resources allocated to ponds, namely for growing additional rain-fed crops. While use costs were easy to determine, opportunity costs were difficult to estimate due to the nature of what they measure. The construction costs and the associated costs of ponds were estimated after consulting with pond

[9] Leafy Vegetable is mainly salad, Chinese kale, green onions, cabbages. In our study site, Chinese kale and lettuce are the most common produced on pond farm.

farmers and local construction companies involved in newly established ponds. Opportunity costs of land used for ponds were calculated as the net benefit that might have been earned if the area used for a pond had not been so allocated. The forgone agricultural production on pond areas is used as the opportunity cost of pond. This cost is estimated by multiplying the area of small (0.04ha), medium (0.16ha) and large (0.47ha) ponds by the average net return (1.72 million LAK or US$215) from rain-fed agriculture. The average opportunity cost of ponds was about 0.38 million LAK (US$48).

Time horizon: the time horizon depends on the environment and multi-purpose uses of ponds. Yuan et al., (2003) uses 10 years as the service life. Because future benefits are discounted, benefits are greatly diminished after 10-20 years and would have a minimal impact on the decision to construct a pond. For this study, the useful life of a pond was estimated to be up to 10 years. Beyond 10 years, rehabilitation work might be required (expected costs of pond improvement).

Discount rate: For the purposes of cost-benefit analysis, interest rates are generally considered to be between 5% to 15% (Kunze, 2000). In relation to individual farm ponds, the study uses 10% of the interest rate. However, sensitivity analysis was performed using 7.5%, 11.5%, and 13% discount rates, as proposed by the State-owned banks and the Lao enterprise development funds (from field survey 2012).

Table 5.1. Descriptive statistics of variables used in the economic analysis[1].

Variable	Measurement unit	Pond size[2]		
		Small(N=45)	Medium(N=44)	Large(N=11)
Pond area	ha	0.041(0.02)	0.16(0.12)	0.47(0.24)
Plot are (cropping areas under irrigation)	ha	0.05(0.06)	0.38(0.24)	0.64(0.11)
Water Storage capacity	Cubic meter	697(133)	3,244(2031)	10,850(5,093)
Cost of construction (2010-2011)	LAK/m^3	12,000	12,000	12,000
Capital costs for a new pond				
Pond construction	million LAK[3]	8.36	38.93	130.20
Price of new pump set (2010-2011)	million LAK	2.53	5.27	12.51
Piping equipment and installation	million LAK	0.44	0.52	1.57
Variable costs				
Cleaning and maintenance	million LAK	0.32 (0.51)	0.72(0.74)	3.91(1.21)
Expected cost of pond improvement	million LAK	5.91	9.53	11.15
Miscellaneous cost	million LAK	0.12(0.11)	0.34(0.57)	1.52(0.83)
Imputed costs of land use for ponds	million LAK	0.07(0.03)	0.28(0.21)	0.81(0.41)
Benefits from pond (Rice, vegetables and fish raising)				
Scenario I: Self-sufficient farm		***N=30***	***N=24***	***N=3***
Net return of DS rice	million LAK/ha	--	--	4.15(0.22)
Net return of DS rice[4]	million LAK/ha	--	--	4.54(1.32)
Net return of DS vegetables and beans	million LAK/ha	9.51(3.23)	12.52(3.12)	6.22(1.32)
Net return of DS vegetables and beans[4]	million LAK/ha	15.24(7.22)	21.33(6.71)	13.73(4.31)
Fish yield	Kg/year	54.32(54.13)	100.45(102.49)	597.7(347.91)
Net return of fish	million LAK/yr	0.48(0.67)	1.16(1.94)	22.75(12.1)
WS rain-fed rice yield	Kg/ha	1754(113)	1803.6(976)	1790(727)
Net return of WS rain-fed rice	million LAK/ha	2.91(0.12)	2.82(1.61)	2.85(0.52)
Net return of WS rain-fed rice[4]	million LAK/ha	3.31(1.11)	3.94(1.03)	3.04(0.42)
Net return of WS vegetable and beans	million LAK/ha	2.74(1.34)	7.32(12.03)	4.81(9.11)
Net return of WS vegetable and beans[4]	million LAK/ha	5.28(3.12)	16.70(10.12)	11.91(5.41)
Scenario II: Intensification farm		***N= 15***	***N= 20***	***N = 7***
Net return of DS rice	million LAK/ha	--	--	3.25(0.22)
Net return of DS rice[4]	million LAK/ha	--	--	4.14(1.32)
Net return of DS vegetables and beans	million LAK/ha	17.51(6.23)	22.32(4.12)	12.42(3.22)
Net return of DS vegetables and beans[4]	million LAK/ha	35.14(5.22)	35.83(5.71)	27.23(8.31)
Fish yield	Kg/year	94.22(74.13)	163.45(122.49)	979.7(647.91)
Net return of fish	million LAK/yr	1.18(2.87)	3.06(4.94)	62.15(52.1)
WS rain-fed rice yield	Kg/ha	2147(513)	2263.6(776)	2080(327)
Net return of WS rain-fed rice	million LAK/ha	1.09(0.12)	2.02(0.41)	1.05(0.82)
Net return of WS rain-fed rice[4]	million LAK/ha	2.72(0.21)	3.11(2.23)	2.14(1.12)
Net return of WS vegetable and beans	million LAK/ha	11.34(4.34)	16.33(18.03)	9.72(10.61)
Net return of WS vegetable and beans[4]	million LAK/ha	17.04(3.12)	32.61(10.02)	15.64(7.41)

Notes: [1] Figures in parenthesis are standard deviation. [2] Small ponds have a storage capacity less than 1000 m^3; medium ponds have a storage capacity 1000 m^3 and 10,000 m3; large ponds have a storage capacity more than 10,000 m^3 (Mushtaq, et al. 2000). [3] LAK is abbreviated of Lao Kip currency. The exchange rate is 1 US$ = 8,000 LAK on October 2012. [4] Net returns do not account for the imputed costs of family labor. DS and WS are abbreviated of Dry season and Wet season, respectively.

Source: Author's calculation from 100 pond farms surveyed in 4 districts, 2012.

5.3.4. Definition of scenarios analysis

From the survey 2012, we observed that many farmers are smallholder producers and have a relative small size of pond irrigation systems on their farms. Some of them have a farm pond for only raising fish and home garden vegetable and some of them have a bigger pond for totally irrigate their crops in all production seasons and also to raise fish for home consumption and selling to local markets. However, rice is still a staple food and mainly produced on farm to ensure food security in term of stretch cereal stock. For that reason, they cannot to convert all their land resources to construct a pond on their farms; other reason is that the cost of pond construction is relatively high for many rural poor farmers in the studied areas.

We assumed that a farmer invests in pond construction on his own farmland and funds this investment through wholly own and available resources. The following two scenarios emerged:

Scenario 1 "Self-sufficient farm": The farmer engages in agricultural production to ensure food security, allocating available land resources (other than paddy field used for producing rice for home consumption) to pond construction. He cultivates DS and WS vegetables and raise fish. Rain-fed rice and wet season vegetables are produced for home consumption and income generation. He uses homemade inputs such as compost, manure for soil fertility improvement and natural feed for fish raising.

Scenario 2 "Intensification farm": The farmer decides to intensify his farm by allocating his available land resources (other than paddy field used for producing) to pond construction. He crops DS and WS vegetables and raises fish for home consumption and income generation. He uses more inputs such as chemical products for crops and soils, and concentrate feed for fish raising in order to achieve higher yields than farmer does in the scenario 1.

As presented in table 5.1, the different net returns can be described by the size of pond for two scenarios of the analysis. For WS rice of scenario I, The net returns of WS rice without the imputed costs of family labor are 3.31 million LAK (US$413.75), 3.94 million LAK (US$492.5) and 3.04 million LAK (US$308) per ha for small, medium and large ponds, respectively. The net returns of

WS rice with and without the imputed cost of family labor are higher than those of the scenario II for all pond sizes. This difference is due to the lower use of chemical fertilizers.

For the vegetables and beans, the net returns without the imputed costs of family labor are significantly different in both scenarios. The net returns per ha of vegetable and beans of scenario II for all pond sizes are higher than those of the scenario I. For the vegetable and beans, the net returns without family costs of intensive farms are 17.44 million LAK (US$2,130), 32.61 million LAK (US$4,076.25) and 15.64 million LAK (US$1,955) for small, medium and large pond farms, respectively. However, Farmers with small and medium ponds generate net returns higher than large pond does in scenario II. When the imputed costs of family labor are accounted for, the medium pond shows highest net returns of vegetable and beans among three cases.

5.4. Empirical results and discussion

5.4.1. Cost-benefit of farm pond irrigations

A Lao farm pond generates tangible and intangible benefits. However, only tangible benefits are used in this analysis. Tangible benefits include incremental benefits from crop production (mainly dry season vegetables) and fish raising, which are major source of income. Intangible benefits include the provision of water for domestic use and livestock as well as the reduced risk of flooding.

The cost-benefit analysis is provided above, in Table 5.2. In scenario I and II, pond investments of all sizes are profitable either with or without the imputed costs for family labor. This is seen by the high IRR, positive NPV and benefit-cost ratio (BCR is greater than 1). However, the internal rates of return are higher for small and medium ponds. Large ponds are more profitable in scenario II due to their larger storage capacity, which allow a greater possibility for fish raising.in the context of rural Laos.

Table 5.2. Net present value, IRR and benefit-cost ratio for farm ponds in South of Laos

Pond size	Net Present Value[1](10%) (million LAK.ha^{-1})	Internal Rate of Return (in %)	Benefit-Cost Ratio (10%)
Scenario I[a]			
Small	26	24	2.02
Medium	29	12	1.15
Large	35	10	1.03
Scenario I[b]			
Small	55	41	3.77
Medium	33	17	1.49
Large	23	14	1.23
Scenario II[a]			
Small	10	16	1.35
Medium	28	12	1.12
Large	53	14	1.28
Scenario II[b]			
Small	16	19	1.55
Medium	42	19	1.60
Large	62	15	1.32

Notes: [1] 1US$=8,000LAK. [a] With the imputed costs of family labor. [b] Without the imputed costs family labor.

Source: Author's calculation based field survey data, 2012.

5.4.2. Sensitivity analysis

It is important to test the robustness of the cost-benefit analysis at different discount rates: 7.5%, 11.5% and 13%. The results in table 5.3 show that the net present values per ha are very sensitive to discount rates. In scenario I, small, medium and large ponds show negative NPV at 13% discount rates (see Table 5.3 below).

Table 5.3. Sensitivity analysis of net present values based on various discount rates

Pond size	Net Present Value (million LAK.ha^{-1})[1]			
	7.5%	10%	11.5%	13%
Scenario I[a]				
Small	35	26	22	-18
Medium	21	29	13	-12
Large	37	35	-31	-24
Scenario I[b]				
Small	62	55	16	-29
Medium	50	33	25	-17
Large	80	23	-16	-6.2
Scenario II[a]				
Small	15	10	7	4
Medium	27	28	8	5
Large	92	53	23	14
Scenario II[b]				
Small	23	16	12	9
Medium	60	42	32	15
Large	103	62	22	21

Notes: [1] NPV is in million LAK per ha. 1US$=8,000LAK. [a] With the imputed costs of family labor. [b] Without the imputed costs family labor.

Source: Author's calculation based field survey data, 2012.

In scenario II (intensification farm), all pond sizes show positive NPV. That means that investing in ponds generates significant profit if pond farmers decide to intensify agricultural production, particularly in relation to dry season crops and fish raising. The potential benefits from ponds are optimized for the cases of medium and large ponds.

5.5. Conclusion

Small-scale irrigation ponds have been used recently in remote rural areas of Southern Laos, generating numerous benefits for farmers. Recently, increased construction of farmstead ponds has occurred in the survey areas due to reduced water availability for rain-fed crops. Ponds are used to store surplus rainfall, providing a supplemental irrigation source for the cultivation of dry season crops as well as a space to raise fish. Additional crops and fish produced in this way are either used for home consumption or income generation.

Economic analysis based on data from the field survey show that small, medium and large ponds are profitable with positive NPVs, IRRs and BCRs. However, these economic indices are not so high as the potential benefits of ponds are not currently optimized in the case of Lao ponds. In general, small and medium ponds show better profits than do large ponds in term of BCR. However, if we look at the results in the scenarios 2 accounting for the opportunity cost of family labor, they are not so much different. In the assumption of constant cost of pond construct per m^3, the lager and wealthier farmers should construct multiple small/medium ponds on their farms rather than having a big pond in the context of rural Southern Laos.

Our results provide the first source of evidence about the multiple-uses and benefits of ponds for agricultural production in Laos. Data strongly indicate the utility of ponds, suggesting the need for further research on methods to optimize their use in the Lao context. Additionally, an evidenced-based case arises for Government and development agencies in Laos to use the farm pond model within community development projects.

To help answering the question on what pond size is optimum in the Lao context of this chapter, further research in the next Chapter 6 is to determine the optimum size of pond irrigation farm based on a pond model in the rural context of Southern Laos.

6. ECONOMIC MODELLING OF POND ON DIFFERENT FARMING MANAGEMENT STRATEGIES IN SOUTHERN LAOS.

6.1. Introduction

The studied areas, Savannakhet and Champasak are two lowland southern provinces of Lao PDR located on the left bank of the Mekong River. The agricultural production in these provinces is increasingly developed to achieve food sufficiency in the region. However, extreme weather conditions of drought and flooding are major threats in these areas. In the dry season, access to water has been identified as a major constraint for the rice-based farming systems in the region.

The construction of farm ponds undoubtedly alleviates the persistent lack of water for agricultural production during the dry season in Champassak and Savanakhet provinces. Small farm ponds can be used to harvest rainwater and runoff during the rainy months and utilize the stored water to grow crops during the dry season. Stored water from the ponds can be used not only for irrigation of crops but also for fish culture and drinking water for livestock. Producing some surplus in dry season such as high value crops (vegetable and beans) and even pond fish may also generate an extra income for rural poor households.

However, lack of understanding among farmers on the availability, use and management of stored water in the small farm ponds and suitable cropping patterns related to water use efficiency limits the potential benefits of the land-water resource in the area. The research project by IRRI was initiated in 2011 through the ACIAR-funded project "Developing Improved Farming and Marketing Systems in Rainfed Regions of Southern Lao PDR" to help farmers improve the management of water in their farm ponds. Farmers' knowledge on land-water resource management and pond water utilizations for irrigation are still an issue for water use efficiency and water productivity on farm pond irrigation modes in the study area. Two questions to be answered are (1) what an optimal pond size (land-water resource ratio) for best economic productivity at farm level and (2) what is the optimal water management to achieve efficient water use for different cropping farming systems (Penning de Vries, F., and Ruaysoongnern, S., 2005).

Up to now, there is no modeling research on pond irrigation and construction to produce guidelines for farmers or contractors on size, location and irrigation schedules in Lao PDR. The objectives of the chapter aimed to determine the best land water ratio (an optimal size of pond irrigation farm) with different scenarios of farm management strategies in different climates in the Southern of Laos, by applying the BoNam model developed by Penning de Vries, F., and Ruaysoongnern, S (2005) to the field data 2012 and the climatic data from Savannakheth and Champasack provinces. The results of this research will help farmers to choose what pond size farmer can specialize in producing crops according to the simulation of BoNam model accounting for different farming management style under the climatic context of Southern regions of Lao PDR.

6.2. Pond modeling research and BONAM model in Thailand

There is a wide range of pond sizes on actual farms, as we could see from the field survey. This suggests that there is no practical way to determine the optimum size depending on different features such as soil characteristics, landscape and local climate, economic factors and the preferred farming management style of farmers. A literature review yielded several models that address optimization and water on farms. These include SWB model (Annandale et al., 1999), Tradeoff Analysis Model (Antle and Stoorvogel, 2000), Dam Ea$y (Lisson et al., 2003), Planwat model (Van Heerden, 2004) and TechnoGIN-3 model (Wolf et al., 2004).

The modeling research by Kono (2001) presented a theoretical approach to farm pond design and to identify strategies for farms with rice as the main product in the USA; based on a simulation to optimize water use for supplementary irrigation. However, this model does not capture all features or parameters encountered on the fields required as the case of Southern Laos, particularly those with respect to multiple uses of water, farming styles and weather-related risk on individual homesteads. For the Lao context, the most important factor to be taken in consideration is the one called 'a climatic condition defined as a tropical monsoon'. This is why the BoNam model developed in Northeast Thailand is chosen to be applied.

The BoNam model was developed by researcher teams of IWMI and Khone Kean University of Thailand in 2005. Farms in Northeast Thailand suffer often from droughts in the dry season and sometimes even in the rainy season. The reason is that much of the ample annual rainfall is not retained on the farms. The new approach for rural development was stimulated strongly by His Majesty King Bhumibol Adulyadej of Thailand in 1987. This new concept provides opportunities for Thai farmers to gain access to more water (rainwater harvesting on farm ponds, extracting from channels, piped water) and use it for various domestic and productive purposes (see figure A6.1). But the question is still about the optimum size of water sources on a Thai farm. The BoNam simulation model on farm pond sizes was developed in order to answer the key formulated three pertinent questions that helped to conceptualize the model. These three questions were as follows:

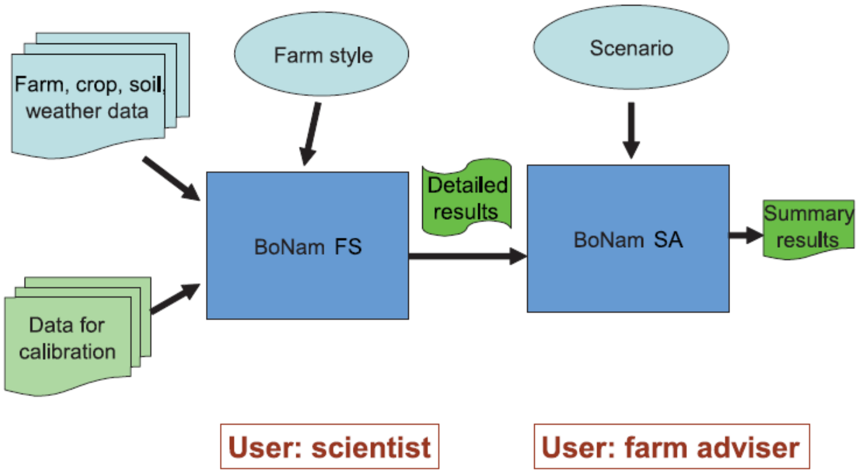
1. What is the land-water resource ratio on farms for best productivity in different ecosystems?
2. How to manage water for high water use efficiency for each crop species (for monocrop as well as integrated farming systems)?
3. What is the water productivity potential per farm in different parts of Northeast Thailand?

Several answers to the question about the land-water ratio, or relative pond size [10], have been provided. The New Theory, for instance, suggests the ratio of 0.3 % which would allow year-round irrigation on a Thai farm. In trials, the ratio around 0.12 have been reported as optimal (LDD, 2005, lnthough, the Land Development Department (LDD) used a fixed size of 1,260 m^3 as the target pond size in the past (Penning de Vries et al., 2005).

[10] The land-water ratio is the ratio to the surface of pond to the total farm land area, e.g., a pond ratio of 0.3 means the pond surface area is 0.3 ha and the total farm land area is 1 ha.

The development of the farm simulation model BoNam (Thai for 'pond'), was shown in Figure 6.1. There are two parts: the core simulator (BoNam-FS for Farm Simulation) and a macro for analysis of the detailed results (BoNam-SA, for Scenario Analysis)[11].

Figure 6.1. A diagram of the inputs required for Bonam, its results and users.



Source: Penning de Vries, F.; Ruaysoongnern, S., 2010, p.17.

BoNam-FS is built in the language SIMILE by Muetzelfeldt and Massheder in 2003 (cited by Penning de Vries, F.; Ruaysoongnern, S. 2010). Its outputs can be inspected in SIMILE or analyzed with BoNam-SA in MS Excel. SIMILE allows a high degree of transparency of the model and easy inspections and modifications.

Farm management in BoNam is characterized by the choice of target yields of crops planted, irrigation levels, use of the soil amendments or mulch, and the fish stocking rate and level of feeding. This choice of management variables is not uniform among homesteads because of different conditions and aspirations. The results of model simulation provide indicators for answering the question on 'what is the optimum pond size related to the ecosystem across Northeast Thailand?' The key feature of the ecosystem in this case is local weather. The optimum pond size was

[11] For more detail on model conceptualization, the working paper published by Penning de Vries, F.; Ruaysoongnern, S., 2010 on '*Multiple sources of water for multiple purposes in Northeast Thailand*' is available on the website of the IWMI.

determined, for simplicity, judging only by the indicator 'annual farm income,' to show the land-water ratio. Before application of the model in specific situations it will be necessary to supply the relevant input data (weather, soils, farm landscape, farm management data).

6.3. Data and model calibration for modeling

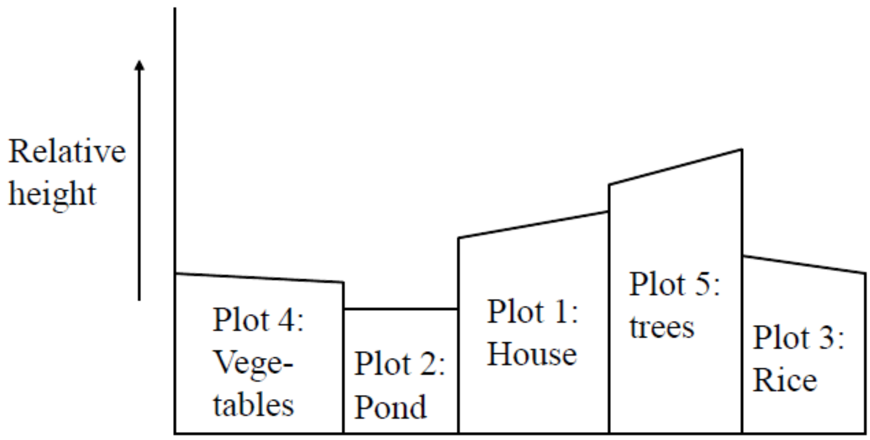
6.3.1. Overview of BoNam model and Calibration

The model is constructed for a typical farm and is built in the language SIMILE 4.2 (Muetzelfeldt and Massheder, 2003) [12] as described in the previous section. SIMILE allows a high degree of transparency of the model and easy inspections and modifications. Checks and double accounting in the model assure consistency and reduce errors. A typical simulation run covers a period of 10 years: 0.5 year of initialization followed by 9.5 consecutive years; this allows us to take into account carryover effects, calculate annual averages and estimate uncertainty. The BoNam model integrates parameters that can be set according to the site specific conditions (soil, weather, produce market prices), farmer preferences (farming 'style', species, target yield, planting dates, irrigation level) by Penning de Vries, F., and Ruaysoongnern, S., in 2005. The acronym of the model, BN, stands for 'BoNam', or in Thai for 'pond'. Running the model and comparing results for different scenario's is user friendly, so that farmer groups can use the program without expert guidance after a few hours of training.

BoNam simulates five farm sections as shown in figure 6.2 below: (Plot 1) the farmhouse, yard and the unplanted area surrounding the pond, (Plot 2) the pond, (Plot 3) the rice field(s), (Plot 4) a plot with vegetables, and (Plot 5) a park with trees. The vegetable crop is irrigated from the pond, and the rice crop receives surface runoff, if any. The pond can be used to produce fish. The water balance connects the plots: excess water on plots runs into the pond and runs off the farm if there is too much.

[12] Website https://www.simulistics.com.

Figure 6.2. Approximate positions of the five plots on a farm model and directions of runoff



Source: Penning de Vries, F., and Ruaysoongnern, S., 2005.

In term of model calibration, it could be done by simply changing the units of parameters for model simulation. Since it is accessible and freely available, one can practice by collecting a number of trials and to compare them with actual observations for the purpose of calibration. With this in view, we collect from the farms:

- Actual size farm and fields (rai or ha), water intake from outside farm? (if yes: approximately how much);
- Land use plan (map showing fields and their crops/uses)
- Planting and harvest dates of the crops
- Pond shapes, depth, maximum volume (m, m^3)
- Water levels in the pond during the year (at least min. and max)
- Soil types (course sand, fine sand, loam, light clay, heavy clay; distinguish top, middle, lower layer)
- Price of products of key crops (local currency per kg fresh or dry)
- Target yields and actual yields of key crops, fish (kg ha^{-1}, fresh or dry)
- Farmer objectives (farm management).

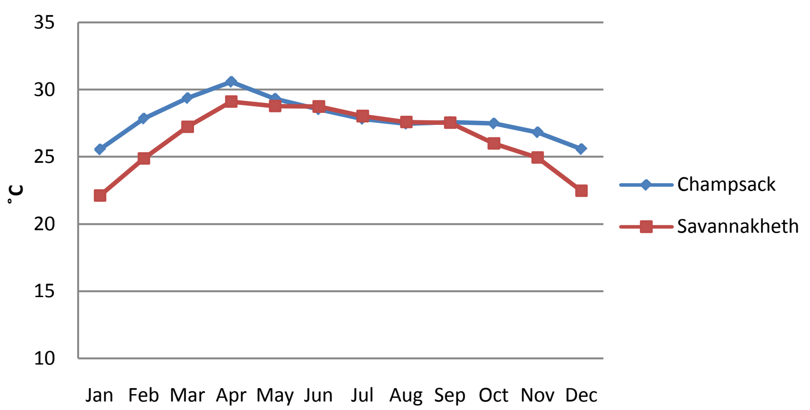
For more detail, the paper entitled Optimizing the Land Water Ratio on farm in N.E. Thailande by Penning de Vries, F., and Ruaysoongnern, S (April, 2005), describes the model BN version 3, and shows some typical examples of use.

To run the model, there are some parameters which are needed to be specified according to the objectives of the model simulation or to the farming 'styles'. Table A6.1 (in Appendix) shows the key parameters to be adjusted in order to get the model ready for the simulation.

6.3.2. Climatic context for modeling

The weather data was obtained from the Provincial Meteorological Offices of Savannakheth and Chamapsack provinces. In our simulation, the weather data was from 2004 to 2012 to calculate the 9 year consecutive dataset for model simulation. The main weather variables are namely rainfall, temperature and potential evapotranspiration as required by the model. The climatic situations in 2 studied areas are slightly different (figure 6.3).

Figure 6.3. Average monthly temperatures of 9 years data (2004-2012) for Savannakheth and Champasack provinces

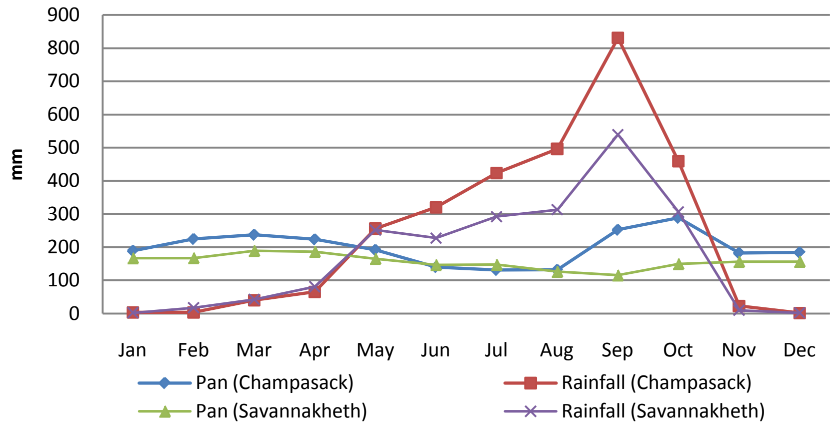


Source: Provincial meteorological offices, 2013.

We observe that the average temperature in the coldest month (January) for two provinces is over 18 °C. The temperature in Champasack province is higher than that in Savannakheth, with a mean of 25.6 °C and 22.1 °C, respectively.

The average monthly precipitation and evaporation are also the main variables to describe the climatic context in the study areas. Figure 6.4 shows the variation of the rainfall and evaporation over 9 years in the two provinces. It has shown that the wet season starts from May to October of each year for Savannakheth and Champasack.

Figure 6.4. Average monthly precipitation (mm) and Pan Evaporation (mm) in Savanakheth and Champasack provinces for 2004-2012



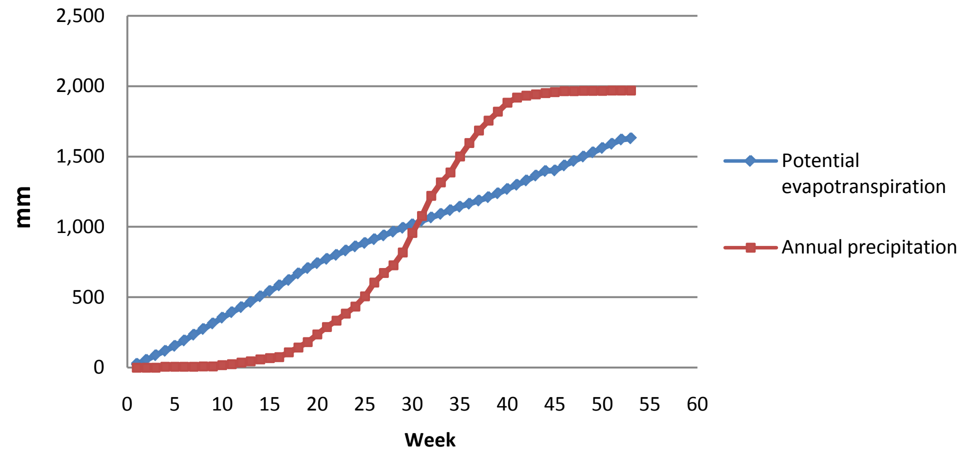
Source: Provincial Metrological office, 2013.

The average annual precipitation in Champasack is higher than that in Savannakheth. Rainfall in Champasack is approximately 1960 mm and only 1503 mm per year for Savannakheth.

For the model simulation, the weekly potential evapotranspiration (ETo) of 9 years data is used for the climatic scenario. The ETo is calculated by using the PAN evaporation method with the Pan coefficients (Kp) for class A for different pan sitting and environment and different levels of mean relative humidity and wind speed (FAO Irrigation Drainage paper, No. 24). Figure 6.5 and 6.6 show the average annual cumulative precipitation and potential evapotranspiration in the studied areas.

In Champasack (figure 6.5), the average cumulative annual precipitation is 1969 mm and potential evapotranspiration is 1631 mm. This average cumulative precipitation becomes increasingly higher than potential evapotranspiration from the 31st week. The value remains higher all over the year. If the rainy season starts from June, 1st (23rd week of the year), the annual precipitation is relatively lower that the potential evapotranspiration. This explains why droughts are common in Champasack during rainy season. However, Champasack province also has higher risk of flooding in rainy season at 40th week of the year compared to Savannakheth, particularly during the last three years 2010 to 2012.

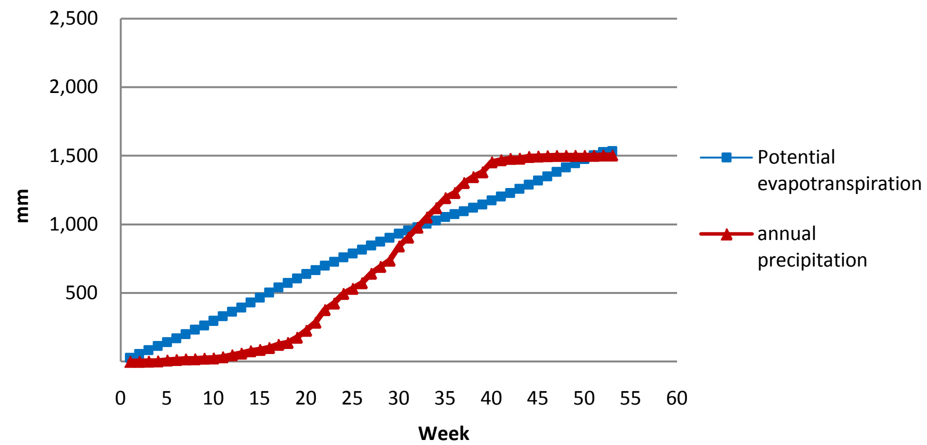
Figure 6.5. Average cumulative annual precipitation (in mm) and potential evapotranspiration for Champasack province.



Source: Provincial Metrological office, 2013.

Figure 6.6 shows that droughts could probably occur in Savannakheth in rainy season. The average cumulative annual precipitation is 1,503 mm and the potential evapotranspiration is 1,534 mm. At the 23rd week of the year, the annual precipitation is lower that the potential evapotranspiration.

Figure 6.6. Average cumulative annual precipitation (in mm) and potential evapotranspiration for Savannakheth province.



Source: Provincial Metrological office, 2013.

6.3.3. A typical pond data of Lao Farms for simulation

The identification of a typical pond farm for the simulation is very important in the modelling work. For our research, the typical pond farms were set up from the field survey 2012 (188 pond farms) and the observation of 7 ponds in the study areas. Table 6.1 show the means of key characteristics of the pond farms in two provinces.

The farm, typically 2 locations of each 2.36 ha for Champsack and 1.54 ha for Savannakheth ; each locations is divided into five plots of different sizes as suggested by the BN model (see Figure 6.1). One of the plots is the pond (water reservoir), another is the farmhouse. Three plots have a plant cover: one plot with rice, one for vegetables and one with trees. From the field survey, many pond farms have few pieces of tree or fallow lands near their houses.

Table 6.1. The average of the key characteristics of the pond farms in two provinces

Main characteristics	Average in Champasack province	Average in Savannakhet province	AVERAGE for modeling
Household members	6.3	6.4	6.35
Yield (kg/ha)	1,973	1,618	1,795.50
Total Farm size (ha)	2.36	1.54	1.95
House yard (ha)	0.09	0.12	0.10
Rice field (ha)	2.11	1.42	1.76
Orchard or tree (ha)	0.02	0.04	0.02
Pond area (ha)	0.113	0.182	0.15
Pond depth maximum	3.01	2.75	2.9
Land-water ratio[13]	0.09	0.06	
Vegetable (ha)	0.09	0.07	

Source: Author's calculation from the household survey data in 2012.

For the simulation this variable is reduced to 0.001 percent of the total surface (this value has been suggested by Dr. Frits during the model study in Thailand), the model will consider automatically as zero hectare of tree plot in the simulation (zero water comes from the tree plot). According to the BN model, we could define and describe the characteristics of these five plots in table 6.2.

[13] Land-water ratio is the pond area over the total farm areas.

Table 6.2. Characteristics of five plots for model simulation (percentage of total farm size)

Plots	Variable in BN model	Pond in Champasack (pond 4)	Pond in Savannakheth (pond 7)
Farm house	Area1	0.100	0.100
Pond area	Area2	0.090	0.060
Rice	Area3	0.551	0.560
Vegetable plot (slider- area2)	Area4	0.259	0.280
Tree	Area5	0.000	0.000
Total areas	Areat	1.000	1.000
Slider		0.349	0.34

Source: Author's calculation from the household survey data in 2012.

Farm size: the default total farm area is 1 ha; other values can be chosen. Many farms will have 2 or 3 pieces of this size, the water in which is managed independently.

Plot 1: the farmhouse, yard and the unplanted area surrounding the pond. The normal value for this area is 1000 m^2 (10 % of surface).

Plot 2: the reservoir or pond. The default value in the model is 0.1 ha (10 %). For our research, in each location, pond ratio is the average obtained from the survey 2012. We use the defaut values of 0.09 ha (9%) for Champasack (pond 4) and 0.06 (6%) for Savannakheth (pond 7) for simulation of two climatic contexts.

The farmer can choose to grow fish. Growth is initiated when the farmers stocks the pond with fingerlings. The fish are fed, and the farmer adjusts the level of feeding to the actual growth rate. Fish are harvested and sold when they are 26 weeks in the pond (i.e. around 0.5 kg fresh weight each). In our survey, fish is raised from the beginning of the rainy season (June), and then harvested at the end of December.

Plot 3: the rice field. The default value in the model is 0.4 (40%), but this fraction is higher for our typical ponds, around 0.55 ha (60%). In BoNam calibration, this section is kept constant. According to the survey, this fraction is rather large since growing rice for the family and possibly for sale has a high cultural value and is a way of arranging for securing food security. However, this fraction can be obtained by calculating the total rice consumption for a whole family. At a common yield level of 2000 kg ha^{-1}(National average of rice paddy yield, 2012), an 6.34-person household with each person consuming 350 kg paddy rice per year (National Food security strategy, 2010), needs this size rice field for its own rice consumption; at higher levels the rice area can be smaller.

Plot 4: the field with vegetables. The plot is typically 0.34 ha in area, or 28-34% of the total. In the model, the sum of the areas for the pond and for vegetables is kept constant (slider), so that if the pond expands, the vegetable area shrinks. This plot is for 80% of its surface covered with vegetable, such as corn, cabbage, yard beans…The top and middle layers are assumed to be light textured sandy soils.

Plot 5: the trees. From the survey, only few Lao farms have a piece of orchard plot. For our simulation, the default value for the area is 0.001 or less that 1% of the farm surface (suggested by Dr. Frits). For this value, the tree growth is not simulated, and fruit production is not counted. Trees can also add significantly to the livelihood and to biodiversity, but these aspects are not considered here by the BN Model.

6.3.4. Model calibration and parameterization

In the original BN model, the model is arranged in 14 logical submodels that have their own characteristics and entity, but that also interact (figure A6.2). There is one submodel for the house_plot, one for the tree_plot, one for the water in the pond and one for the fish in the pond, if any, one module for the soil in plot_vegetable and one for the crop itself on this plot, one module for the rice soil and one for the rice crop. The module for weather provides weekly weather data for the simulation. The models farm_manager and area_manager handle management choices and area choices, respectively. Finally the modules Farm_performance and Annual_income collect the relevant information to evaluate indicators of farm performance on a long term and annual basis

In our research, another three new submodels were integrated in the original BN model, namely **Simpleponds**, **Drainage_Irrigation_manager** and **Weatherpond_manager**. The equations of these submodels are in Appendix (These new submodels help to estimate the values of drainage: a constant and vertical drainage from the pond). The later was defined as a constant for the BN model which is drainage expressed in a percentage per week of the total volume of pond. Figure A6.3 in appendix 6 shows the diagram of submodels and all equation of the new extended BoNam model.

For irrigation, the value was obtained by the rough estimation from the survey, 2012. The water requirement for soybean, sweet corn, and cabbage or water melon were obtained from different sources and used for estimating the total amount of irrigation. However, this value is calculated automatically by the model by entering type of crops, potential yield, crop water requirement and target yield in the model (see Appendix Table A6. 2, A6.3, A6.4 and A6.5).

The Simpleponds_submodel simulations helped to estimate the total amount of drainage per week by comparing the water level between modeled values and actual values measured from the pond no. 4 and 7 (See Appendix Figure A6.4). The fitness of the model is evaluated by the RMSE method. The modeled values fit with the actual values with the RMSE of 6.8% and 6.03% (without considering the last three values of the simulations).

From the model simulations, the total annual drainages for the two ponds are 18 m^3 and 20.04 m^3. In the BN model, the parameter for the drainage is in a percent of total volume per week (% per week). From the simulations results, these drainages are 0.02 (2%) and 0.05 (5%) for pond in Champasack (Pond4) and for pond in Savannakheth (Pond7), respectively.

For the parameter of irrigation, there is a set of equation to estimate the total irrigation water in case of irrigation is applied. Type of crops, crop duration and water requirement are needed. For model justification by parameterizing key variables related to the running process (see Appendix Table A6.7). Each submodel is calibrated and described in Appendix, figure A6.5).

6.3.5. Farm management scenarios

In our model simulation, management of the farm is characterized by choice of target yields of crops planted, irrigation levels, and the fish stocking rate and level of feeding. This choice of management variables is not uniform among homesteads because of different conditions and aspirations.

In chapter 5, we analyzed the costs and benefits of pond investments; we observed that many pond farms produce for home consumption and for generating extra income by selling some surplus.

Some farmers intensified their farms and use efficiently water from the pond to produce crops (vegetable in dry season) for commercial production, they try to increase their production by using new varieties and chemical products for soil amendment or plant protection on their farm. The target yield and the levels of inputs application are considered as key features to distinguish farming management styles. We simulated two scenarios of farm management styles in our study. In this chapter, we investigate deeply the optimal size of pond (pond ratio) in particular climatic conditions of the studied areas. Two farming management strategies in Chapter 5 are revisited for pond modeling:

- ***Style A: ('Self-sufficiency and wellbeing of household'):*** the farmer who makes sure that his farm is sustainable, that his family has always adequate rice and that he seeks stability. He produces crops to ensure food security of his family and to sell some parts of production in case of surplus. This case is used as a default value for all analysis, recalled a 'base case' for simulation with different climatic scenarios.
- ***Style B: ('intensification farm'):*** the farmer who seeks maximum benefit by increasing his farm outputs for commercial purpose. Mostly commercial and input-intensive production: fertilizer, labor. This case is used in our analysis only for farm income comparison with style A.

The parameters and standards values for management simulation are in Appendix TableA6.6.

6.3.6. Hydro-economic indicators of simulation outputs

The BN simulation results show how the farm is doing. We have three hydro-economic indicators of farm performance:

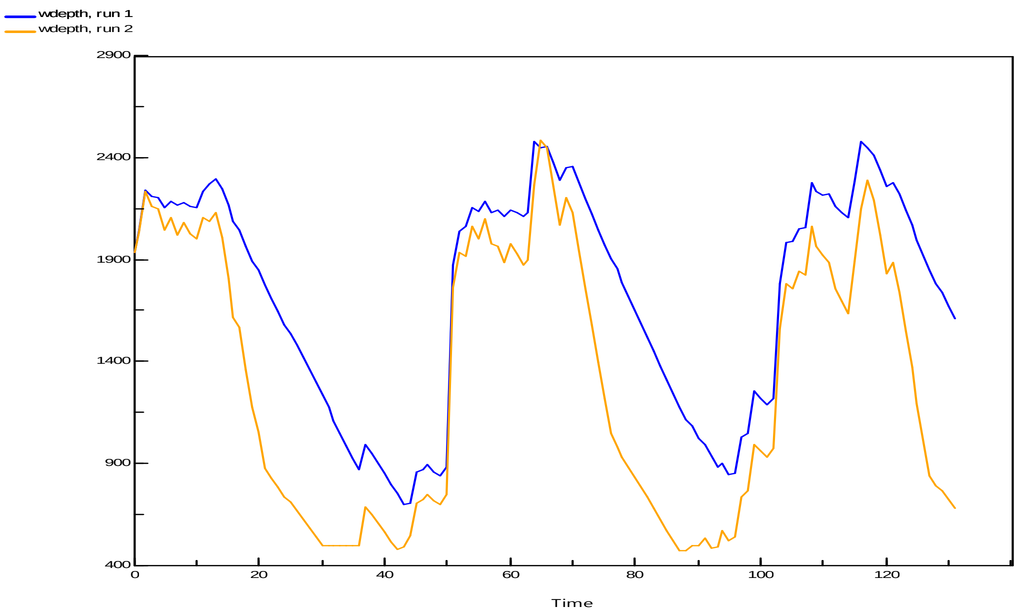
- ***Indicator 1***: Annual farm gross income (million LAK per year) from production of rice, crops, vegetables, beans, and fish.
- ***Indicator 2***: Number of weeks per year that a pond is dry as a measure of risk.
- ***Indicator 3***: The quantity of irrigation water applied (m^3 per year) to measure how much more water the pond actually made available.

6.4. Simulation results and discussion

6.4.1. Water ponds with and without irrigation in two provinces

By parameterizing all variables and calibrating the BN model with the field measurement data from two provinces, the first simulation results are about the variation of water levels of observation ponds in two locations. The results show different water levels in irrigation ponds with irrigation and without irrigation as shown in Figure 6.7 and 6.8.

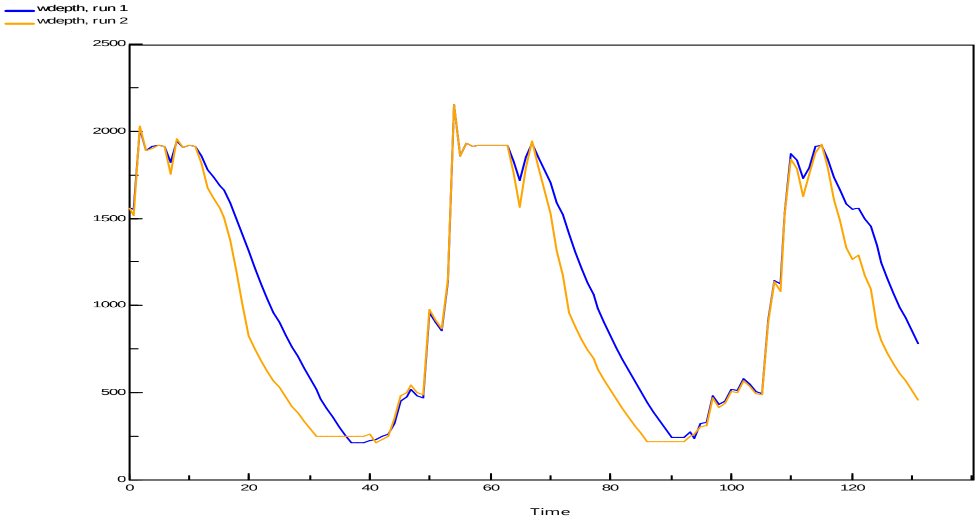
Figure 6.7. Fluctuation of water levels (water depth in mm) over 131 weeks (2.5 years simulation). The blue line is the water depth without irrigation and the orange line is with irrigation, Champasack province.



Source: Author's simulation with BN model

In Chamapsack, there is a difference between the water depth in pond with irrigation and without irrigation. In time axis, it is in weekly interval. The dry season (DS) starts from 17th up to 44th week, where run-on water is zero (no rainfall) but farmer use water for irrigating DS crops such as beans, maize and vegetables. The simulation shows slight difference between two cases. Without irrigation, water level could lower steadily to 80-85 cm, and with irrigation, water level goes down sharply and lower down to the minimum at 42 cm. The water level starts to raise up from 45th week, where rainfall is accumulated to fill up the pond at the maximum depth, 300 cm.

Figure 6.8. Fluctuation of water levels (water depth in mm) over 131 weeks (2.5 years simulation). The blue line is the water depth without irrigation and the orange line is with irrigation, Savannakheth province.



Source: Author's simulation with BN model

In Savannakheth (figure 6.8), variation of pond water level is different from those of Chamapsack's pond. The maximum depth of water is about 200 cm, lower than that of pond in Champasack. The difference between water depth with irrigation and without irrigation is slightly smaller, and the minimum depth of water is down to 22 cm. For the model, the minimum level of pond water is set up at 25 cm which allows possible water to be used for pond fish culture. The water under this minimum depth is considered as a dry week for pond.

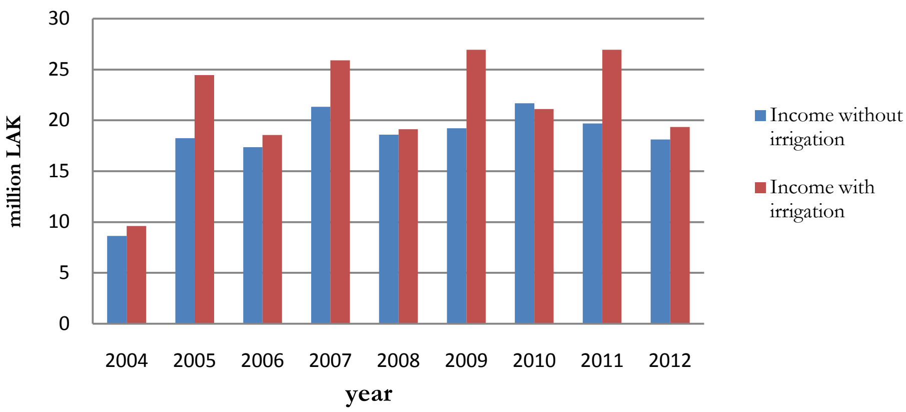
To explain these differences in water depth, the first reason is due to the importance of higher rainfall in Champasack province which fills up the pond and enhances a higher level of pond water. Secondly, pond farmers in Champasack use more water to irrigation various crops in dry season. For the minimum level of water, it is lower in Savannakheth due to a higher drainage of pond in the observation areas. For the next section, the parameters values for pond 4 are used for the analysis of management analysis.

6.4.2. Variation of Farm Incomes in 9 years

The results from the model simulation carry a degree of uncertainty due to variability in weather, in pest, seed quality and other variables. Weather is the main one and analyzed here further under weather variability.

Figure 6.9 shows the results for a series of 9 years. Big variations are due to rainfall. Whenever average data are given this refers to the mean of the nine results, so in this case farm annual income is 21.34 million LAK with irrigation of soybeans and vegetable plots. For the standard (without irrigation), the average annual income of nine years is 15.1 million LAK. This difference in income is statistically significant at 5 per cent level. However, for both cases, all annual income includes fish raising in the ponds which is an additional source of household income for pond farmers in the studied areas. The model simulates with the market price 2011/2012.

Figure 6.9. Annual income for nine years simulations for the standard values (with irrigation and without irrigation of vegetable plot, weather data (2004-2012).



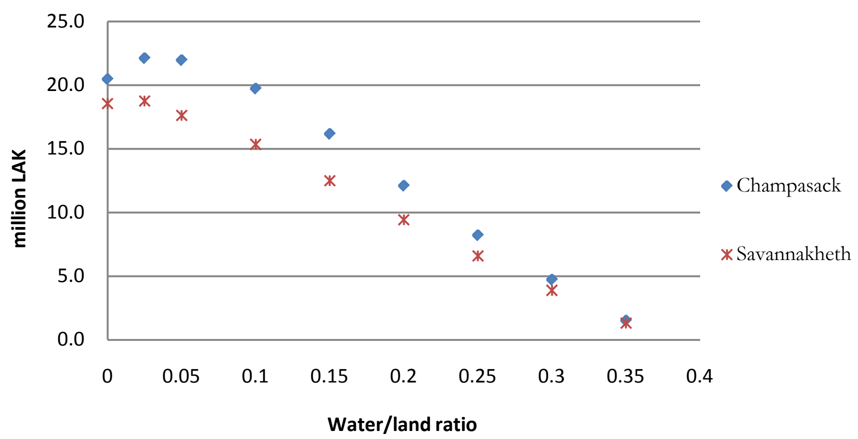
Source: Author's simulation, BN model.

The relationship between the pond size and the farm income is the main result of simulation to explain what the best land-water resource ratios are for the best productivity in different farming management styles. These results help to answer a question on the investment of excavating a pond or constructing a reservoir/or pond, which was empirically studied in Chapter 5.

6.4.3. Optimum pond size and Farm income

We run the model for a series of values for the pond size and present the variation of annual income for a pond ratio in a farm. The annual income is the average of nine years simulations. Figure 6.10 shows the results of running the model for several values of pond size (0 up to 0.35) with the same input data (all default values for management parameters).

Figure 6.10. The relation between pond size (water/land ratio) and Annual farm income (average of nine years simulations) in Champasack and Savannakheth.



Source: Author's simulation, BN model.

From Figure 6.10, the optimum farm income is obtained when the pond size is between 0.03 and 0.09 percent in two locations, where the climatic conditions are slightly different. Only pond characteristics are the key variables explaining their difference. This optimum pond size is different from that of the case study of Frits et al., (2010); the optimum income was attained when the pond size was at 0.08 up to 0.11.

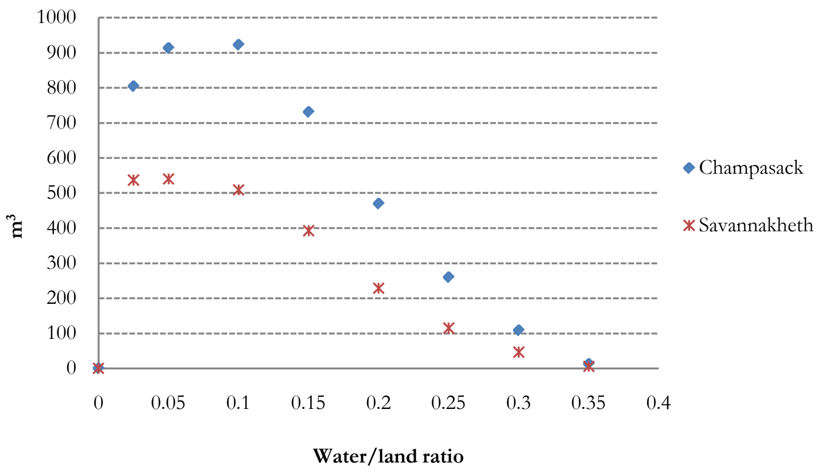
In Chamsapack, the optimum income is attained when pond size is 0.05 - 0.09 and in Savannakheth when the pond size is 0.03 - 0.06. These results suggest that only 5-9 per cent of farm land resource could be converted to a pond to optimize income in the context of rural farming systems under climatic scenarios of the studied areas.

6.4.4. Optimum pond size and irrigation water

Irrigation water from a pond is considered as an important indicator which helps farmers to know about the water availability in a whole year and the possibility to use it for crops during the dry season. The pond size can affect the total water actually used for irrigation (beans and vegetable plot) and also the fish culture. The optimum for the indicator volume of pond water for irrigation is shown in figure 6.11. The optimum value of pond size is between 0.07-0.09 with the total irrigation water used about 914 m^3. The similar research in Thai pond farms shows the optimum pond size between 0.085-0.1, and the total irrigation water used for a whole year is 1,500 m^3 (Frits et al., 2010).

In our simulation results, the optimum pond size is 0.8-0.11 for Chamapsack, this pond size could make irrigation water available about 914 m^3 for irrigation on pond farmers in Champasack. For Savannakheth, the situation is different. The pond size is 0.05-0.08 for the maximum irrigation water available of 540 m^3 for crops in a whole year.

Figure 6.11. The relation between pond size (water/land ratio) and amount of water for irrigation (average of 9 years simulations, 2004-2012)

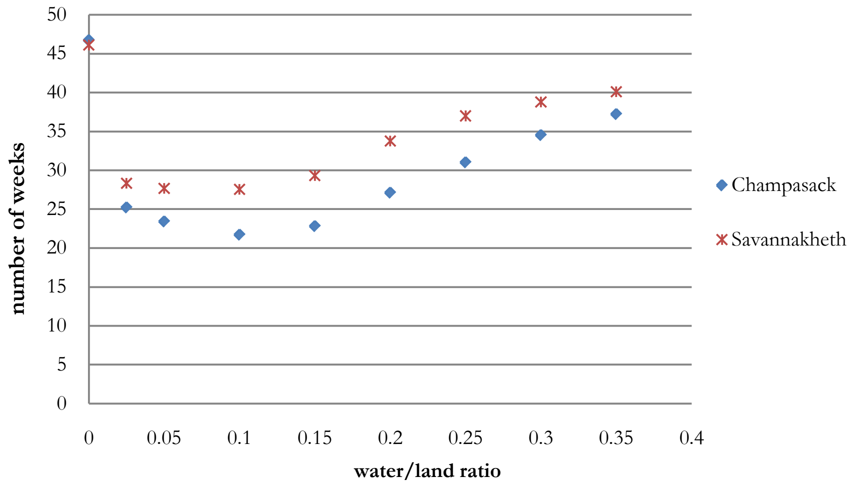


Source: Author's simulation, BN model.

However, we observed the difference in irrigation water used on farms among two provinces. Pond farmers in Chamapasck province irrigate more crops on dry season, which is requiring higher volume of water.

For the indicator 'number of weeks dry' the optima are similar to those of other indicators: close to 0.08 and between 0.05 and 0.11, depending on the rainfall (Figure 6.12). In addition, the pond is dry for at least 1–2 weeks in wet season but for several weeks in a dry season.

Figure 6.12. The relation between pond size (water/land ratio) and number of weeks that the pond is dry (average of 9 years simulations, 2004-2012)



Source: Author's simulation, BN model.

The optimum pond size is 0.09 for both locations. This is consistent with the results in Thailand by Frits et al. (2010). However, the number of dry weeks is different from the cases studied in Thailand. In southern Laos, pond is dry between 22-27 weeks per years, but only 14 weeks in the case of Thai farmers. The number of dry weeks will become more important if pond water is applied for rice plot.

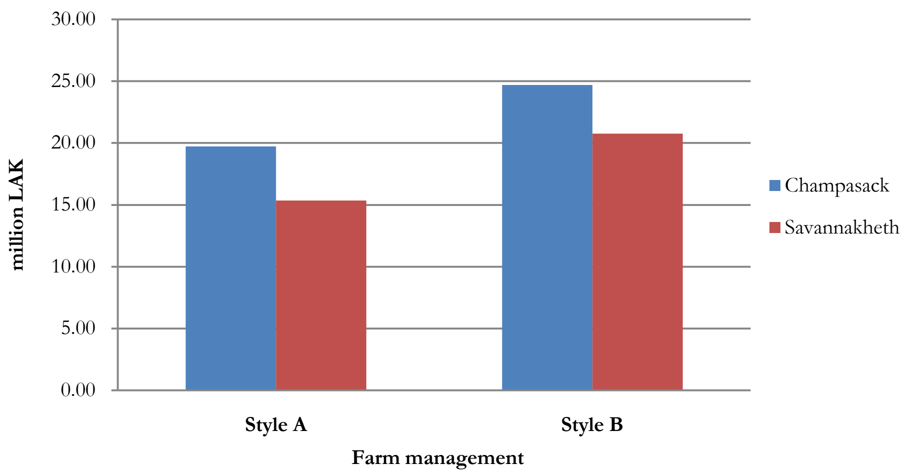
This big difference is not surprising in the case of Lao farmers because in rural areas of Laos, pond or on-farm ponds are not well managed by farmers due to their limited knowledge on water and irrigation utilization. A problem of drainage is one issue which is needed to be addressed in pond research for water use efficiency in the future.

6.4.5. Optimum pond size and farm income in different farming strategies

Management of the farm in BoNam is characterized by choice of target yields of crops planted, irrigation levels, production inputs, and the fish stocking rate and level of feeding. The key question to be answer is 'what is the optimum pond size' for rural poor farmers in the context of the Southern Laos. For simplicity, judging only the indicator 'farm income,' one sees a rather flat response with an optimum of 0.03–0.09 in both provinces.

Figure 6.13 shows how farm gross income (total value of production) depends on the farming style A and B in Chamapsack and Savannakheth for the relative pond size 0.09 (recall that expenses for farm inputs are not yet deducted). Unsurprisingly, style B (the farmer who aims at intensifying his farm for commercial production) provides the highest result and style A where the farmers produce for self sufficiency.

Figure 6.13. The farm gross income is shown in relation to farm management style in two provinces in Champasack and Savannakheth (2004-2012)



Source: Author's simulation, BN model.

It is important to mention that we apply the BoNam for modeling the pond size in the Southern Laos. The model computes gross income of the farm (based on 2010-2013 prices) and hence focuses on the productive process on the farm. A full picture of farm income and expenses could be obtained by accounting for farm expenses (which can be derived from BoNam simulations if prices of seed, fertilizer, fish food, and hired labor are supplied, and estimates are made of cost of electricity, gasoline, equipment hire, crop protection) and for nonfarm income and expenses.

6.5. Conclusion

The analysis in this chapter helped to answer the question on the optimum pond size related to different climatic conditions in two southern province of Laos: Savannakheth and Champasack. It provides answers with respect to the optimum pond-land ratio given a fair approximation of local conditions and farm management.

We applied the BoNam model developed in Thailand (Frits et al., 2010) with the Lao case using parameters from the survey in the Southern Laos. The optimum pond size is 0.09 for both locations. Pond water for irrigation is important for farmers. In Lao case, pond is dry between 22-27 weeks per years, but only 14 weeks in the case of Thai farmers. This difference is their limited knowledge on water and irrigation utilization in the study site. The base case of study is a self-sufficient farm for a farmer who has subsistence of family on top of his priority list. The simulation provides the optimum pond-land ratio which appears to be around 0.03-0.09. However, it is important to note that the optimum pond size for the individual indicators (income, irrigation water or number of dry week) is not the same. Hence, here is a choice that the farmer should make: for his farm and the household, which indicator is the most important? Simulation can help oversee the consequences but the farmer should make the choice. This is the basic trade between land and water surfaces: the additional production per unit land that results from irrigation is accompanied by a loss of land.

For rural poor farmers in Laos, the question 'how to manage water for high water use efficiency, remains a key constraint for an effective pond irrigation management. To deal with this question, it can be addressed with BoNam by looking at the water use efficiency indicator. The value of this indicator is strongly related to the farming practice and not so much dependent on the relative pond size or rainfall. This could be one issue for researcher, scientist and development agencies to reconsider in order to help rural poor farmers to improve their knowledge on pond irrigation management.

7. CONCLUSION

This dissertation aimed to evaluate the economics of small-scale pond irrigation on farm production, household income and rural development in southern of Laos. The four core chapters (chapter 3 to 6) of the dissertation analyzed each of the research questions respectively by using the primary information obtained through a household survey conducted in the four districts during August to September, 2012. In total 23 villages were selected to conduct a field survey, in 4 districts which are namely Outhoumphone, Champhone, Phonthong and Sukhuma districts due to their intensity of individual farm ponds in southern Laos

To achieve its objectives, the first research of this dissertation assesses the economic impact of farmstead pond irrigation on the decomposition of farm household income under rice-based farming systems, the comparative analysis of two groups from farm household survey 2012 (188 pond farms and 34 no-pond farms) is used to describe the potential benefits of pond irrigation for the farmers' annual incomes. The empirical models of crop annual incomes (mainly soybean, vegetable and total crops) and models for per capita incomes are developed to investigate the impacts and linkages. The results from our research show that there are significant differences in household income from famers with a pond and that without a pond. The premise is that resource water can be developed on many homesteads by construction of ponds: this can support more sustainable production systems, higher productivity and income, and greater well being of the family.

However, the impact of pond irrigation on household income for poor famers in the southern also could be referred to the increase in agricultural commercialization due to water availability for enhancing production in both dry and wet season for pond farms. This increase in production encourages poor famers to participate in market by selling their products to local traders appointed at their village. The empirical study on the extent of pond irrigation and informal contact of sales for the poor farmers has provided some evidences of the impact of small scale irrigation on market participation of poor pond farmers in Southern Laos. This contact of sales created between the farmers and local traders affects significantly the smallholders' household income. In general, this kind of market arrangement is informal in many places of rural areas of Laos, where farmers are isolated from the infrastructure development. Only local small traders are their mean of market access and facilitate to sell out their farm outputs.

In order to be able to provide some guidelines for interested farmers on pond irrigation projects, the chapter 5 studied the effectiveness of the pond construction investment by using the data collected from the 100 ponds surveys categorized as small, medium and large pond (Mustaqu, et al. 2007). The economic analysis based on data from the field survey show that small, medium and large ponds are profitable with positive NPVs, IRRs and BCRs. However, these economic indices are not so high as the potential benefits of ponds are not currently optimized. Overall, small and medium ponds show better profits than do large ponds. Our results provide the first source of evidence about the multiple-uses and benefits of ponds for agricultural production in Laos. Data strongly indicate the utility of ponds, suggesting the need for further research on methods to optimize their use in the Lao context.

The analysis in the chapter 6 helped to answer the question on how is the optimum pond size related to different climatic conditions in two southern province of Laos? This case is local weather. The optimum pond size was determined for two locations: Savannakheth and Champasack. It provides answers with respect to optimum size given a fair approximation of local conditions and farm management. The simulation provides the optimum size of the pond which appears to be around 0.07-0.09 of the farm area. However, it is important to note that the optimum pond size for the individual indicators (income, irrigation water or number of dry week) is not the same. Hence, here is a choice that the farmer should make: for his farm and the household, which indicator is the most important? Simulation can help oversee the consequences but the farmer should make the choice. This is the basic trade between land and water surfaces: the additional production per unit land that results from irrigation is accompanied by a loss of land.

For policy recommendations: it needs to have an approach for rural development should integrate small-scale pond model to help the poor farmers having water availability for production.

Appropriate knowledge should be provided to rural farmers in order to make pond irrigation farms contribute to food security and nutrition issues in rural areas where the malnutrition is still discussed

The infrastructure development such as road could help to encourage rural poor farmers to participate to the market and intensify their production. The Government should help rural farmers to have access to input markets and credit. As we have seen, irrigation equipment and mechanization of farm are determinants of farm commercialization.

The improvement of institutional capacity of the public agencies is needed to provide better agricultural and forestry extension services. This would help to improve agricultural productivity and market participation by providing appropriate techniques of production and access to market information.

For further research, as we have seen that an individual on-farm pond irrigation is beneficial to farm household. However, research on pond ratio should be also scaled-up to village or community level in order to see the impact on food security and poverty reduction at regional level. The question 'how to manage water for high water use efficiency, remains a key constraint for an effective pond irrigation management for rural poor farmers in Laos. To deal with this question, it can be addressed with BoNam by looking at the water use efficiency indicator. The value of this indicator is strongly related to the farming practice and not so much dependent on the relative pond size or rainfall. This could be one issue for researcher, scientist and development agencies to reconsider in order to help rural poor farmers to improve their knowledge on pond irrigation management.

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APPENDIXES

Appendix to Chapter 1

Table A1.1. A Household survey questionnaire 2012

HOUSEHOLD SURVEY QUESTIONNAIRE
FARM PONDS WATER UTILIZATION IN SOUTHERN LAOS 2012

Province: …………. District: …………. Village Cluster: …………………. Village:…………
Form code:……………..
Day____ Month____ Year_______ Interviewee:……………………… Pond or No-pond farmers:………….
Interviewer:…………………… Tel:……………………………… Distance: From House to district:……………..(km)
Distance: From House to City:……………..(km)

I. Demographic and Socio-Economic Characteristics (from Jan 20011)
A. Household members and Family Income
Pond owner or user:………………

1. Information about household members							Work on agriculture		Work on non-agriculture			
							cropping (days)	livestock (days)	employment /regular		employment /temporary	
Name	Relation to the family head	Age	Sex	Education*	Schooling years**	Has ever received an extension training?***			Months /year	wage (1000 kip /month)	days/year	wage (1000 kip/day)
(1)												
(2)												
(3)												
(4)												
(5)												
(6)												
(7)												

*code: 1= didn't go to school, 2=elemenary, 3=secondary, 4=higher
** Total number of years
***Extension training/service provided by DAFEO or PAFEO since 2011

2. Household income 2011 by sources*:

% from rice sales	
% from agriculture	
% from non-agriculture	

B. Land of households (as of Jan 2012)

as of Jan 2012	housing	Paddy field area		Pond	Orchard	Forest	grazing areas	(.....)	(......)	Total
		Rainy area	dry season area							
Your LUC (land-use certificates) area										
1. Owned land (ha)										
2. Cultivated land rent to others (ha)										
- Price for renting										
(what is the arrangement)										
Rental areas										
3. Cultivated land rented from other (ha)										
- Price for renting										
(what is the arrangement)										
4. Total cultivated land area (ha) (= 1- 2 +3)										

C. Farming cropping Pattern in the farmstead

1. Can you give us some information on crop planted on your farm in 2012

Crops	Cultivated area (ha)	Variety	Type of seeds used1	Amount of seeds (kg)	Price of seed/ kg (kip)	Source of seed2	Date planted	Date harvested	Total production (kg)	Price/ kg (kip)	Self-consumption (kg)	sales (kg)	to whom	contract[3]	type of contract contract4
WS2012															
DS2012															

Code:

[1]Type of seeds: 1=Certified, 2=Non-certified, 3= High quality seeds (This means higher non-certify and lower than certify seeds)

[2]Source of seeds: 1=Seed producer ,2=Farmer exchange, 3=Owned, 4= other (specify):______________

[3]contract: 1 with contract and 2 without contract

[4] type: 1 formal and 2 informal

2. Can you give us some information on crop planted on your farm in 2011

Crops	Cultivated area (ha)	Variety	Type of seeds used1	Amount of seeds (kg)	Price of seed/ kg (kip)	Source of seed2	Date planted	Date harvested	Total production (kg)	Price/ kg (kip)	Self-consumption (kg)	sales (kg)	to whom	contract[3]	contract type4
WS2011															
DS2011															

Code:

[1]Type of seeds: 1=Certified, 2=Non-certified, 3= High quality seeds (This means higher non-certify and lower than certify seeds)

[2]Source of seeds: 1=Seed producer ,2=Farmer exchange, 3=Owned, 4= other (specify):______________

[3]contract: 1 with contract and 2 without contract

[4] type: 1 formal and 2 informal

D. Costs of Rice Production from Jan 2011 to Dec 2012

This sheet is one of the main part of this survey. It takes much time to hear the cost structure. WS2012 might not be complete but try to ask as much s possible

If you cannot hear the price of items, please survey the representative local price.

1. Costs of rice in 2011 and 2012

1.1. Material costs

	Rice WS2012................		Rice DS2012................		Rice WS2011................		Rice DS2011................	
	Volume (kg or litre..)	Prices (1000 kip)	Volume (kg or litre..)	Prices (1000 kip)	Volume (kg or litre..)	Prices (1000 kip)	Volume (kg or litre..)	Prices (1000 kip)
Fertilizer								
- Organic								
farm residues (animal dungs…)								
compost								
- Chemical fertilizer:								
- 46-00-00 (urea)								
- 15-15-15:								
- NPK: 16-20-00								
- Other:..........................								
....								
Pesticide: 1..........................								
2..........................								
Herbicide: 1..........................								
2..........................								
Fuel: Petrol. Oil								
(Irrigation expenditure) Water fee								
Field protection (fence)								
Small tools								
Machine workings*								
- Land preparation								
- Cultivation								
- Harvesting								
- Other:( )								

* Machine working includes rent of machinary and operator.

1.2. Total Labor costs in 2012 and 2011

1.2.1 Labor costs of Rice WS2012

Activity	Familty		Exchange		Hired		
	# of persons	Hours per day	# of persons	Hours per day	# of persons	Hours per day	wage payment
Land preparation (plowing, leveling….)							
Seed sowing							
Transplanting							
Fertilizer application							
Weeding							
Harvesting							
Threshing							
Transportation							
Other							

1.2.2 Labor costs for Rice DS 2012

Activity	Familty		Exchange		Hired		
	# of persons	Hours per day	# of persons	Hours per day	# of persons	Hours per day	wage payment
Land preparation (plowing, leveling….)							
Seed sowing							
Transplanting							
Fertilizer application							
Weeding							
Harvesting							
Threshing							
Transportation							
Other							

E. Costs of Production in other crops from Jan 2011 to Dec 2012

1.1 Material costs 2012

	WS2012				DS2012			
	crop……………….		crop………..……….		crop:…………………..		crop:……………………..	
	Volume (kg or litre..)	Prices (1000 kip)	Volume (kg or litre..)	Prices (1000 kip)	Volume (kg or litre..)	Prices (1000 kip)	Volume (kg or litre..)	Prices (1000 kip)
Fertilizer								
- Organic								
farm residues (animal dungs…)								
compost								
- Chemical fertilizer:								
- 46-00-00 (urea)								
- 15-15-15:								
- NPK: 16-20-00								
- Other:………………………								
……………………….								
Pesticide: 1………………………..								
2………………………..								
Herbicide: 1………………………..								
2……………………….								
Fuel: Petrol. Oil								
(Irrigation expenditure) Water fee								
Field protection (fence)								
Small tools								
Machine workings*								
- Land preparation								
- Cultivation								
- Harvesting								
- Other:( )								

* **Machine working** includes rent of machinary and operator.

1.2. Material costs 2011

	WS2011				DS2011			
	crop………………..		crop……………..………		crop:…………………..		crop:.……………………..	
	Volume (kg or litre..)	Prices (1000 kip)	Volume (kg or litre..)	Prices (1000 kip)	Volume (kg or litre..)	Prices (1000 kip)	Volume (kg or litre..)	Prices (1000 kip)
Fertilizer								
- Organic								
farm residues (animal dungs…)								
compost								
- Chemical fertilizer:								
- 46-00-00 (urea)								
- 15-15-15:								
- NPK: 16-20-00								
- Other:.………………………								
……………………….								
Pesticide: 1……………………….								
2……………………….								
Herbicide: 1……………………….								
2……………………….								
Fuel: Petrol. Oil								
(Irrigation expenditure) Water fee								
Field protection (fence)								
Small tools								
Machine workings*								
- Land preparation								
- Cultivation								
- Harvesting								
- Other:( )								

* **Machine working** includes rent of machinary and operator.

2. Total Labor costs in 2012 and 2011

2.1 Labor costs of WS 2012

Activity	Familty		Exchange		Hired		
	# of persons	Hours per day	# of persons	Hours per day	# of persons	Hours per day	wage payment
crop:...............							
land preparation							
Crop establishment + planting							
weeding							
Harvesting							
crop:....................							
land preparation							
Crop establishment + planting							
weeding							
Harvesting							

2.2 Labor costs for DS 2012

Activity	Familty		Exchange		Hired		
	# of persons	Hours per day	# of persons	Hours per day	# of persons	Hours per day	wage payment
crop:...............							
land preparation							
Crop establishment + planting							
weeding							
Harvesting							
crop:....................							
land preparation							
Crop establishment + planting							
weeding							
Harvesting							

2.3 Labor costs of WS2011

Activity	Familty		Exchange		Hired		
	# of persons	Hours per day	# of persons	Hours per day	# of persons	Hours per day	wage payment
crop:...............							
land preparation							
Crop establishment + planting							
weeding							
Harvesting							
crop:..................							
land preparation							
Crop establishment + planting							
weeding							
Harvesting							

2.4. Labor costs for DS 2011

Activity	Familty		Exchange		Hired		
	# of persons	Hours per day	# of persons	Hours per day	# of persons	Hours per day	wage payment
crop:...............							
land preparation							
Crop establishment + planting							
weeding							
Harvesting							
crop:..................							
land preparation							
Crop establishment + planting							
weeding							
Harvesting							

3. Other costs

	Rainy season 2012		Dry season 2012		Rainy season 2011		Dry season 2011	
	Area (ha)	Prices (1000 kip)	Area (ha)	Area (1000 kip)	Area (ha)	Prices (1000 kip)	Area (ha)	Prices (1000 kip)
Land tax								
Others (Land rent,… etc)								

F. Sales and Costs of production in Livestock from Jan 2011 to Dec 2012

	2012:....................		**2012:.....................**		**2011:.....................**		**2011:....................**		**2011:....................**	
	Quantity	Price	Quantity	Price	Quantity	Price	Quantity	Price	Quantity	Price
Sales of Livestock (number of heads)										
Feed costs										
Processed feeds										
Broken rice										
Purchased										
Home-made										
Bran										
Purchased										
Home-made										
Other ( )										
Purchased										
Home-made										
Other ( )										
Purchased										
Home-made										
Raw feeds										
- Vegetable										
- Termit										
- worms										
- Other (.....................)										
Miscellaneous material cost										
Veterinary and medicine cost										
Labor cost										
Family labor										
Hired labor										
Others costs										

II. Source of Water and Purposes of Uses

This section will investigate the sources of water and multiple purposes of uses in daily life and Productive activities
Quality of water: 1= very good, 2= good, 3= fairly good, 4= bad and 5= do not know
Volume can be estimated by measuring the water storage and container.

1. Where do you draw water from for your uses?...
……………………………………………………………………………….

2. If any from the list, what are the main purpose of uses? (please check from the list)

No	Sources of Water	period when available	quality of water	Purposes of uses	To check (x)
1	Jar (roof water from rain			1. Drinking, cooking	
				2. other domestic uses	
				3. home garden	
				4. vegetable garden	
				5. Livestock	
				6. Fish	
				7. Fruit trees	
				8. Rice	
				9. Other:……………….	
2	Bottle water			1. Drinking, cooking	
				2. other domestic uses	
				3. home garden	
				4. vegetable garden	
				5. Livestock	
				6. Fish	
				7. Fruit trees	
				8. Rice	
				9. Other:……………….	
3	Tap (piped water)			1. Drinking, cooking	
				2. other domestic uses	
				3. home garden	
				4. vegetable garden	
				5. Livestock	
				6. Fish	
				7. Fruit trees	
				8. Rice	
				9. Other:……………….	
4	Shallow well			1. Drinking, cooking	
				2. other domestic uses	
				3. home garden	
				4. vegetable garden	
				5. Livestock	
				6. Fish	
				7. Fruit trees	
				8. Rice	
				9. Other:……………….	

5	Deep well (forage)			1. Drinking, cooking	
				2. other domestic uses	
				3. home garden	
				4. vegetable garden	
				5. Livestock	
				6. Fish	
				7. Fruit trees	
				8. Rice	
				9. Other:……………….	
6	Private pond			1. Drinking, cooking	
				2. other domestic uses	
				3. home garden	
				4. vegetable garden	
				5. Livestock	
				6. Fish	
				7. Fruit trees	
				8. Rice	
				9. Other:……………….	
7	Public canal, stream			1. Drinking, cooking	
				2. other domestic uses	
				3. home garden	
				4. vegetable garden	
				5. Livestock	
				6. Fish	
				7. Fruit trees	
				8. Rice	
				9. Other:……………….	
8	Run-on water			1. Drinking, cooking	
				2. other domestic uses	
				3. home garden	
				4. vegetable garden	
				5. Livestock	
				6. Fish	
				7. Fruit trees	
				8. Rice	
				9. Other:……………….	
9	Green water (Rain wets the soil for all cropped areas)			1. Drinking, cooking	
				2. other domestic uses	
				3. home garden	
				4. vegetable garden	
				5. Livestock	
				6. Fish	
				7. Fruit trees	
				8. Rice	
				9. Other:……………….	

III. Farm Pond Characteristics

this section concerns the farm pond characteristics and main owner and users including private and communnity ponds. If the interviewee is Non-pond farmer, please move to section IV.

1. Approximate dimensions of the pond:

Length ………………..m Distance from house or Village:………………..km

Width ………………..m

Ave depth ………………..m Soil type:………………………

2. Type of pond:………………………

1= natural, 2= semi-natural, 3=constructed

3. Year of starting to use:…………………If constructed, what year:…………………..

4. If constructed pond, what is the stimated cost of pond construction: __________ ________Kip

4.1. Why are the reasons to construct a pond?

4.2. Which investment?

1= government, 2= private

4.3. If private investment, How did you (the community) finance the construction? (cicle the answers)

1. Individual cash
2. Loan
3. Community fund
4. NGO:……………………….
5. Private donation
6. Others:…………………..

5. Can you tell abou the pond's location and lanscape of your farmstead?

5.1. GPS (longitude, altitude):

5.2. Please draw a map of your farmstead and pond

6. How many farmers are using the pond? ___________________

6.1. If YES, do they need to pay for water? (YES or NO)

If YES, how do they contribute?................................(kip or kg of rice)

7. The pond water is used for the following activities (please check):

_______ irrigating/watering crops in the dry season

_______ supplemental irrigation in the wet season

_______ preparing early seedbeds/nurseries for wet season rice crops

_______ raising fish (what fish?)

_______ for domestic use (dishwashing, washing of cloths)

_______ source of drinking water for animals in the dry season

Number of animals (e.g. buffalo __; cattle ___; etc)

________ Others (please specify):…………………………………

8. Is the water in the pond available for the whole year? (Yes/No):____

If answer is No, what month the water in the pond disappears?

Why (what factors) the water in the pond disappears?

9. If pond is also used to raise fish, can you give us some information about the fish stocked in the pond?

9.1 Production, Sales and Input costs for fish raising

Species of fish	Estimated number of fry stocked or raised	Date start of stocking	Price of fry (Kip) (put units)	Date harvesting of fish	Source of fry	Estimated total harvest (kg)	No. of kg used for family consumption (kg)	Number of kg sold (kg)	Price/ kg (1000kip)
1									
2									
3									
4									
5									
6									

9.2. Total Input Costs of fish production

	2011		2012	
	Volume	Price	Volume	Price
Processed feeds	(kg)	(1000Kip)	(kg)	(1000Kip)
Broken rice				
Purchased				
Home-made				
Rice Bran				
Purchased				
Home-made				
Other ( )				
Purchased				
Home-made				
Raw feeds				
- Vegetable				
- Insect, worms….				
- Beer dregs				
- Animal drungs				
Miscellaneous material cost				
Veterinary and medicine cost				
Others				

9.3. Labor Costs of fish production

	2011		2012	
	ManDay*	Price	ManDay	Price
Family Labors (days)	(day)	(1000Kip)	(day)	(1000Kip)
Pond cleaning (Rehabilitation)				
Pond fencing (net, ..)				
Pond desinfection				
Feeding				
Harvesting				
Transporting for sales				
Other ( )				
Hired Labor (days)				
Pond cleaning (Rehabilitation)				
Pond fencing (net, ..)				
Pond desinfection				
Feeding				
Harvesting				
Transporting for sales				
Other ( )				

*ManDay = 8 hours per day per one worker

IV. Irrigation for dry season Production 2012:

this section investigates the practices of irrigation for crop field for farmers who use the pumping system

1. How do you irrigate your fields? [ ]

1= by pump, 2= canal, 3=pipe, 4= hand watering, 5= other (specify):.............................

2. Do you have problem with access to irrigation? [ ] (YES/ NO)

IF YES, what do you do?

[ ]

3. What is the cost of investment for your irrigation ?

DS, WS2011: ____________________kip

DS, WS2012: ____________________kip

4. Number of irrigation application?

IRRIGATION APPLICATION	*Crop production in dry season 2012 and 2011*				
	Rice DS 2012	Rice DS 2011	Crops.......	Crops.......	Crops.......
No. of irrigation before sowing/transplanting					
No. irrigation from sowing/transplanting to flowering					
No. irrigation from flowering to harvesting					
Ave. number of day interval between 2 irrigations					
Ave. depth of water from soil surface for each irrigation (cm)					

5. Farmers' practices related to Pond Water irrigation (pumping)

This section is for the farmers who use pumping for irrigation from pond, if NOT, move to section V

5.1. Size of pump: __________________ hp, or ______________ inches

Year of purchasing:.................. cost of purchasing:.........................KIP

5.1.1 Rice production

Purpose of irrigation	Irrigation No	DBS/DAS	Duration (# of hours)	Fuel & oil (liter)	Cost/liter
For seed bed					
Mainfield					

DBS= Days before sowing, DAS=Days after Sowing/planting

5.1.2. Other crops:

Crop 1 :..........

Purpose of irrigation	Irrigation No	DBS/DAS	Duration (# of hours)	Fuel & oil (liter)	Cost/liter

DBS= Days before sowing, DAS=Days after Sowing/planting

Crop 2 :..........

Purpose of irrigation	Irrigation No	DBS/DAS	Duration (# of hours)	Fuel & oil (liter)	Cost/liter

DBS= Days before sowing, DAS=Days after Sowing/planting

Crop 3 :..........

Purpose of irrigation	Irrigation No	DBS/DAS	Duration (# of hours)	Fuel & oil (liter)	Cost/liter

DBS= Days before sowing, DAS=Days after Sowing/planting

V. Farm Pond Irrigation Management

This section investigate how the farmers (users) manage their pond? What mechanism do they use to maintain the water (pond) irrigation system. IF NOT, move to sextion VI

1. How do you manage the pond and irrigation system? (cleaning, repairing, fencing...?)

Please explain:

2. What are the main problems related to pond and its management?

(ex: water availability, pond management, water use, water allocation……….)

3. What are your future plans to solve the problems? (What solutions)

4. In your opinion, what should you do to ensure the sustainability of water and pond at your farm?

what strategie? Please explain

5. Do you think that we should encourage farmers to have a pond within the farm?

Please justify the answer

VI. ADDITIONAL INTERVIEW: BENEFITS FROM FARM POND

(SOME KEY INFORMANT INTERVIEW)

Date:……………….

Interviewee name:………………………

Category: [ ] Tel:……………………

1. PAFO staff, 2. DAFO staff, 3. Village head, 4: Water User Committee, 5= Pond constructor, 6=other (specify)

1. Can you tell us about the benefits of farm pond to the farmers as a whole?

2. Is there a change of economic situation of the farmers after the pond as constructed and operated?

please explain:

3. How to improve the management of the farmpond?

4. Did you find ponds as solution for water scarity problem in the village?

why?:

5. Aside from farm ponds, what support is needed by farmers to improve the production and Income

6. Is there a plan/program envisioned by the province/district/village to promote or encourage farmers to construct farm ponds?

Table A1.2. Villages and pond sampling, 2012

District	Village's name	Number. of households	Number of Pond farmers	Number of Pond farmers surveyed	Number of no-pond farmers surveyed	Total sample
Uthoumphone	Noandokmai	127	27	12	2	14
	Nong Ahong	77	21	12	2	12
	Noansavang	54	15	12	2	12
	Phinh nuea	233	37	13	2	15
Total		*491*	*100*	*49*	*8*	*57*
Champhone	Khamthao	107	17	11	2	13
	Phaikhong	131	14	9	2	11
	Phaleang	115	15	11	4	15
	Bok	99	8	5	2	7
	Lao huakham	163	15	9	2	11
Total		*615*	*69*	*45*	*12*	*57*
Sukhuma	Thub cham	135	39	13	6	19
	Samkha	87	18	6	2	8
	Kongkhienne	110	22	16	4	20
	koknongbua	65	6	1	1	2
	Bark	107	27	2	1	3
		504	*112*	*42*	*14*	*56*
Phoanthong	Nongbua	245	21	8	3	11
	Noan hinh	110	28	8	2	10
	Mai sivilai	81	44	12	2	14
	Noan savanh	78	13	3	0	3
	Pha ding	57	10	1	0	1
	Ouparath	152	35	13	2	15
	Donelay	118	16	5	1	6
	Houay phaek	132	12	2	0	2
Total		*973*	*179*	*52*	*10*	*62*
Total	*22*	*2,583*	*480*	*188*	*34*	*222*

Appendix to Chapter 3

Table A3.1. A summary of samples in NNM PSM of crop yields

Source	Before matching		After matching		PS score range	Test of balancing of property of PSC
	No .Treatment (Pond farm)	No. Control (no-pond farm)	No. Treatment (Pond farm)	No. Control (no-pond farm)		
Soybean	54	31	54	28	0.24599 - 1	Satisfied
DS vegetable	80	24	80	17	0.23137 - 0.99934	Satisfied
WS Rice	184	29	184	24	0.33412 - 1	Satisfied

Table A3. 2. A summary of sample in NNM PSM of per capita income

Income source	Before matching		After matching		PS score range	Test of balancing of property of PSC
	No. Treatment (Pond farm)	No. Control (no-pond farm)	No. Treatment (Pond farm)	No. Control (no-pond farm)		
Rice	184	29	184	25	0.30312 -1	Satisfied
Livestock	153	30	153	21	0.27812 - 1	Satisfied
Off-farm	158	30	158	21	0.30310 -1	Satisfied
Bean income	54	31	54	19	0.22727 - 0.99996	Satisfied
Total vegetable	168	34	168	26	0.22834 - 1	Satisfied
Farm income (agricultural)	184	34	184	25	0.33039 -1	Satisfied
Total household	188	34	188	25	0.33099 -1	Satisfied

Appendix to Chapter 4

Table A4.1. Propensity score ranges of having farm pond for commercialization NNM

Source	Before matching		After matching		PS score range	Test of balancing of property of PSC
	No .Treatment (Pond farm)	No. Control (no-pond farm)	No. Treatment (Pond farm)	No. Control (no-pond farm)		
Agricultural commercialization	184	29	185	22	0.22499 - 0.99875	Satisfied
%Rice sold	184	29	184	21	0.22137 - 0.99994	Satisfied
%Livestock sold	153	30	153	24	0.233412 - 1	Satisfied
%Crops sold	168	34	168	19	0.32337 - 0.99984	Satisfied

Table A4.2. Propensity score ranges of contract for commercialization NNM

Source	Before matching		After matching		PS score range	Test of balancing of property of PSC
	No .Treatment (contract)	No. Control (non contract)	No. Treatment (contract farm)	No. Control (no-contract)		
Pond farms	104	81	104	74	0.15233 - 0.99853	Satisfied
No-pond farms	16	18	16	12	0.35563 - 0.99993	Satisfied

Table A4.3. Propensity score ranges of contract for per capita income of 185 pond farms NNM

Source	Before matching		After matching		PS score range	Test of balancing of property of PSC
	No .Treatment (contract)	No. Control (non contract)	No. Treatment (contract farm)	No. Control (no-contract)		
Rice	104	81	104	74	0.05233 - 0.99853	Satisfied
Soybean	36	12	36	8	0.01563 - 0.99993	Satisfied
Vegetable	104	81	104	72	0.01233 - 0.99899	Satisfied
Livestock	95	81	95	71	0.02563 - 0.99983	Satisfied
Farm income	104	81	104	75	0.01233 - 0.99953	Satisfied
Total household income	104	81	104	73	0.04563 - 0.99973	Satisfied

Table A4.4. Propensity score ranges of contract for per capita income of 34 no-pond farms NNM

Source	Before matching		After matching		PS score range	Test of balancing of property of PSC
	No .Treatment (contract)	No. Control (non contract)	No. Treatment (contract farm)	No. Control (no-contract)		
Rice	16	18	16	12	0.04533 - 1	Satisfied
Soybean	16	18	26	10	0.01463 - 1	Satisfied
Vegetable	16	18	16	12	0.01333 - 0.9998	Satisfied
Livestock	15	18	15	13	0.03563 - 0.99983	Satisfied
Farm income	16	18	16	11	0.01223 - 1	Satisfied
Total household income	16	18	16	13	0.03563 - 0.99997	Satisfied

Source: Author’s calculation from all 219 farmers, 2012

Appendix to Chapter 6

Figure A6.1. A Pond Farm model by The Thai Theory of Self-sufficiency farm by His Majesty King Bhumibol Adulyadej in 1987, Thailand.

Source: cited by Penning de Vries, F.; Ruaysoongnern, S. 2010.

The theory is: 'growing what you eat and eating what you grow,' farm households become independent, creative, more productive, sustainable and self-confident masters of their own lives.

Household self-sufficiency is achieved on homesteads of 2.5 ha divided into four plots: one for a pond (30% of the area), one for rice paddy (30%), one for vegetables and upland crops (30%) and one part for housing, roads and trees.

Source: Ministry of Education 1999; LDD 2005, cited by Penning de Vries, F.; Ruaysoongnern, S. 2010.

Table A6.1. Key parameters to be specified for running the BN model.

Module	Parameter description	Name in model	Unit	BN model (default value)
Area manager	House	area1	ha	0.1
	Pond or Reservoir surface area (when full), min 6*12= 72m2 0r 0.0072 ha, if less than 72 m2, area2 = 0, no simulation	area2 (slider)	ha	(0-0.30)
	Vegetable plot	area4	ha	0.30 -area2
	Rice field	area3	ha	0.4
	Tree plot	area5	ha	0.15
	Total area	areat	ha	1
Farm manager	Bentonite (clay) application of adding a full load (50t per ha)	benton	fraction of full (0 or 1)	0
	Choice of upland or bundled lowland fields. In upland situation, no irrigation	choiceulr	(1=upland) or (0 = lowland)	1
	Development stage rice at transplanting	ds3i	fraction	0.15
	Development stage vegetables (purchased) at planting	ds4i	fraction	0.2
	Feed level fish 1 (hight) or 0.5 (medium)	feedlev	fraction of ad lib	0.5
	Fraction irrigation on lowland rice	firrig3	fraction of full (0-1)	0
	Irrigation vegetable crops	firrig4	fraction of full (0-1)	1
	Target yield paddy (dry) relative to potential yield	fpoty3	fraction (0.3-0.9)	0.4
	Target yield vegetable (dry weight) relative to potential yield	fpoty4	fraction (0.3-0.9)	0.5
	Potential yield paddy rice (dry)	poty3	kg ha^{-1}	4000
	Potential economic yield vegetables (dry weight)	poty4	kg ha^{-1}	3000
	Replant delay vegetables	repldveg	1 (2 weeks) or 2 (4 weeks)	2
	Replanting for 2^{nd} rice (if, yes' 2nd planting 3 weeks after harvest 1st crop	replrice	either 0 (no) or 1	1
	Planting weight rice (dry)	tdw3i	kg ha^{-1}	250
	Planting (dry, shoots) weight vegetables	tdw4i	kg ha^{-1}	200
	Planting date main rice crop	wfplrice	weekno	28
	Planting date vegetable	wfplveg	weekno	4
	Week of harvesting fish	whvfish	weekno	4
	Week of stocking single fish crop	wstfish	weekno	30

Table A6.1: Key parameters to be specified for running the BN model (cont.)

Module	Parameter description	Name in model	Unit	BN model (default value)
Farm performance	Price of fish feed on market (supplemental concentrate feed)	pricefeed	Bt kg^{-1} (dry)	3
	Price of fish on market	pricefish	Bt kg^{-1} (live)	30
	Price of rice (paddy, 5% moisture)	pricerice	Bt kg^{-1}	7
	Price of vegetables (50% moisture; styles produce different products)	priceveg	Bt kg^{-1}	40
Plot-1-house	Rainwater storage on surface	surfstor1	mm	5
Plot-2-Fish in pond	Initial stocking weight	iwfishs	kg (live) ha^{-1}	150
Plot 2-Pond	Drainage	dr2c	fraction w^{-1}	0.01
	Maximum water depth	wdepthm	mm	3000
Plot-3-Rice-Crop	Development rate constant in reproductive phase	dr3trc	w^{-1}	0.2
	Development rate constant in vegetative phase	dr3tvc	w^{-1}	0.052
	Fraction economic yield	feyield3	kg kg^{-1}	0.4
Plot-3-Rice-soil	water content at field capacity, middle layer	ml3fc	cm cm^{-3}	0.38
	water content at middle layer at wilting point	ml3wp	cm cm^{-3}	0.24
	water content when air-dry	tl3ad	cm cm^{-3}	0.05
	water contents top layer at field capacity	tl3fc	cm cm^{-3}	0.38
	water contents top layer at saturation	tl3st	cm cm^{-3}	0.45
	water contents top layer at wilting point	tl3wp	cm cm^{-3}	0.24
Plot-4-Veg-crop	Development rate constant in reproductive phase	dr4trc	w^{-1}	0.25
	Development rate constant in vegetative phase	dr4tvc	w^{-1}	0.12
	Fraction economic yield of total biomass	feyield4	kg kg^{-1}	0.4
Plot-4-Veg-soil	middle layer 4 field capacity	ml4fc	cm cm^{-3}	0.21
	middle layer 4 wilting point	ml4wp	cm cm^{-3}	0.06
	Rainwater storage on surface	surfstor4	mm	25
	field capacity top layer 4	tl4fc	cm cm^{-3}	0.17
	Top layer 4 wilting point	tl4wp	cm cm^{-3}	0.05

Figure A6.2. Original BN model with 14 submodels associated with each variable.

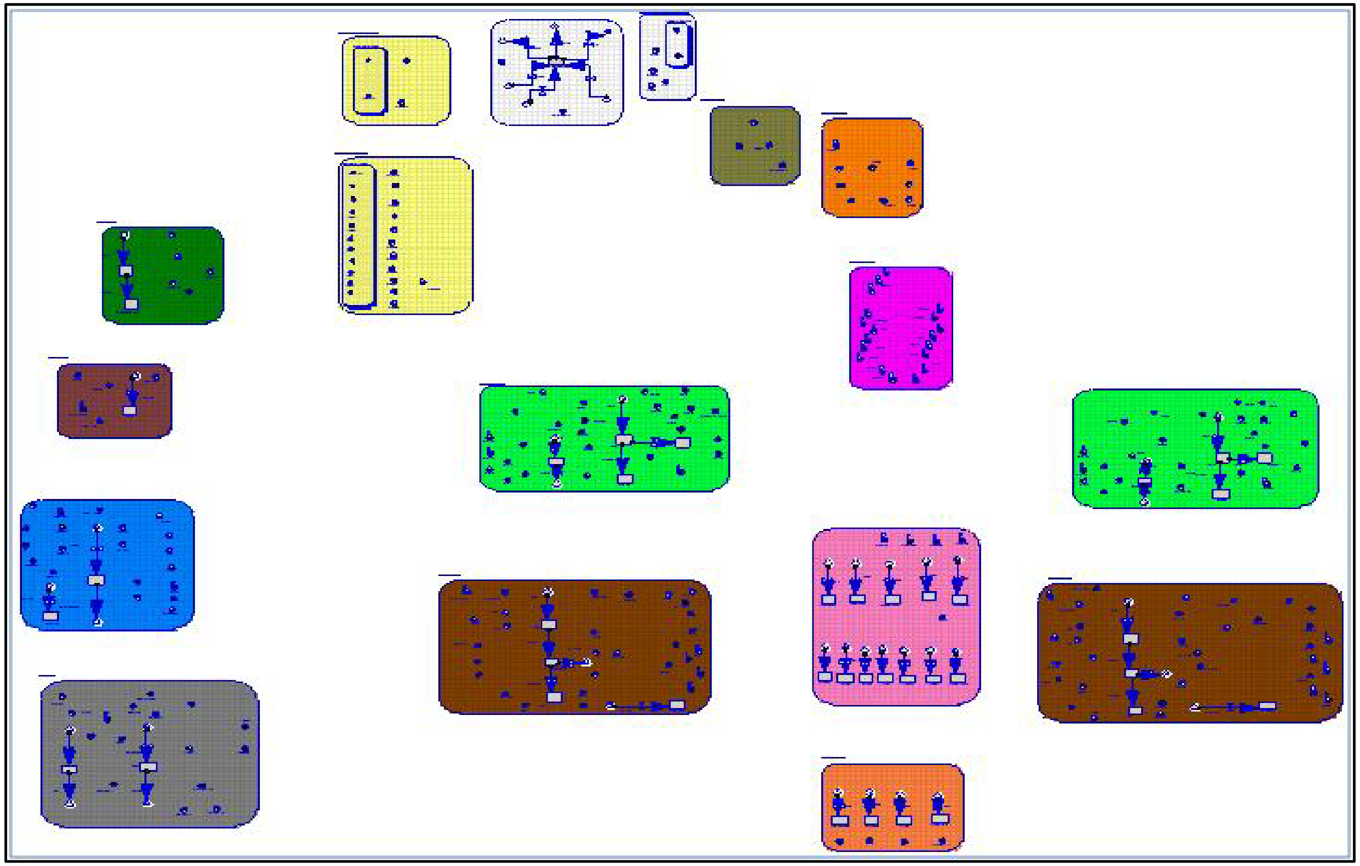
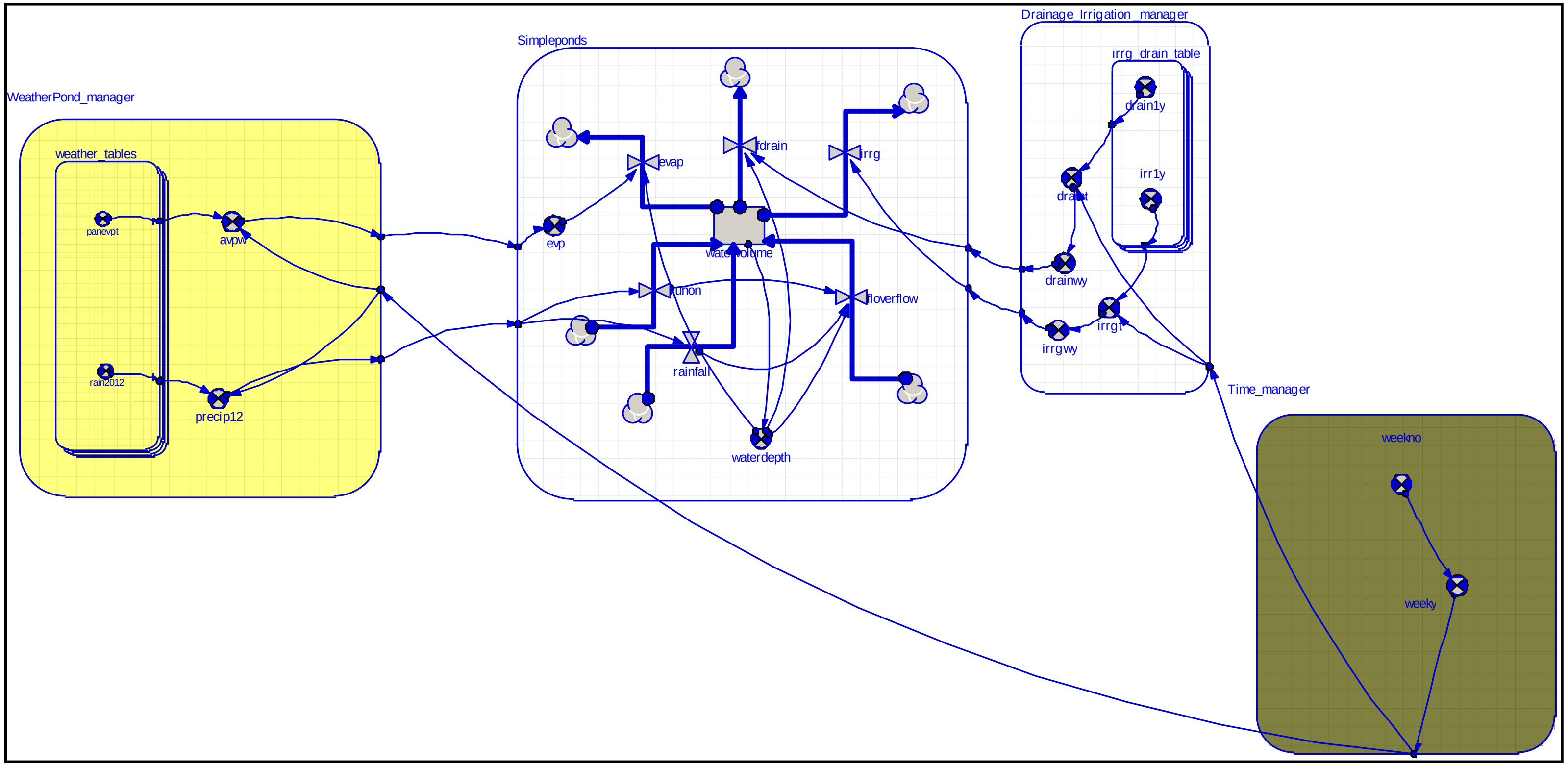


Figure A6.3. Three new submodels added to BN model for Pond irrigation simulation



Equation of the new submodels and BoNam model:

Model Simpleponds_pond4_Style A :

Submodel WeatherPond_manager :

Variable avpw : average weekly rate of evaporation
avpw = element([panevpt],weeky)*7 (real)
Where:
weeky = Value(s) of ../Time_manager/weeky
[panevpt] = Value(s) of weather_tables/panevpt

Comments: values is average: not affected by actual daily weather

Variable precip12 :
precip12 = element([rain2012],weeky)*7 (real)
Where:
weeky = Value(s) of ../Time_manager/weeky
[rain2012] = Value(s) of weather_tables/rain2012

Submodel WeatherPond_manager/weather_tables : weather data used for calibration

Submodel "WeatherPond_manager/weather_tables" is a fixed_membership multi-instance submodel with dimensions [53].

Variable panevpt : average daily values of pan evaporation (mm d-1)
panevpt = table(index(1)) (real)

Variable rain2012 : weekly rainfall in year 1
rain2012 = table(index(1)) (real)

Submodel Drainage_Irrigation _manager :
Variable draint :
draint = element([drain1y],weeky) (real)
Where:
[drain1y] = Value(s) of irrg_drain_table/drain1y
weeky = Value(s) of ../Time_manager/weeky
Variable drainwy :
drainwy = draint (real)
Where:
draint = Value(s) of draint
Variable irrgt :
irrgt = element([irr1y], weeky) (real)
Where:
weeky = Value(s) of ../Time_manager/weeky
[irr1y] = Value(s) of irrg_drain_table/irr1y
Variable irrgwy :
irrgwy = irrgt (real)
Where:
irrgt = Value(s) of irrgt

Submodel Drainage_Irrigation _manager/irrg_drain_table :

Submodel "Drainage_Irrigation _manager/irrg_drain_table" is a fixed_membership multi-instance submodel with dimensions [53].

Variable drain1y : weekly percolation in 1 year, mm per week
drain1y = table(index(1)) (real)

Variable irr1y : weekly irrgation in 1 year
irr1y = table(index(1)) (real)

Submodel Simpleponds :

Compartment watervolume : initial water depth of the pond is 191 cm in wet season
Initial value = (193*900.9)/100 (real)
Rate of change = + rainfall + runon + floverflow - evap - fdrain - irrg

Flow evap :
evap = if waterdepth < 50 then 0 else evp (real)
Where:
waterdepth = Value(s) of waterdepth
evp = Value(s) of evp

Flow fdrain : if water depth is less than 50, no drainage.
fdrain = if waterdepth <50 then 0 else drainwy (real)

Where:
waterdepth = Value(s) of waterdepth
drainwy = Value(s) of ../Drainage_Irrigation _manager/drainwy

Flow floverflow :
floverflow = if (waterdepth > 235) then (-rainfall-runon) else 0 (real)
Where:
waterdepth = Value(s) of waterdepth
runon = Value(s) of runon
rainfall = Value(s) of rainfall

Flow irrg :
irrg = irrgwy (real)
Where:
irrgwy = Value(s) of ../Drainage_Irrigation _manager/irrgwy

Flow rainfall :
rainfall = precip12*900.9/1000 (real)
Where:
precip12 = Value(s) of ../WeatherPond_manager/precip12
Flow runon :
runon = 0.35*precip12*(2*900.9/1000) (real)
Where:
precip12 = Value(s) of ../WeatherPond_manager/precip12

Variable evp :
evp = avpw*900/1000 (real)
Where:
avpw = Value(s) of ../WeatherPond_manager/avpw

Variable waterdepth : water depth is equal to water volume devided by the pond area
waterdepth = watervolume/(0.09*100) (real)
Where:
watervolume = Value(s) of watervolume

Submodel Plot_2_fish :

Compartment afish : age fish, one category
Initial value = 0. (real)
Rate of change = + aging - ahf

Compartment wfish : live weight fish in the pond
Initial value = 0. (real)
Rate of change = + increasewf - harvestwf
Comments:
in kg live weight; dry matter fraction around 0.20.

Flow aging :
aging = stockf*iafish+arfish (real)
Where:
stockf = Value(s) of stockf
iafish = Value(s) of iafish
arfish = Value(s) of arfish
Flow ahf :
ahf = aharvestf (real)
Where:
aharvestf = Value(s) of aharvestf
Flow harvestwf :
harvestwf = if harvestf==1 then wfish+agrowthf else 0 (real)
Where:
wfish = Value(s) of wfish
agrowthf = Value(s) of agrowthf
harvestf = Value(s) of harvestf

Flow increasewf : increase in weight due to stocking or growth
increasewf = ifiwfish*stockf+agrowthf>0.001 then iwfish*stockf+agrowthf else 0 (real)
Where:
iwfish = Value(s) of iwfish
stockf = Value(s) of stockf
agrowthf = Value(s) of agrowthf
Comments: kg w-1. Death not simulated, only harvest. If construction used to avoid underflows (1.E-300 !) that are harmless but halt simulation.

Variable agrowthf :

agrowthf = if pondlow==0 and densfish<0.75*densfishm then pgrowthf elseif pondlow==0 and densfish>densfishm then 0 else pgrowthf*0.20000000000000001 (real)

Where:

pgrowthf = Value(s) of pgrowthf
pondlow = Value(s) of ../Plot_2_pond/pondlow
densfish = Value(s) of densfish
densfishm = Value(s) of densfishm

Variable aharvestf :

aharvestf = if harvestf==1 then afish+arfish else 0 (real)

Where:

arfish = Value(s) of arfish
harvestf = Value(s) of harvestf
afish = Value(s) of afish

Variable arcfish : aging rate constant

arcfish = 1. (real)

Comments: w-1. As age and time are expressed in weeks, the constant is 1 per week. This is valid for for clean water, 25C

Variable arfish : aging rate fish depends on temperature

arfish = if afish<iafish then 0 else arcfish*avtempw/25. (real)

Where:

afish = Value(s) of afish
iafish = Value(s) of iafish
arcfish = Value(s) of arcfish
avtempw = Value(s) of ../Plot_2_pond/avtempw

Comments: w-1. dependency very crude. If age less than inital value: no stocking took place yet.

Variable densfish : fish density

densfish = wfish/(wvol2+1.0000000000000001e-005) (real)

Where:

wfish = Value(s) of wfish
wvol2 = Value(s) of ../Plot_2_pond/wvol2

Comments: kg m-3. Value computed as an indicator of when fish growth rate reaches a level where it become reduced or even stops.

Variable densfishm : maximum density of fish

densfishm = 0.5 (real)

Comments: kg live weight m-3 pond water. Twice level at which fish growth stops to grow fast inspite of feeding level, but at only 20% of maximum rate. At the full value the fish stop growing. Value of 0.5 or 0.75 is just a guess

Variable feedce : feed conversion efficiency

feedce = 0.5 (real)

Comments: kg live fish per kg dry feed

Variable feedf : feed required for actual growth rate

feedf = agrowthf/feedce (real)

Where:

agrowthf = Value(s) of agrowthf
feedce = Value(s) of feedce

Comments:kg. Assumed 0.5 kg feed (dry) for 1 kg of fish, fresh weight. At a dry weight fraction of around 20%, this implies a food conversion efficiency of 40%. Sounds reasonable, but not checked yet. Feedf depends on the growth rate, and note vice versa, assumiing that the manager will more or less give the fish what they want to eat.

Variable harvestf : harvest fish

harvestf = if harvestfm==1 or harvestfd==1 then 1 else 0 (int)

Where:

harvestfm = Value(s) of harvestfm
harvestfd = Value(s) of harvestfd

Comments: Value is 0 or 1. Leads to fish harvest when time is ripe (manager determined) or when the level of water gets too low.

Variable harvestfd :

harvestfd = if ponddry==1 then 1 else 0 (int)

Where:

ponddry = Value(s) of ../Plot_2_pond/ponddry

Variable harvestfm :

harvestfm = if weeky==whvfish then 1 else 0 (int)

Where:

weeky = Value(s) of ../Time_manager/weeky
whvfish = Value(s) of ../Farm_Manager/whvfish

Variable iafish : age fish at stocking

iafish = 4 (int)

Comments: depends on age of fish purchased

Variable iwfish : inital weight at stocking of species 1
iwfish = iwfishs*element([tareas],2.) (real)
Where:
[tareas] = Value(s) of ../Area_manager/tareas
iwfishs = Value(s) of iwfishs
Comments: estimate fingerlings (5 cm, 0.5 g fresh), 20000 pieces. Dry weight around 20% of fresh weight.

Variable iwfishs : initial weight fish, standardized per hectare
iwfishs = Fixed parameter (real)

Comments: kg live ha-1 pond

Variable pgrowthf : potential growth rate
pgrowthf = 0.29999*(25/avtempw)*feedlev_0*wfish (real)
Where:
wfish = Value(s) of wfish
avtempw = Value(s) of ../Plot_2_pond/avtempw
feedlev_0 = Value(s) of ../Farm_Manager/feedlev
Comments: kg kg-1 w-1. temperature and feeding level related; standard rate 30% per week

Variable stockf : stocking condition
stockf = if wfish<iwfish and weeky==wstfish then 1 else 0 (int)
Where:
wfish = Value(s) of wfish
iwfish = Value(s) of iwfish
weeky = Value(s) of ../Time_manager/weeky
wstfish = Value(s) of ../Farm_Manager/wstfish
Comments: stocking when farm_manager indicates unless there are still fish in the pond.

Submodel Area_manager :
Variable area1 :
area1 = 0.1 (real)
Variable area1n : area plot 1
area1n = area1-roofarea/10000. (real)
Where:
roofarea = Value(s) of ../Plot_1_house/roofarea
area1 = Value(s) of area1
Comments: effective area is areaplot1 minus roofarea, as roofwater goes into the jars.

Variable area2 : area pond
area2 = Fixed parameter (real)
Comments: ha. Measured at surface when full with water. Slopes 45o inwards.

Variable area2l : area2 except when too small
area2l = if area2<0.0071998 then 0 else area2 (real)
Where:
area2 = Value(s) of area2
Comments: ha. When area is too small (min 6*12=72 m2) mathematical error occurs in depth calculation, and resettting to zero avoids this.

Variable area3 :
area3 = 0.55 (real)
Variable area4 : area of plot 4 (vegetables)
area4 = areat-(area1n+area2l+area3+area5) (real)
Where:
area2l = Value(s) of area2l
area3 = Value(s) of area3
area1n = Value(s) of area1n
area5 = Value(s) of area5
areat = Value(s) of areat
Variable area5 :
area5 = 0.001 (real)
Variable areat : surface area farm
areat = 1 (real)
Variable tareas : areas of the plots 1-5 plus total, each in ha
tareas = [area1n,area2l,area3,area4,area5,areat] (6 of real)
Where:

area2l = Value(s) of area2l
area4 = Value(s) of area4
area3 = Value(s) of area3
area1n = Value(s) of area1n
area5 = Value(s) of area5
areat = Value(s) of areat

Submodel Plot_1_house :

Compartment wjars : contents jars
Initial value = 0. (real)
Rate of change = + roofflow
Comments: one or more jars with water, expressed in liters. No maximum contents specified.

Flow roofflow : water from roof into jars
roofflow = precipwy*roofarea-hhuse (real)
Where:
hhuse = Value(s) of hhuse
precipwy = Value(s) of ../Weather_manager/precipwy
roofarea = Value(s) of roofarea
Comments: in l w-1;.

Variable hhreq :
hhreq = 560. (real)
Variable hhuse : domestic water consumption
hhuse = if wjars>hhreq then hhreq else 0 (real)
Where:
wjars = Value(s) of wjars
hhreq = Value(s) of hhreq
Comments: Set at 80 l per household per day, or 560 l w-1. No livestock considerd yet. If jars nearly empty, then consumption stops. No maximum volume given or overflow defined. Not yet elaborated with well or something like that.

Variable roofarea : roof area
roofarea = 100. (real)
Comments: for roof water harvesting, in m2. This water runto into jar with infinite capacity! Use only for household. Water that goes into jar does not flow off into pond.

Variable runoffw1 : runoff from plot 1
runoffw1 = max(precipy-avpetw/7-surfstore1,0) (real)
Where:
precipy = Value(s) of ../Weather_manager/precipwy
surfstore1 = Value(s) of surfstore1
avpetw = Value(s) of ../Weather_manager/avpetw
Comments: in mm. all precipw minus minus evaporation of today and minus 'surfstor' (that will evaporate tomorrow), so no infiltration in this area.

Variable surfstore1 : surface storage on farm house plot
surfstore1 = Fixed parameter (real)
Comments: mm.

Submodel Farm_Manager :

Variable benton : 0 or 1
benton = Fixed parameter (real)
Minimum = 0, Maximum = 1
Comments: choice of exploring the consequences of adding a full load (50 t ha-1) of bentonite (acts via fc of soil in vegetables plot).

Variable choiceulr : choice upland or lowland rice
choiceulr = Fixed parameter (int)

Comments: upland (=1) or lowland (=0). Second with dikes and larger surface water storage capacity. In upland situations, no irrigation (switch value overridden)

Variable ds3i : development stage at planting
ds3i = Fixed parameter (real)

Comments: fraction

Variable ds4i : development stage at transplating
ds4i = Fixed parameter (real)
Comments: fraction

Variable feedlev : feeding level 1 (high) or medium (0.5) feedlev = Fixed parameter (real)

Comments: this selects a level of feeding. The actual amounts are calculated after (!) growth rates were established.

Variable firrig3 : fraction irrigation on rice, either 0 or 1
firrig3 = Fixed parameter (int)
Minimum = 0, Maximum = 1
Comments: switch

Variable firrig4 : fraction irrigation
firrig4 = Fixed parameter (int)
Minimum = 0, Maximum = 1
Comments: set to either 0 (no irrigation) or 1 (full)

Variable fpoty3 : target yield
fpoty3 = Fixed parameter (real)
Minimum = 0.230001, Maximum = 0.9000002
Comments: fraction. of potential yield, due to due to suboptimal seed, crop protection and mainly fertilizer.

Variable fpoty4 : target yield is fraction of potential yield
fpoty4 = Fixed parameter (real)
Minimum = 0.29999999999999999, Maximum = 0.90000000000000002
Comments: fraction. first reduction due to path and smallness of the fields: -10%. Next reductions due to sub-maximal fertilization and pest protection, Choice between 30-90%

Variable poty3 : potential economic yield vegetables
poty3 = Fixed parameter (real)

Comments: kg ha-1

Variable poty4 : potential yield
poty4 = Fixed parameter (int)

Comments: economic yield obtained in the best management conditions. Values are several thousands of kg (dry weight) per hectare. Crop variety specific.

Variable repldlveg : delay of planting after previous harvest.
repldlveg = Fixed parameter (int)

Comments:
if value = 1 then 2 week, otherwise 4 weeks

Variable replrice : second planting of rice yes (1) or no (0)
replrice = Fixed parameter (int)
Comments: If ‚yes', second planting 3 weeks after harvest first crop

Variable tdw3i : dry weight at planting
tdw3i = Fixed parameter (real)
Comments: kg ha-1

Variable tdw4i : dry weight at transplanting
tdw4i = Fixed parameter (int)
Comments: kg ha-1

Variable wfplrice :
wfplrice = Fixed parameter (int)
Comments: week of planting rice for the rainy season: first part of july

Variable wfplveg : week of first planting of vegetables
wfplveg = Fixed parameter (int)

Variable whvfish : week of harvesting fish
whvfish = Fixed parameter (int)

Variable wstfish : week of stocking fish
wstfish = Fixed parameter (real)

Submodel Weather_manager :

Variable avpetw : average weekly rate of evapotranspiration
avpetw = element([petavt],weeky)*7 (real)
Where:
[petavt] = Value(s) of weather_tables/petavt

weeky = Value(s) of ../Time_manager/weeky

Comments: values is average: not affected by actual daily weather

Variable avtemp :
avtemp = element([tempavt],weeky) (real)
Where:
[tempavt] = Value(s) of weather_tables/tempavt
weeky = Value(s) of ../Time_manager/weeky

Variable precip1 :
precip1 = element([rain1t],weeky) (real)
Where:
weeky = Value(s) of ../Time_manager/weeky
[rain1t] = Value(s) of weather_tables/rain1t
Variable precip2 :
precip2 = element([rain2t],weeky) (real)
Where:
weeky = Value(s) of ../Time_manager/weeky
[rain2t] = Value(s) of weather_tables/rain2t
Variable precip3 :
precip3 = element([rain3t],weeky) (real)
Where:
weeky = Value(s) of ../Time_manager/weeky
[rain3t] = Value(s) of weather_tables/rain3t
Variable precip4 :
precip4 = element([rain4t],weeky) (real)
Where:
weeky = Value(s) of ../Time_manager/weeky
[rain4t] = Value(s) of weather_tables/rain4t
Variable precip5 :
precip5 = element([rain5t],weeky) (real)
Where:
[rain5t] = Value(s) of weather_tables/rain5t
weeky = Value(s) of ../Time_manager/weeky
Variable precip6 :
precip6 = element([rain6t],weeky) (real)
Where:
[rain6t] = Value(s) of weather_tables/rain6t
weeky = Value(s) of ../Time_manager/weeky
Variable precip7 :
precip7 = element([rain7t],weeky) (real)
Where:
[rain7t] = Value(s) of weather_tables/rain7t
weeky = Value(s) of ../Time_manager/weeky
Variable precip8 :
precip8 = element([rain8t],weeky) (real)
Where:
[rain8t] = Value(s) of weather_tables/rain8t
weeky = Value(s) of ../Time_manager/weeky
Variable precip9 :
precip9 = element([rain9t],weeky) (real)
Where:
[rain9t] = Value(s) of weather_tables/rain9t
weeky = Value(s) of ../Time_manager/weeky
Variable precipwy :
precipwy =
element([precip1,precip2,precip3,precip4,precip5,precip6,precip7,precip8,precip9
],year) (real)
Where:
year = Value(s) of ../Time_manager/year
precip1 = Value(s) of precip1
precip2 = Value(s) of precip2
precip3 = Value(s) of precip3
precip4 = Value(s) of precip4
precip5 = Value(s) of precip5
precip6 = Value(s) of precip6
precip7 = Value(s) of precip7
precip8 = Value(s) of precip8
precip9 = Value(s) of precip9
Submodel Weather_manager/weather_tables :

Submodel "Weather_manager/weather_tables" is a fixed_membership multi-instance submodel with dimensions [53].

Variable petavt : average daily values of potential evapotranspiration (mm d-1)

petavt = table(index(1)) (real)
Variable rain1t : weekly rainfall in year 1
rain1t = table(index(1)) (real)
Variable rain2t : weekly rainfall in year 2
rain2t = table(index(1)) (real)
Variable rain3t : weekly rainfall in year 3
rain3t = table(index(1)) (real)
Variable rain4t : weekly rainfall year 4
rain4t = table(index(1)) (real)
Variable rain5t : weekly rainfall year 5
rain5t = table(index(1)) (real)
Variable rain6t : weekly rainfall year 6
rain6t = table(index(1)) (real)
Variable rain7t : weekly rainfall year 7
rain7t = table(index(1)) (real)
Variable rain8t : weekly rainfall year 8
rain8t = table(index(1)) (real)
Variable rain9t : weekly rainfall year 9
rain9t = table(index(1)) (real)
Variable tempavt : weekly average tempatures
tempavt = table(index(1)) (real)

Submodel Annual_results :

Compartment drywfold : number of weeks that the pond has been dry, cumulative
Initial value = 0. (real)
Rate of change = + flow3
Comments: number

Compartment fincomeold : income farm during one year
Initial value = 0. (real)
Rate of change = + flow4
Comments: LAK

Compartment firriold : total irrigation water used on plots 4 and 3
Initial value = 0. (real)
Rate of change = + flow1
Comments: m3.

Compartment frunoffold : water running from the farm, annual total
Initial value = 0. (real)
Rate of change = + flow2
Comments: m3. all water that runs of the farm because the pond gets filled beyond its capacity plus all water running from the rice field

Flow flow1 :
flow1 = if weeky==27 then tirrigf-firriold else 0 (real)
Where:
firriold = Value(s) of firriold
weeky = Value(s) of ../Time_manager/weeky
tirrigf = Value(s) of ../Farm_performance/tirrigf
Flow flow2 :
flow2 = if weeky==27 then trunoffarm-frunoffold else 0 (real)
Where:
frunoffold = Value(s) of frunoffold
weeky = Value(s) of ../Time_manager/weeky
trunoffarm =Value(s) of ../Farm_performance/trunoffarm
Flow flow3 :
flow3 = if weeky==27 then drywf-drywfold else 0 (real)
Where:
drywfold = Value(s) of drywfold
drywf = Value(s) of ../Farm_performance/drywf
weeky = Value(s) of ../Time_manager/weeky
Flow flow4 :
flow4 = if weeky==27 then fincome-fincomeold else 0 (real)
Where:
weeky = Value(s) of ../Time_manager/weeky
fincome = Value(s) of ../Farm_performance/fincome
fincomeold = Value(s) of fincomeold
Variable adrywf : running value during year
adrywf = drywf-drywfold (real)
Where:
drywfold = Value(s) of drywfold
drywf = Value(s) of ../Farm_performance/drywf
Comments: number of weeks pond dry in one year.

Variable aincomef : running value during the year.
aincomef = fincome-fincomeold (real)
Where:
fincomeold = Value(s) of fincomeold
fincome = Value(s) of ../Farm_performance/fincome
Comments: million LAK per farm.

Variable airrigf : running value during year.
airrigf = tirrigf-firriold (real)
Where:
firriold = Value(s) of firriold
tirrigf = Value(s) of ../Farm_performance/tirrigf
Comments: m3 farm-1

Variable arunofff : running value during year
arunofff = trunoffarm-frunoffold (real)
Where:
frunoffold = Value(s) of frunoffold
trunoffarm= Value(s) of ./Farm_performance/trunoffarm
Comments: m3 per farm

Submodel Plot_4_veg-crop :
Compartment ds4 :
Initial value = 0. (real)
Rate of change = + dr4 - hvds4
Compartment eyield4 :
Initial value = 0. (real)
Rate of change = + hvveg4
Compartment residue4 :
Initial value = 0. (real)
Rate of change = + resid
Compartment tdw4 : crop dry weight
Initial value = 0. (real)
Rate of change = + ngr4 - resid - hvveg4
Flow dr4 :
dr4 = dr4t+plantingds (real)
Where:
plantingds = Value(s) of plantingds
dr4t = Value(s) of dr4t
Flow hvds4 :
hvds4 = hvrds4 (real)
Where: hvrds4 = Value(s) of hvrds4
Flow hvveg4 :
hvveg4 = hvbm4*feyield4 (real)
Where:
hvbm4 = Value(s) of hvbm4
feyield4 = Value(s) of feyield4
Flow ngr4 :
ngr4 = tdw4p+agr4 (real)
Where:
tdw4p = Value(s) of tdw4p
agr4 = Value(s) of agr4
Flow resid :
resid = hvbm4*(1-feyield4) (real)
Where:
hvbm4 = Value(s) of hvbm4
feyield4 = Value(s) of feyield4
Variable aatr4 : actual transpiration rate plot 4
aatr4 = atr4 (real)
Where:
atr4 = Value(s) of ../Plot_4_veg-soil/atr4
Comments: mm w-1, auxillary only
Variable agr4 : actual growth rate, water stress dependent
agr4 = mgr4*min(max(aatr4/(mtr4+0.0001),0),1) (real)
Where:
mgr4 = Value(s) of mgr4
mtr4 = Value(s) of mtr4
aatr4 = Value(s) of aatr4
Comments: kg ha-1 w-1
Variable dr4t :
dr4t = if ds4<1 then dr4tv else (if ds4<2 then dr4tr else 0) (real)
Where:
dr4tv = Value(s) of dr4tv
dr4tr = Value(s) of dr4tr
ds4 = Value(s) of ds4
Variable dr4tr : development rate reproductive phase

dr4tr = dr4trc*etdr4 (real)
Where:
etdr4 = Value(s) of etdr4
dr4trc = Value(s) of dr4trc
Comments: w-1. Assumed Flowering to ripe in 4 weeks.
Variable dr4trc :
dr4trc = Fixed parameter (real)
Variable dr4tv : development rate vegetables, vegetative phase
dr4tv = if ds4==0 then 0 else dr4tvc*etdr4 (real)
Where:
ds4 = Value(s) of ds4
etdr4 = Value(s) of etdr4
dr4tvc = Value(s) of dr4tvc
Comments: fraction w-1. Approximated rate: development from dsi (0.2) to flowering (dsm = 1) in 60 d = 8.5 weeks. So DRC = 0.12 per week. Effect temperature small
Variable dr4tvc :
dr4tvc = Fixed parameter (real)
Variable etdr4 :
etdr4 = avtemp/25 (real)
Where:
avtemp = Value(s) of ../Weather_manager/avtemp
Variable feyield4 :
feyield4 = Fixed parameter (real)
Variable hvbm4 :
hvbm4 = if harvestsw==1 then tdw4 else 0 (real)
Where:
harvestsw = Value(s) of hvsw4
tdw4 = Value(s) of tdw4
Variable hvrds4 :
hvrds4 = if hvsw4==1 then ds4 else 0 (real)
Where:
hvsw4 = Value(s) of hvsw4
ds4 = Value(s) of ds4
Variable hvsw4 :
hvsw4 = if ds4>2 then 1 else 0 (int)
Where:
ds4 = Value(s) of ds4

Variable mgr4 : growth rate without water stress
mgr4 = if ds4<2 then (if tdw4<1500 then mgre4 else mgrl4) else 0 (real)
Where:
tdw4 = Value(s) of tdw4
ds4 = Value(s) of ds4
mgre4 = Value(s) of mgre4
mgrl4 = Value(s) of mgrl4
Comments: kg ha-1 w-1. rate of dry matter increase in dry weight; at 1500 canopy closes and exponential growth converts to linear growth.
Variable mgre4 :
mgre4 = pgre4*(1+mngmtstress4)/2 (real)
Where:
pgre4 = Value(s) of pgre4
mngmtstress4 = Value(s) of mngmtstress4
Variable mgrl4 :
mgrl4 = pgrl4*mngmtstress4 (real)
Where:
pgrl4 = Value(s) of pgrl4
mngmtstress4 = Value(s) of mngmtstress4
Variable mngmtstress4 : nutrient stress
mngmtstress4 = fpoty4+0*poty4 (real)
Where:
poty4 = Value(s) of ../Farm_Manager/poty4
fpoty4 = Value(s) of ../Farm_Manager/fpoty4

Comments: approximation of target yield divided by potential yield (note: both numbers refer to economic yield', but it is also applied to the vegetative phase).
Variable mtr4 : transpiration rate
mtr4 = max(mgr4/20,0) (real)
Where:
mgr4 = Value(s) of mgr4
Comments: mm w-1. Found by multiplying crop growth rate (kg ha-1 w-1) by 0.5 m3 kg-1 and dividing by 10 to convert to mm

Variable pgre4 : potential growth rate in exponential phase
pgre4 = tdw4*1 (real)
Where:

tdw4 = Value(s) of tdw4
Comments: kg ha-1 w-1.
Variable pgrl4 : potential growth rate linear phase
pgrl4 = 1400. (real)

Comments: kg ha-1 w-1

Variable plantingds :
plantingds = if replantsw4+plantsw4>=1 then ds4i else 0 (real)
Where:
replantsw4 = Value(s) of replsw4
ds4i = Value(s) of ../Farm_Manager/ds4i
plantsw4 = Value(s) of plsw4
Variable plsw4 :
plsw4 = if weeky==wfplveg then 1 else 0 (int)
Where:
wfplveg = Value(s) of ../Farm_Manager/wfplveg
weeky = Value(s) of ../Time_manager/weeky
Variable replsw4 :
replsw4 = if ds4<0.01 then replantsw412 else 0 (real)
Where:
ds4 = Value(s) of ds4
replantsw412 = Value(s) of replsw412
Comments: simulates replanting after 1 (min) to 2 (max) decades.
Variable replsw41 :
replsw41 = last(last(hvsw4)) (int)
Where:
hvsw4 = Value(s) of hvsw4
Variable replsw412 :
replsw412 = if repldlveg==1 then replsw41 else replsw42 (int)
Where:
replsw42 = Value(s) of replsw42
replsw41 = Value(s) of replsw41
repldlveg = Value(s) of ../Farm_Manager/repldlveg
Variable replsw42 :
replsw42 = last(last(replsw41)) (int)
Where:
replsw41 = Value(s) of replsw41

Variable tdw4p :
tdw4p = if replantsw4+plsw4>=1 then tdw4i else 0 (int)
Where:
replantsw4 = Value(s) of replsw4
tdw4i = Value(s) of ../Farm_Manager/tdw4i
plsw4 = Value(s) of plsw4
Submodel Plot_5_trees :
Compartment groundwater5 : groundwater
Initial value = 500. (real)

Rate of change = + tl5fout
Comments: mm. just accumulating water; not (yet) connected to groundwater of other plots.

Compartment wtl5 : water contents soil layer under trees
Initial value = 100. (real)
Rate of change = + tl5fin - tl5fout
Comments: mm. no layers are distinguished, only subsoil with 'groundwater'. no full simulation here.

Flow tl5fin : infiltration into the soil layer
tl5fin = infilt5-atr5 (real)
Where:
atr5 = Value(s) of atr5
infilt5 = Value(s) of infilt5
Comments: soil evaporation is subtracted except when soil already very dry (to prevent negative values). Infiltration has no ceiling value, assuming good soil structure.
Flow tl5fout :
tl5fout = max(wtl5*0.01,0) (real)
Where:
wtl5 = Value(s) of wtl5
Variable atr5 : transpiration by trees
atr5 = if wtl5>20 then 0.5*avpetw else 0 (real)
Where:
wtl5 = Value(s) of wtl5
avpetw = Value(s) of ../Weather_manager/avpetw
Comments: mm w-1. rate is half that of potential evapotranspiration

Variable frunoff5 : fraction runoff
frunoff5 = 0.4 (real)
Comments: fraction of the water that runs off the tree plot of all water that cannot infiltrate

Variable infilt5 : water infiltrating the soil
infilt5 = max(if wtl5>10 then precipwy-runoffw5-avpetw*0.378 else precipwy-runoffw5,0.) (real)
Where:
runoffw5 = Value(s) of runoffw5
wtl5 = Value(s) of wtl5
precipwy = Value(s) of ../Weather_manager/precipwy
avpetw = Value(s) of ../Weather_manager/avpetw
Comments: mm w-1. If the soil is too dry, evaporation does not take place

Variable runoffw5 : runoff from tree plot
runoffw5 = max(precipy-surfstor5,0)*frunoff5 (real)
Where:
surfstor5 = Value(s) of surfstor5
precipy = Value(s) of ../Weather_manager/precipwy
frunoff5 = Value(s) of frunoff5
Comments: assumed 50% of all rain in a week over what can be stored on the surface and eveporates from there. Effectively, surfstor stand salso for tree interception of rain water, which may be around 2 mm per individual rain.
Variable surfstor5 : surface storage of water in layer that evaporates quickly: intercepted rain and soil surface.
surfstor5 = 20. (real)
Comments: Estimate 25 mm; all this water evaporates within the week.

Submodel Plot_3_rice-soil :
Compartment wfluxes :
Initial value = 0. (real)
Rate of change = + sfluxes

Compartment wml3 : water contents middle layer rice field
Initial value = wml3i (real)
Where:
wml3i = Value(s) of wml3i
Rate of change = + ml3fin - ml3foutp - ml3fout
Comments: in mm. Typically 500 mm in depth. No capillary rise.

Compartment wsl3 : wsubsoil: water in the soil below the rooting zone.
Initial value = wsl3i (real)
Where:
wsl3i = Value(s) of wsl3i
Rate of change = + ml3fout
Comments: Layer typically unlimited in absorption capacity. No capillary rise.

Compartment wtl3 : water contents top layer rice field
Initial value = wtl3i (real)
Where:
wtl3i = Value(s) of wtl3i
Rate of change = + tl3fin - ml3fin
Comments: cm3 cm-2. Represent water in topsoil plus standing water, if any! Checks of water balance calculation in plot 3 and 4 in Bonam-60 /85show very good behaviour of all components.
Flow ml3fin : net flux into second soil layer
ml3fin = max(tl3rwc-tl3fc,0)*dtl3*tl3hc+max(min(tl3rwc,tl3fc)-tl3wp,0)/(tl3rwc-tl3wp)*dtl3*0.10000000000000001 (real)
Where:
tl3hc = Value(s) of tl3hc
tl3fc = Value(s) of tl3fc
tl3wp = Value(s) of tl3wp
dtl3 = Value(s) of dtl3
tl3rwc = Value(s) of tl3rwc
Comments: cm3 cm-2 w-1. In two components: saturated flow (all water over field capacity in one week) and unsaturated flow (7.5% of water between fc and wp in a week).

Flow ml3fout :
ml3fout=max((ml3rwc-ml3wp)/(ml3fc-ml3wp),0)*wml3*0.050000003 (real)
Where:
wml3 = Value(s) of wml3
ml3wp = Value(s) of ml3wp
ml3fc = Value(s) of ml3fc

ml3rwc = Value(s) of ml3rwc

Flow ml3foutp :

ml3foutp = atrml3 (real)

Where:

atrml3 = Value(s) of atrml3

Flow sfluxes :

sfluxes = precipwy+irriw3-evapw3-atr3-runoffw3 (real)

Where:

atr3 = Value(s) of atr3
runoffw3 = Value(s) of runoffw3
irriw3 = Value(s) of irriw3
evapw3 = Value(s) of evapw3
precipwy = Value(s) of ../Weather_manager/precipwy

Flow tl3fin : Net flux of water into the topsoil in one week

tl3fin = precipwy+irriw3-evapw3-atrtl3-runoffw3 (real)

Where:

evapw3 = Value(s) of evapw3
atrtl3 = Value(s) of atrtl3
irriw3 = Value(s) of irriw3
runoffw3 = Value(s) of runoffw3
precipwy = Value(s) of ../Weather_manager/precipwy

Comments: mm w-1.

Variable atr3 : effect of water shortage

atr3 = atrtl3+atrml3 (real)

Where:

atrtl3 = Value(s) of atrtl3
atrml3 = Value(s) of atrml3

Comments: effect of water shortage weighted across layers. Factor 1.25 indicates that at rwc between 1 and 0.8 there is no stress, and then it increases linearly to 1.0.

Variable atrml3 :

atrml3 = mtrml3*rwcml3f (real)

Where:

mtrml3 = Value(s) of mtrml3
rwcml3f = Value(s) of rwcml3f

Variable atrtl3 :

atrtl3 = mtrtl3*rwctl3f (real)

Where:

mtrtl3 = Value(s) of mtrtl3
rwctl3f = Value(s) of rwctl3f

Variable dml3 : dpeth middle layer

dml3 = 500. (real)

Comments: mm

Variable dtl3 : depth top layer

dtl3 = 300. (real)

Comments: mm

Variable evapw3 : evaporation rate soil

evapw3 = if tl3rwc<0.070000000000000007 then 0 else (if tl3rwc>tl3fc then max(avpetw-0.5*mtr3,0) else evapw3d) (real)

Where:

mtr3 = Value(s) of ../Plot_3_rice-crop/mtr3
tl3fc = Value(s) of tl3fc
tl3rwc = Value(s) of tl3rwc
evapw3d = Value(s) of evapw3d
avpetw = Value(s) of ../Weather_manager/avpetw

Comments: mm w-1. If the soil is wet, then potential evaporation; if between air dry and field capacity then calculated as for upland soil, and zero when the soil is airdry. For the latter, we take 0.07 rather then 0.05 to ensure that rwc does not get below rwcad.

Variable evapw3d : evaporation rate rice crop when when surface is dry.

evapw3d = max(avpetw*(rwctl3fe-0.14999999999999999)*(rwctl3fe-0.14999999999999999)-0.5*mtr3,0) (real)

Where:

mtr3 = Value(s) of ../Plot_3_rice-crop/mtr3
rwctl3fe = Value(s) of rwctl3fe
avpetw = Value(s) of ../Weather_manager/avpetw

Comments: mm w-1. Potential rate times relative water content (fraction) squared, and water content reduced by 0.15 to anticipate lower values during the next ime interval. Weak part; same as for vegetable crop.

Variable infiltmax3 : max infirltration

infiltmax3 = max(tl3st-tl3rwc,0)*dtl3+surfstor3 (real)

Where:

tl3st = Value(s) of tl3st
dtl3 = Value(s) of dtl3
tl3rwc = Value(s) of tl3rwc
surfstor3 = Value(s) of surfstor3

Comments: mm w-1

Variable irriw3 : quantity water supplied for irrigation
irriw3 = if choiceulr==0 and pondlow==0 then 0.5*surfstor3*firrig3 else 0 (real)

Where:

choiceulr = Value(s) of ../Farm_Manager/choiceulr
pondlow = Value(s) of ../Plot_2_pond/pondlow
firrig3 = Value(s) of ../Farm_Manager/firrig3
surfstor3 = Value(s) of surfstor3

Comments: mm w-1. For lowland cultivation, water provided to toplayer from reservoir fills topsoil in one week up to saturation, plus an equal amount in surfstore. This is multiplied with the 'fraction irrigation' to allow for suboptimal water supply.

Note: (1) irrigation does not depend on the presence of a crop. So if no second planting but switch is 'on', then a bare field is irrigated. Is OK. (2) In upland conditions, no irrigation, overriding the irrigation switch for rice

Variable ml3fc : water contents at field capacity, middle layer
ml3fc = Fixed parameter (real)

Variable ml3rwc :
ml3rwc = min(max(wml3/dml3,0),1) (real)

Where:

wml3 = Value(s) of wml3
dml3 = Value(s) of dml3

Variable ml3rwci :
ml3rwci = 0.25 (real)

Variable ml3wp : water contents middle layer at wiltingpoint
ml3wp = Fixed parameter (real)

Variable mtrml3 :
mtrml3 = mtr3*0.20000000000000001 (real)

Where:

mtr3 = Value(s) of ../Plot_3_rice-crop/mtr3

Variable mtrtl3 :
mtrtl3 = mtr3*0.80000000000000004 (real)

Where:

mtr3 = Value(s) of ../Plot_3_rice-crop/mtr3

Variable runoffw3 : runoff plot
runoffw3 = if precipy>infiltmax3 then precipy-infiltmax3 else 0 (real)

Where:

infiltmax3 = Value(s) of infiltmax3
precipy = Value(s) of ../Weather_manager/precipwy

Comments: mm w-1

Variable rwcml3f :
rwcml3f = min(max((ml3rwc-ml3wp)/(ml3fc-ml3wp),0),1) (real)

Where:

ml3rwc = Value(s) of ml3rwc
ml3fc = Value(s) of ml3fc
ml3wp = Value(s) of ml3wp

Variable rwctl3f :
rwctl3f = max(min((tl3rwc-tl3wp)/(tl3fc-tl3wp),1),0) (real)

Where:

tl3fc = Value(s) of tl3fc
tl3wp = Value(s) of tl3wp
tl3rwc = Value(s) of tl3rwc

Variable rwctl3fe :
rwctl3fe = min(max((tl3rwc-tl3ad)/(tl3fc-tl3ad),0),1) (real)

Where:

tl3ad = Value(s) of tl3ad
tl3fc = Value(s) of tl3fc
tl3rwc = Value(s) of tl3rwc

Variable surfstor3 : surface storage
surfstor3 = if choiceulr==1 then 20 else 200 (int)

Where:

choiceulr = Value(s) of ../Farm_Manager/choiceulr

Comments: significant for lowland rice, low for upland rice

Variable tl3ad : water content when air-dry
tl3ad = Fixed parameter (real)
Comments: cm3 cm-3. Used for evaporatiion rate calculation.

Variable tl3fc : water contents top layer at field capacity
tl3fc = Fixed parameter (real)
Variable tl3hc : top layer plot 3, hydraulic conductivity
tl3hc = if choiceulr==1 then 1 else 0.40000000000000002 (real)
Where:
choiceulr = Value(s) of ../Farm_Manager/choiceulr
Comments: fraction; fraction of water contents top layer (above field capacity) drained in one week. Under upland conditions, soil rather permeable and all drains. In lowland conditions, soil has been puddled to limit percolation to only 0.5 (for 300 mm top soil and if full with water, difference saturation-field cap = 0.64 yields 0.4*190=76 mm per week; OK).

Variable tl3rwc : relative water contents top soil
tl3rwc = min(max(wtl3/dtl3,0),1) (real)
Where:
dtl3 = Value(s) of dtl3
wtl3 = Value(s) of wtl3
Comments: Typical values are saturation (0.4), field capacity (0.25), wilting point (0.1), and iar dry (0.03).

Variable tl3rwci :
tl3rwci = 0.3 (real)
Variable tl3st : water contents top layer at saturation
tl3st = Fixed parameter (real)
Variable tl3wp : water contents top layer at wilting point
tl3wp = Fixed parameter (real)
Variable wdiff3 : Check on water balance calculations.
wdiff3 = wstates-wfluxes (real)
Where:
wstates = Value(s) of wstates
wfluxes = Value(s) of wfluxes
Comments: value remained zero (correct) inversion 5.

Variable wdiff3s :
wdiff3s = if abs(wdiff3)>1.e-10 then stop(3) else 0 (int)
Where:
wdiff3 = Value(s) of wdiff3
Variable wml3i :
wml3i = ml3rwci*dml3 (real)
Where:
ml3rwci = Value(s) of ml3rwci
dml3 = Value(s) of dml3
Variable wsl3i :
wsl3i = 100 (int)
Variable wstates : sum of water contents
wstates = wtl3-wtl3i+(wml3-wml3i)+(wsl3-wsl3i) (real)
Where:
wsl3 = Value(s) of wsl3
wml3 = Value(s) of wml3
wtl3 = Value(s) of wtl3
wsl3i = Value(s) of wsl3i
wml3i = Value(s) of wml3i
wtl3i = Value(s) of wtl3i
Comments: mm. value used to check water balance calculations
Variable wtl3i :
wtl3i = tl3rwci*dtl3 (real)
Where:
tl3rwci = Value(s) of tl3rwci
dtl3 = Value(s) of dtl3
Submodel Plot_2_pond :
Compartment toverflow :
Initial value = 0. (real)
Rate of change = + overflow

Compartment wvol2 : water volume (absolute)
Initial value = wdepthi*element([tareas],2)*10. (real)
Where:
wdepthi = Value(s) of wdepthi
[tareas] = Value(s) of ../Area_manager/tareas

Rate of change = + flowin2 - netdrainage2

Comments: m3. Pond is throught to a rectangle (l is 2x w), with wall under 45o. Pond surface is measured at maximum water contents.

Flow flowin2 :
flowin2 = min(flowin2p,flowin2m) (real)
Where:
flowin2p = Value(s) of flowin2p
flowin2m = Value(s) of flowin2m

Flow netdrainage2 : net drainage rate out of pond
netdrainage2 = drainage2-upwelling (real)
Where:
drainage2 = Value(s) of drainage2
upwelling = Value(s) of upwelling
Comments: m3.

Flow overflow :
overflow = max(flowin2p-flowin2m,0) (real)
Where:
flowin2p = Value(s) of flowin2p
flowin2m = Value(s) of flowin2m

Variable a : 'a' in disciminant
a = if pondw>6 then 3*pondw-12 else 1 (real)
Where:
pondw = Value(s) of pondw
Comments: if ponwd > 6 then OK, otherwise dummy value of 1

Variable avtempw : water temperature
avtempw = avtemp-5. (real)
Where:
avtemp = Value(s) of ../Weather_manager/avtemp
Comments: oC. Effective water temperature as experienced by fish that can go deep or to the surface. Equation is approxiation.

Variable b : 'b'
b = if pondw>6 then 2*pondw*pondw-18*pondw+36 else 1 (real)
Where:
pondw = Value(s) of pondw
Comments: 'b' in the quadratic equation to solve depth. If b,6 (minimum) only dummy value

Variable dr2c : drainage from plot 2, fraction
dr2c = Fixed parameter (real)

Comments: fraction of pond volume per week. Lower values should be used if pond bottom s well sealed.

Variable drainage2 : drainage through bottom and side walls
drainage2=ifwdepth>500 then dr2c*wdepth*(element([tareas],2)*10*redgeom)else 0 (real)
Where:
[tareas] = Value(s) of ../Area_manager/tareas
redgeom = Value(s) of redgeom
wdepth = Value(s) of wdepth
dr2c = Value(s) of dr2c
Comments: m3 w-1. 1% per week of water in pond is a rough estimate and should be calibrated whenever possible.

Variable evap2 : pond surface evaporation rate
evap2 = if ponddry==0 then avpetw else 0. (real)
Where:
ponddry = Value(s) of ponddry
avpetw = Value(s) of ../Weather_manager/avpetw
Comments: mm w-1

Variable flowin2m : maximum inflow
flowin2m = (wdepthm-wdepth)*element([tareas],2)*10. (real)
Where:
wdepth = Value(s) of wdepth
wdepthm = Value(s) of wdepthm
[tareas] = Value(s) of ../Area_manager/tareas
Comments: m3. Value is equal to remain storgate capacity. Since walls sloping, value slightly overestimated particularly of low depths.

Variable flowin2p : potential inflow
flowin2p = netflux2+runoffw145-takeout (real)
Where:
runoffw145 = Value(s) of runoffw145

netflux2 = Value(s) of netflux2
takeout = Value(s) of takeout
Comments: m3. potential quantity of inflow; actual value of less if unused storage capacity too small.

Variable netflux2 : net sum of rainfall and evaporation
netflux2 = precipwy*element([tareas],2)*10.-evap2*element([tareas],2)*10.*redgeom (real)
Where:
evap2 = Value(s) of evap2
redgeom = Value(s) of redgeom
precipwy = Value(s) of ../Weather_manager/precipwy
[tareas] = Value(s) of ../Area_manager/tareas
Comments: m3. There is no shade simulated. Evaporation reduces if area of pond shrinks at reduced water levels, and stops if water level is "dry'.

Variable ponddry : switch to allow/stop evaporation
ponddry = if wdepth<500 then 1 else 0 (int)
Where:
wdepth = Value(s) of wdepth
Comments: level at which the pond is supposed to be dry: no more evaporation or drainage. Irrigation stopped allready at 'pondlow'.

Variable pondlow : switch to allow/stop irrigation
pondlow = if wdepth<1000 then 1 else 0 (int)
Where:
wdepth = Value(s) of wdepth
Comments: Level below which pumping for irrigation of vegetable (and rice) plot stops.

Variable pondw : pond width
pondw = sqrt((element([tareas],2)+1.0E-05)/2)*100. (real)
Where:
[tareas] = Value(s) of ../Area_manager/tareas
Comments: in m. standard shape asumed: width (measured at top of the pond) is half the length; maximum depth is 3 m and slopes are under 45 degree.

Variable redgeom :
redgeom = max(0,(pondw-6+2*wdepth/1000)*(2*pondw-6+2*wdepth/1000)/(2*pondw*pondw)) (real)
Where:
pondw = Value(s) of pondw
wdepth = Value(s) of wdepth

Variable ru2c : rate of upwelling
ru2c = 0. (real)

Variable runoffw145 : runoff flow into pond
runoffw145 = (runoffw1*element([tareas],1)+runoffw4*element([tareas],4)+runoffw5*element([tareas],5))*10. (real)
Where:
runoffw1 = Value(s) of ../Plot_1_house/runoffw1
[tareas] = Value(s) of ../Area_manager/tareas
runoffw5 = Value(s) of ../Plot_5_trees/runoffw5
runoffw4 = Value(s) of ../Plot_4_veg-soil/runoffw4
Comments: m3.

Variable takeout : water taken for irrigation
takeout = (irriw3*element([tareas],3)+irriw4*element([tareas],4))*10. (real)
Where:
irriw4 = Value(s) of ../Plot_4_veg-soil/irriw4
[tareas] = Value(s) of ../Area_manager/tareas
irriw3 = Value(s) of ../Plot_3_rice-soil/irriw3
Comments: in m3. for plots 4 and 3.

Variable upwelling : upwelling of water from bottom
upwelling = ru2c*(element([tareas],2)*10.0) (real)
Where:
ru2c = Value(s) of ru2c
[tareas] = Value(s) of ../Area_manager/tareas
Comments: m3 w-1. Potential to mimick this proces exists but is not yet utilized (constant multiplier of 0).

Variable wdepth : water depth in pond
wdepth = if pondw>6 then(sqrt(b*b+4*a*wvol2)-b)/(2*a)*1000 else 0. (real)
Where:
wvol2 = Value(s) of wvol2
pondw = Value(s) of pondw
b = Value(s) of b
a = Value(s) of a

Comments: mm. A rectangular a pond with 45 degree walls, and width is half the lengths. Max volume for 20*40 m pond and 3 m max. depth is 1752 m3 . When pond area is specified to be less than 6 x 12 m, calculation suppressed.

Variable wdepthi : initial depth
wdepthi = 1405 (int)
Comments: mm.

Variable wdepthm : max depth
wdepthm = Fixed parameter (real)
Comments: mm. If more water present, overflow occurs.

Submodel Farm_performance :

Compartment drywf : number of weeks the pond was dry
Initial value = 0. (real)
Rate of change = + dryweeks
Comments: number

Compartment dwricecum :
Initial value = 0. (real)
Rate of change = + hrice
Comments: Paddy, dry weight harvested, cumulative, per plot

Compartment dwvegcum : dry weight vegetables, economic product, cumulative
Initial value = 0. (real)
Rate of change = + hveg

Compartment feedfcum : cumulative value of all fish feed required
Initial value = 0. (real)
Rate of change = + feedf

Compartment fincome : farm income, cumulative.
Initial value = 0. (real)
Rate of change = + sales
Comments: million LAK.
Compartment fwfishcum : cumulative weight of fish harvested
Initial value = 0. (real)
Rate of change = + hfish
Compartment tdrainf : total deep drainage from farm: now only fields 3 and 4 and 2 (pond)
Initial value = 0. (real)
Rate of change = + drainf
Compartment tirrigf :
Initial value = 0. (real)
Rate of change = + irrigf
Compartment tprecipf : total precip on farm
Initial value = 0. (real)
Rate of change = + precipf
Comments: m3. evaluated: output farm corresponds with input from weather data
Compartment truninf :
Initial value = 0. (real)
Rate of change = + runinpond
Comments: total runoff from plots 1, 4 and 5 to pond
Compartment trunoffarm :
Initial value = 0. (real)
Rate of change = + trunoff
Compartment ttranspf : cumulative transpiration
Initial value = 0. (real)
Rate of change = + transpf
Comments: m3
Flow drainf :
drainf = (tl5fout*element([tareas],5)+ml4fout*element([tareas],4)+ml3fout*element([tareas],3))*10+netdrainage2 (real)
Where:
[tareas] = Value(s) of ../Area_manager/tareas
ml4fout = Value(s) of ../Plot_4_veg-soil/ml4fout
ml3fout = Value(s) of ../Plot_3_rice-soil/ml3fout
netdrainage2 = Value(s) of ../Plot_2_pond/netdrainage2
tl5fout = Value(s) of ../Plot_5_trees/tl5fout
Flow dryweeks :
dryweeks = pondlow (int)
Where:

pondlow = Value(s) of ../Plot_2_pond/pondlow
Flow feedf :
feedf = feedf (real)
Where:
feedf = Value(s) of ../Plot_2_fish/feedf
Flow hfish :
hfish = harvestwf (real)
Where:
harvestwf = Value(s) of ../Plot_2_fish/harvestwf
Flow hrice :
hrice = hvrice3*element([tareas],3) (real)
Where:
[tareas] = Value(s) of ../Area_manager/tareas
hvrice3 = Value(s) of ../Plot_3_rice-crop/hvrice3
Flow hveg :
hveg = hvveg4*element([tareas],4) (real)
Where:
hvveg4 = Value(s) of ../Plot_4_veg-crop/hvveg4
[tareas] = Value(s) of ../Area_manager/tareas
Flow irrigf : cumulative value irrigation farm
irrigf = (irriw3*element([tareas],3)+irriw4*element([tareas],4))*10 (real)
Where:
irriw4 = Value(s) of ../Plot_4_veg-soil/irriw4
irriw3 = Value(s) of ../Plot_3_rice-soil/irriw3
[tareas] = Value(s) of ../Area_manager/tareas
Comments: m3
Flow precipf : total precipitation on farm
precipf = precipwy*element([tareas],6)*10 (real)
Where:
[tareas] = Value(s) of ../Area_manager/tareas
precipwy = Value(s) of ../Weather_manager/precipwy
Flow runinpond : total water runoff from plots 1,4,5 into pond
runinpond =
(runoffw1*element([tareas],1)+runoffw4*element([tareas],4)+runoffw5*element([tareas],5))*10 (real)
Where:
runoffw4 = Value(s) of ../Plot_4_veg-soil/runoffw4
[tareas] = Value(s) of ../Area_manager/tareas
runoffw5 = Value(s) of ../Plot_5_trees/runoffw5
runoffw1 = Value(s) of ../Plot_1_house/runoffw1
Comments: m3
Flow sales :
sales = hveg*priceveg+hrice*pricerice+hfish*pricefish-feedf*pricefeed (real)
Where:
hveg = Value(s) of hveg
hrice = Value(s) of hrice
priceveg = Value(s) of priceveg
pricerice = Value(s) of pricerice
pricefish = Value(s) of pricefish
pricefeed = Value(s) of pricefeed
feedf = Value(s) of feedf
hfish = Value(s) of hfish
Flow transpf : cumulative value transpiration farm (vegetables and rice only)
transpf =(aatr3*element([tareas],3)+atr4*element([tareas],4))*10 (real)
Where:
[tareas] = Value(s) of ../Area_manager/tareas
atr4 = Value(s) of ../Plot_4_veg-soil/atr4
aatr3 = Value(s) of ../Plot_3_rice-crop/aatr3
Comments: m3

Flow trunoff : total water ruoff from farm (rice field and overflow)
trunoff = runoffw3*element([tareas],3)*10+overflow (real)
Where:
overflow = Value(s) of ../Plot_2_pond/overflow
runoffw3 = Value(s) of ../Plot_3_rice-soil/runoffw3
[tareas] = Value(s) of ../Area_manager/tareas
Comments: m3
Variable pricefeed : price fish feed (dry)
pricefeed = Fixed parameter (real)
Variable pricefish : price fish on market
pricefish = Fixed parameter (real)

Variable pricerice : price paddy
pricerice = Fixed parameter (real)

Comments: 1000 LAK kg-1.
Variable priceveg : price beans (nearly dry)
priceveg = Fixed parameter (real)
Comments: 1000 LAK kg-1.

Submodel Plot_3_rice-crop :
Compartment ds3 :
Initial value = 0. (real)
Rate of change = + dr3 - harvest3
Compartment eyield3 :
Initial value = 0. (real)
Rate of change = + hvrice3
Compartment residue3 :
Initial value = 0. (real)
Rate of change = + resid
Compartment tdw3 : crop dry weight
Initial value = 0. (real)
Rate of change = + ngr3 - resid - hvrice3
Flow dr3 :
dr3 = dr3t+ds3p (real)
Where:
ds3p = Value(s) of ds3p
dr3t = Value(s) of dr3t
Flow harvest3 :
harvest3 = harvestds (real)
Where:
harvestds = Value(s) of harvestds
Flow hvrice3 :
hvrice3 = hvbm3*feyield3 (real)
Where:
hvbm3 = Value(s) of hvbm3
feyield3 = Value(s) of feyield3
Flow ngr3 :
ngr3 = tdw3p+agr3 (real)
Where:
tdw3p = Value(s) of tdw3p
agr3 = Value(s) of agr3
Flow resid :
resid = hvbm3*(1-feyield3) (real)
Where:
hvbm3 = Value(s) of hvbm3
feyield3 = Value(s) of feyield3
Variable aatr3 : available water, inverse of stress
aatr3 = atr3 (real)
Where:
atr3 = Value(s) of ../Plot_3_rice-soil/atr3
Comments: fraction. (repeated for presentation purposes)

Variable agr3 :
agr3 = mgr3*(aatr3/(mtr3+0.0001)) (real)
Where:
mgr3 = Value(s) of mgr3
aatr3 = Value(s) of aatr3
mtr3 = Value(s) of mtr3
Variable dr3t :
dr3t = if ds3<1 then dr3tv else (if ds3<2 then dr3tr else 0) (real)
Where:
dr3tr = Value(s) of dr3tr
dr3tv = Value(s) of dr3tv
ds3 = Value(s) of ds3
Variable dr3tr : development rate rice, reproductive stage
dr3tr = dr3trc*etdr3 (real)
Where:
etdr3 = Value(s) of etdr3
dr3trc = Value(s) of dr3trc
Comments: fraction w-1. DS 1 to DS 2 in about 35 d or 5 weeks, so DR = 0.2 week-1

Variable dr3trc :
dr3trc = Fixed parameter (real)
Variable dr3tv : Development rate rice, vegetative stage.
dr3tv = if ds3==0 then 0 else dr3tvc*etdr3 (real)
Where:
ds3 = Value(s) of ds3
etdr3 = Value(s) of etdr3
dr3tvc = Value(s) of dr3tvc

Comments: fraction w-1. Approximated rate: development from DSi (0.1) to flowering (DS = 1) in 120 d = 14.3 weeks. So DRC = 0.052 per week. Variety characteristic.

Variable dr3tvc :
dr3tvc = Fixed parameter (real)
Variable ds3p :
ds3p = if replsw3+plantsw3>=1 then ds3i else 0 (real)
Where:
replsw3 = Value(s) of replsw3
ds3i = Value(s) of ../Farm_Manager/ds3i
plantsw3 = Value(s) of plsw3
Variable etdr3 :
etdr3 = avtemp/25 (real)
Where:
avtemp = Value(s) of ../Weather_manager/avtemp
Variable feyield3 :
feyield3 = Fixed parameter (real)
Variable harvestds :
harvestds = if hvsw3==1 then ds3 else 0 (real)
Where:
hvsw3 = Value(s) of hvsw3
ds3 = Value(s) of ds3
Variable hvbm3 :
hvbm3 = if harvestsw==1 then totalbiomass4 else 0 (real)
Where:
totalbiomass4 = Value(s) of tdw3
harvestsw = Value(s) of hvsw3
Variable hvsw3 :
hvsw3 = if ds3>2 then 1 else 0 (int)
Where:
ds3 = Value(s) of ds3
Variable mgr3 : growth rate
mgr3 = if ds3<2 then (if tdw3<1500 then mgre3 else mgrl3) else 0 (real)
Where:
tdw3 = Value(s) of tdw3
ds3 = Value(s) of ds3
mgre3 = Value(s) of mgre3
mgrl3 = Value(s) of mgrl3
Comments: rate of dry matter increase in dry weight, taken as standard 200 kg ha-1 d-1 and proportionally reduced for leaf area below 5 and for a realtive water content of the top layer below field capacity. Oversimpified.

Variable mgre3 : growth rate with management stress in exponentional phase
mgre3 = pgre3*(1+mngmtstress3)/2 (real)
Where:
mngmtstress3 = Value(s) of mngmtstress3
pgre3 = Value(s) of pgre3
Comments: kg ha-1 w-1. Effect suboptimal management in early stages less than in linear phase.
Variable mgrl3 :
mgrl3 = pgrl3*mngmtstress3 (real)
Where:
mngmtstress3 = Value(s) of mngmtstress3
pgrl3 = Value(s) of pgrl3
Variable mngmtstress3 : management stress
mngmtstress3 = fpoty3+0*poty3 (real)
Where:
fpoty3 = Value(s) of ../Farm_Manager/fpoty3
poty3 = Value(s) of ../Farm_Manager/poty3
Comments:Fraction. Results from suboptimal seed, fertilizer, crop protection.
Poty mentioned in equation to keep a link, but currently not functional
Variable mtr3 : transpiration rate
mtr3 = max(mgr3/20,0) (real)
Where:
mgr3 = Value(s) of mgr3
Comments: mm w-1. depends on actual growth rate.
Variable pgre3 :
pgre3 = tdw3*1 (real)
Where:
tdw3 = Value(s) of tdw3
Variable pgrl3 : potential growth rate linear phase
pgrl3 = 1400. (real)
Comments: kg ha-1 w-1.
Variable plsw3 :
plsw3 = if weeky==wfplrice then 1 else 0 (int)

Where:

wfplrice = Value(s) of ../Farm_Manager/wfplrice

weeky = Value(s) of ../Time_manager/weeky

Variable repldel3 : replant-delay

repldel3 = last(last(last(hvsw3))) (int)

Where:

hvsw3 = Value(s) of hvsw3

Comments:

if rice gets replanted for the second crop in a year, replanting occurs 3 weeks after harvest

Variable replsw3 :

replsw3 = if repldel3*replrice*wetseason==1 and ds3==0 then 1 else 0 (int)

Where:

replrice = Value(s) of ../Farm_Manager/replrice

repldel3 = Value(s) of repldel3

ds3 = Value(s) of ds3

wetseason = Value(s) of ../Time_manager/wetseason

Comments:

initiation planting of second rice 3 weeks after harvest first rice, if second planting is selected, the dry season has not yet started, and if there is no crop yet.

Variable tdw3p :

tdw3p = if replantingsw3+plantsw3>=1 then tdw3i else 0 (real)

Where:

replantingsw3 = Value(s) of replsw3

tdw3i = Value(s) of ../Farm_Manager/tdw3i

plantsw3 = Value(s) of plsw3

Submodel Plot_4_veg-soil :

Compartment wfluxes : sum fluxes

Initial value = 0. (real)

Rate of change = + sfluxes

Comments:

sum fluxes must be equal to sum of changes in states. Is used as check on water balance calculations.

Compartment wml4 : water contents middle layer

Initial value = wml4i (real)

Where:

wml4i = Value(s) of wml4i

Rate of change = + ml4fin - ml4foutp - ml4fout

Comments:

Typically 0.5 m in depth. No capilary rise.

Compartment wsl4 : wsubsoil: water in the soil below the rooting zone.

Initial value = wsl4i (real)

Where:

wsl4i = Value(s) of wsl4i

Rate of change = + ml4fout

Comments:

Layer typically unlimited in absorption capacity. No capillary rise.

Compartment wtl4 : water contents top layer

Initial value = wtl4i (real)

Where:

wtl4i = Value(s) of wtl4i

Rate of change = + tl4fin - ml4fin

Comments:

cm3 cm-2 toplayer, full dpeth. Toplayer typcially 0.3 m depth.

For check of calculations: see wtl3

Flow ml4fin : net flux into second soil layer
ml4fin = max((tl4rwc-2*tl4wp)/(tl4fcm-2*tl4wp),0)*wtl4*0.25 (real)
Where:
wtl4 = Value(s) of wtl4
tl4fcm = Value(s) of tl4fcm
tl4wp = Value(s) of tl4wp
tl4rwc = Value(s) of tl4rwc

Comments:
fraction of water in toplayer per week. Constant 0.1 is estimate.

Flow ml4fout : flux from middle into deep soil layer.
ml4fout = max((ml4rwc-2*ml4wp)/(ml4fc-2*ml4wp),0)*wml4*0.050000000000000003 (real)
Where:
wml4 = Value(s) of wml4
ml4wp = Value(s) of ml4wp
ml4fc = Value(s) of ml4fc
ml4rwc = Value(s) of ml4rwc

Comments:
fraction of water in middle layer per week. Constant 0.05 is estimate. No capilary rise assumed.

Flow ml4foutp :
ml4foutp = atrml4 (real)
Where:
atrml4 = Value(s) of atrml4

Flow sfluxes :
sfluxes = precipwy+irriw4-evapw4-atr4-runoffw4 (real)
Where:
runoffw4 = Value(s) of runoffw4
irriw4 = Value(s) of irriw4
precipwy = Value(s) of ../Weather_manager/precipwy
atr4 = Value(s) of atr4
evapw4 = Value(s) of evapw4

Flow tl4fin : net flux across top surface
tl4fin = precipwy+irriw4-evapw4-atrtl4-runoffw4 (real)
Where:
precipwy = Value(s) of ../Weather_manager/precipwy
irriw4 = Value(s) of irriw4
runoffw4 = Value(s) of runoffw4
evapw4 = Value(s) of evapw4
atrtl4 = Value(s) of atrtl4

Comments:
mm w-1. Sum of inputs and losses.

Variable atr4 :
atr4 = atrtl4+atrml4 (real)
Where:
atrml4 = Value(s) of atrml4
atrtl4 = Value(s) of atrtl4

Variable atrml4 :
atrml4 = mtrml4*rwcml4f (real)
Where:
mtrml4 = Value(s) of mtrml4
rwcml4f = Value(s) of rwcml4f

Variable atrtl4 :
atrtl4 = mtrtl4*rwctl4f (real)
Where:
mtrtl4 = Value(s) of mtrtl4
rwctl4f = Value(s) of rwctl4f

Variable dml4 : depth middle layer

dml4 = 600. (real)

Variable dtl4 : depth top layer
dtl4 = 400 (real)

Comments:
mm.

Variable evapw4 : soil evaporation rate
evapw4 = if tl4rwc>0.050000000000000003 then max(avpetw*(rwctl4f-0.14999999999999999)*(rwctl4f-0.14999999999999999)-mtr4*0.5,0) else 0 (real)
Where:
tl4rwc = Value(s) of tl4rwc
rwctl4f = Value(s) of rwctl4f
avpetw = Value(s) of ../Weather_manager/avpetw
mtr4 = Value(s) of ../Plot_4_veg-crop/mtr4

Comments:
mm w-1. soil evaporation rate related to standardized relative water contents in the top layer, quadratically. An approximation. Value 0.15 (anticipates drying during the week (0.85*0.85=0.7 so reduction 0.3 of about 60 mm maximally stored = 18 mm less due to surface drying, when avpet is 30-40: sounds fair). Half of potential transpiration is deducted to reflect that shading by plants will reduce soil evaporation.

Variable infiltmax4 : max infiltration in one week
infiltmax4 = max(tl4fc-tl4rwc,0)*dlt4+surfstor (real)
Where:
dlt4 = Value(s) of dtl4
tl4rwc = Value(s) of tl4rwc
tl4fc = Value(s) of tl4fcm
surfstor = Value(s) of surfstor4

Comments:
mm. Assumed: surfstor plus fill up soil to field capacity. Need detailed reflection or other model.

Variable irriw4 : quantity water supplied for irrigation
irriw4 = if pondlow==0 and firrig4==1 then max(avpetw-0.5*precipwy,0) else 0 (real)
Where:
pondlow = Value(s) of ../Plot_2_pond/pondlow
avpetw = Value(s) of ../Weather_manager/avpetw
precipwy = Value(s) of ../Weather_manager/precipwy
firrig4 = Value(s) of ../Farm_Manager/firrig4

Comments:
mm w-1. water provided to toplayer from reservoir fills topsoil to field capacity. If the management has set 'irrigation' to 'yes' tand there is still sufficient in the pond then water is applied at least once a week to fill up the top soil to field capacity plus 10 mm; the latter is to compensate for rapid drying in surface layer.
Note: if drip irrigation applied,, evaporation should be less and the less than 10 mm would be needed.

Variable ml4fc : middle layer 4 field capacity
ml4fc = Fixed parameter (real)

Comments:
cm3 cm-3

Variable ml4rwc : relative water content middel layer
ml4rwc = min(max(wml4/dml4,0.),1.) (real)
Where:
wml4 = Value(s) of wml4
dml4 = Value(s) of dml4

Comments:
cm3 cm-3

Variable ml4rwci : middle layer plot 4 initial relative water contents
ml4rwci = 0.1 (real)

Variable ml4wp : middle layer 4 wilting point
ml4wp = Fixed parameter (real)

Comments:
cm3 cm-3

Variable mtrml4 :
mtrml4 = mtr4*0.25 (real)
Where:
mtr4 = Value(s) of ../Plot_4_veg-crop/mtr4

Variable mtrtl4 : transpiration water taken from top soil layer
mtrtl4 = mtranspw4*0.75 (real)
Where:
mtranspw4 = Value(s) of ../Plot_4_veg-crop/mtr4

Comments:
mm. Constant 0,.7 reflects that most roots are in the topsoil.

Variable runoffw4 : runoff from plot
runoffw4 = if precipwy>infiltmax then precipwy-infiltmax else 0 (real)
Where:
infiltmax = Value(s) of infiltmax4
precipwy = Value(s) of ../Weather_manager/precipwy

Comments:
mm

Variable rwcml4f : effect of relative water contents on water uptake
rwcml4f = min(max((ml4rwc-ml4wp)/(ml4fc-ml4wp),0),1) (real)
Where:
ml4fc = Value(s) of ml4fc
ml4wp = Value(s) of ml4wp
ml4rwc = Value(s) of ml4rwc

Comments:
fraction

Variable rwctl4f : relative water content as fraction between 1 and 0
rwctl4f = max(min((tl4rwc-tl4wp)/(tl4fcm-tl4wp),1.),0.) (real)
Where:
tl4fcm = Value(s) of tl4fcm
tl4wp = Value(s) of tl4wp
tl4rwc = Value(s) of tl4rwc

Comments:
fraction

Variable surfstor4 : surface storage of water
surfstor4 = Fixed parameter (real)

Comments:
mm. estimate.

Variable tl4fc : field capacity top layer 4
tl4fc = Fixed parameter (real)

Comments:
cm3 cm-3.

Variable tl4fcm : top layer 4 field capacity, possibly modified
tl4fcm = tl4fc+0.059999999999999998*benton (real)
Where:
tl4fc = Value(s) of tl4fc
benton = Value(s) of ../Farm_Manager/benton

Variable tl4rwc : relative water content top soil
tl4rwc = min(max(wtl4/dtl4,0),1) (real)
Where:
dtl4 = Value(s) of dtl4
wtl4 = Value(s) of wtl4

Comments:
cm3 cm-3.

Variable tl4rwci : relative water contents top layer, initial value
tl4rwci = 0.15 (real)

Comments:
cm3 cm-3

Variable tl4wp : top layer 4 wilting point
tl4wp = Fixed parameter (real)

Comments: cm3 cm-3.

Variable wdiff4 : Check on water balance calculations.
wdiff4 = wstates-wfluxes (real)
Where:
wstates = Value(s) of wstates
wfluxes = Value(s) of wfluxes

Comments: Value remained zero (correct) in version 5. Also in version 82. Also in version 1.96 and 2.18

Variable wdiff4s :
wdiff4s = if abs(wdiff4)>1.e-10 then stop(4) else 0 (int)
Where:
wdiff4 = Value(s) of wdiff4
Variable wml4i :
wml4i = ml4rwci*dml4 (real)
Where:
ml4rwci = Value(s) of ml4rwci
dml4 = Value(s) of dml4
Variable wsl4i :
wsl4i = 100. (real)
Variable wstates : sum of changes in states. Used for checking water balance calculations.
wstates = wtl4-wtl4i+(wml4-wml4i)+(wsl4-wsl4i) (real)
Where:
wsl4 = Value(s) of wsl4
wml4 = Value(s) of wml4
wtl4 = Value(s) of wtl4
wsl4i = Value(s) of wsl4i
wml4i = Value(s) of wml4i
wtl4i = Value(s) of wtl4i
Comments: cm3 cm-2 surface.

Variable wtl4i :
wtl4i = tl4rwci*dtl4 (real)
Where:
tl4rwci = Value(s) of tl4rwci
dtl4 = Value(s) of dtl4

Submodel Time_manager :
Variable weekno :
weekno = if int(time(1))+1<469 then int(time(1))+1 else int(time(1))+1-468 (int)
Comments: Cumulative number of weeks since simulation started. If the number goes beyond 468 (9 years in weeks) it returns to the first year.

Variable weeky : decade of the specific year
weeky = max(1,weekno-(year-1)*52) (real)
Where:
weekno = Value(s) of weekno
year = Value(s) of year
Comments: time in decades
Variable wetseason :
wetseason = if weeky<18 or weeky>44 then 1 else 0 (int)
Where:
weeky = Value(s) of weeky
Variable year : Number of the decade, within a year.
year = int((weekno-1)/52)+1. (real)
Where:
weekno = Value(s) of weekno
Comments: Runs up to 36, and then returns to 1. Last half decade gets neglected.

Table A6. 2. Potential yield of vegetable crops by Frits et al., 2005.

Species	Variety	Potential economic yield (1000 $kg.ha^{-1}$)	Comment
Tomato		25	Sold fresh (20% d.m.)
Yard beans		5	Dry pods with beans (80% d.m.)
Cabbages		8	Vegetative heads (50% d.m.)
Rice	Dog hom mali	6	indigenous
Rice	..	8	modern

Table A6.3. Crop water requirement for vegetable crops by Frits et al., 2005.

Name	Crop duration (d)	Duration irrigation	ET (mm d^{-1})*	ET/E	Water requirement (mm d^{-1}) **
Rice	100	86	5.4	1.3	8.5
Jasmin rice	100	86	5.4	1.14	7.6
Basmati rice	100	86	5.4	1.29	8.5
Wheat rice	100	86	5.4	0.71	3.8
maize	100	86	5.4	0.80	4.3
sweet corn	75	68	5.4	0.79	4.3
millet rice	110	96	5.4	0.79	4.3
soybean	100	86	5.4	0.85	4.6
peanut	105	91	5.4	0.80	4.3
mungbean	70	63	5.4	0.67	3.6
sesame	90	76	5.4	0.76	4.1
tobacco	90	83	5.4	0.94	5.1
sunflower	110	96	5.4	0.80	4.3
water melon	85	78	5.4	1.05	5.7
cotton	160	130	5.4	0.71	3.8
sugarcane	300	290	5.4	0.71	3.8
castor oil	230	200	5.4	0.73	3.9

Table A6.4. Target yield of vegetable crops for the simulation by Frits et al., 2005

Species and variety	Characteristics					
	Target yield: 40-80% of x kg ha^{-1} (dry weight)	Planting to flowering (w)	Flowering to maturity (w)	Sensitivity to water stress	Harvest Index (fraction)	Fresh weight over dry weight
Yard beans	6000			Moderate		
Tomato	6000	7	7	High	0.30	6
Rice (dog hom mali)	4000	14	5	High	0.40	1.1

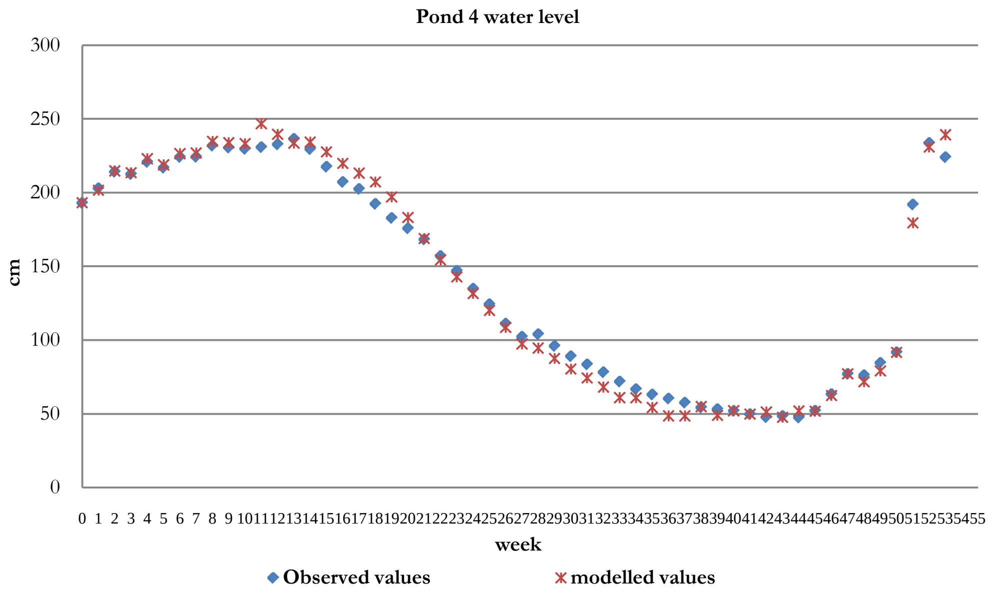
Table A6. 5. Water holding characteristics for some typical soils

(Source: Penning de Vries et al, 1989, pg 157)

	Soil water content ($cm^3\ cm^{-3}$) when			
Soil type	air dry	wilting point (WP)	field capacity (FC)	saturation (ST)
Course sand	0.005	0.01	0.06	0.40
Fine sand	0.005	0.03	0.21	0.36
Light textured sandy soil*, plain	n.a.	0.03	0.17	0.30
Same, with bentonite*	n.a.	0.05	0.23	0.39
Loam	0.01**	0.11	0.36	0.50
Light clay	0.05**	0.24	0.38	0.45
Heavy clay	0.18	0.36	0.49	0.54

Percolation of water downwards is simulated as a fraction of the water in the layer: all water above field capacity within one week, plus a quarter of the water between field capacity and 2x wilting point within in a week. The upper layer of the vegetable plot is light textured sand, the middle layer fine sand; for both top and middle layer is the wilting point artificially elevated to 6% to avoid instabilities in the water balance computations.

Figure A6.4. Simulations results of Simpleponds_submodels for estimation of drainage



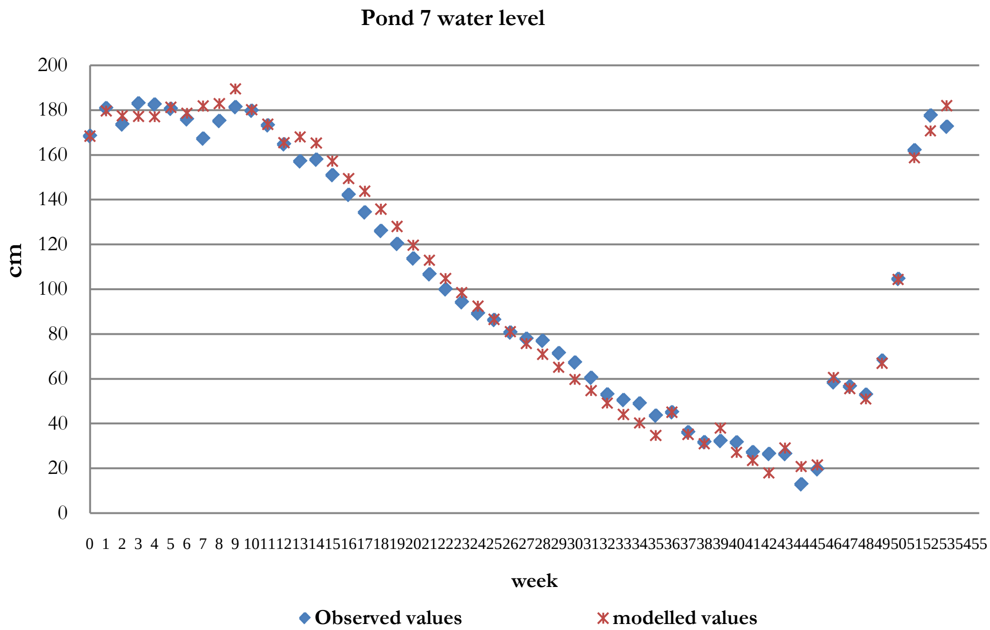


Table A6.6. Parameter values for model simulation with Lao farms

When a range is given ('a-b'), a slider is present to choose any value between the extremes of the range.

Table A6.6a: Parameter value for management

Module	Parameter description	Name in model	Unit	Style A Self-sufficiency and default (Pond4)	Style B Intensive production
Farm manager	Planting date vegetable	wfplveg	week no	4	2
	Development stage vegetables (purchased) at planting	ds4i	fraction	0.2	0.2
	Planting (dry, shoots) weight vegetables	tdw4i	kg ha^{-1}	150	300
	Potential economic yield vegetables (dry weight)	poty4	kg ha^{-1}	3000	4200
	Target yield vegetable (dry weight)	tary4	kg ha^{-1}	1600	3200
	Replant delay vegetables	repldveg	1 (2 weeks) or 2 (4 weeks)	2	1
	Irrigation vegetable crops	firrig4	yes (1) or no (0)	1	1
	Fraction evaporation due to irrigation method	feim4	fraction	1.0	0.5
	Planting date main rice crop	wfplrice	week no	28	26
	Development stage rice at transplanting	ds3i	fraction	0.15	0.15
	Planting weight rice (dry)	tdw3i	kg ha^{-1}	70	60
	Potential yield paddy (dry)	poty3	kg ha^{-1}	3500	6000
	Target yield paddy (dry)	tary3	kg ha^{-1}	2000	3500
	Replanting for 2nd rice	replrice	either 0 (no) or 1	0	1
	Fraction irrigation on lowland rice	firrig3	fraction of full (0-1)	0	0
	Choice of upland or bunded lowland fields	choiceulr	(1) or (0 = lowland)	0	0
	Bentonite (clay) application	benton	fraction of full (0 – 1)	0	0
	Week of stocking single fish crop	wstfish	week no	30	30
	Week of harvesting fish	whvfish	week no	4	50
	Feed level fish	feedlev	fraction of ad lib	0.5	1
Produce prices	Price of rice (paddy, 5% moisture)	pricerice	THLAK kg^{-1}	1.5	2
	Price of vegetables (50% moisture; styles produce different products)	priceveg	THLAK kg^{-1}	15	20
	Price of fish	pricefish	THLAK kg^{-1} (live)	20	20
	Price of fish feed	pricefeed	LAK kg^{-1} (dry)	5	5

Table A6.6b. Parameter values for crops (vegetable, rice and fish)

Module	Parameter description	Name in model	Unit	Style A (Pond4)	Style B
Crop, vegetable	Fraction economic yield of total biomass	feyield4	kg kg^{-1}	0.4	0.5
	Development rate constant in vegetative phase	dr4tvc	w^{-1}	0.12	0.12
	Development rate constant in reproductive phase	dr4trc	w^{-1}	0.25	0.25
Crop, rice	Fraction economic yield	feyield3	kg kg^{-1}	0.4	0.45
	Development rate constant in vegetative phase	dr3tvc	w^{-1}	0.052	0.06
	Development rate constant in reproductive phase	dr3trc	w^{-1}	0.2	0.2
Fish in pond	Initial stocking weight	iwfishs	kg (live) ha^{-1}	100	200

TableA6.6c: Parameter values for soil (plot 3, 4), and the house, and the pond

Module	Parameter description	Name in model	Unit	Style A (Default Pond4)	Style B
Area manager	House yard	area1	ha	0.1	0.1
	Reservoir surface area (when full)	area2	ha	(0-0.35) 0.09	(0-0.55) 0.09
	Vegetable plot	area4	ha	0.35 -area2	0.55 -area2
	Rice field	area3	ha	0.55	0.35
	Tree plot	area5	ha	0.001	0.001
	Total area	areat	ha	1	1
Plot-1-house	Rainwater storage on surface	surfstor1	mm	5	3
	Roof area	roofarea	m^2	100	100
	Domestic water requirement	hhreq	l w^{-1}	560	560
Plot 2-reservoir/pond	Maximum water depth	wdepthm	mm	3000	3000
	Drainage	dr2c	fraction w^{-1}	0.02	0.02
Plot-3-rice field	Water storage on surface	surfstor3	mm	200 (bounded lowland)	200 (bounded lowland)
Plot-4-vegetable crops	Rainwater storage on surface	surfstor4	mm	25	25
Plot-5-trees	Rainwater storage on surface	surfstor5	mm	0	0
	Runoff fraction	frunoff5	fraction	0.001	0.001

TableA6.d. Parameter values for soil

	Soil water content (cm^3 cm^{-3}) when			
Soil type	air dry	wilting point (WP)	field capacity (FC)	saturation (ST)
Light sandy soil, plain	n.a.	0.03	0.17	0.30
Light clay	0.05	0.24	0.38	0.45

Figure A6.5. Description of Main submodels for running the model

Module Plot_2_pond.

Area between 0 and 35% of the farm, with 0.09% as default value. The shape is a rectangular with length is twice width, and maximum depth is 3 m.

A significant amount of water from the reservoir gets lost through evaporation from the surface; this process stops when the water depth is less than 0.5 m and much of the bottom is actually dry. If there is demand for irrigation water, this is fully met when the pond depth exceeds 1 m; none is provided at lower levels. Water can also leave the pond lost through seepage, the rate of which is obtained from the calibration by the Simpleponds_submodels simulation and for which we estimate values of about 0.02% of the pond volume per week. In reality it will depend on soil type and underlying soil.

Modules Plot_fish.

We use the default value of the Conversion efficiency feed into fish (live) proposed by the BN model, is efficient: 0.5 kg kg^{-1}. Age at stocking: 4 weeks (a constant). Aging rate fish set at 1w w^{-1} (i.e.: no effect temperature yet). This depends on type of fish

Modules Plot3-Rice and Plot4_vegetables.

A 'target' yield and 'potential' yield of rice and beans are the main parameters to be specified (see Appendix, Table A6.2 and Table A6.4).

Details for rice. The variety for which default parameters will be chosen in rice variety 'Phonegnam', a good quality rice that withstands local weather conditions well. The average rice yield in Champasack is 1,973 kg gain per ha, but we use the national average of 2000 kg grain ha-1 (paddy, dry weight). The farmer grows always one rice crop late in the rainy season (July-December) and has the option of growing a second rice crop if supplementary irrigation possible. Harvesting is in week, planting in week.

Potential yield. These are yields obtained if soils and weather are excellent, good quality seed is chosen and crop management perfects. Such values are obtained in good experimental conditions. For our model, we use the potential yield provided by Dr. Frits, 2005 (see Appendix Table A6.4).

Details for vegetables. The parameters chosen are for a crop like field beans or yard beans as suggested by Dr. Frits in the model. The harvest index for vegetables is 0.7; residues have no commercial value. Different vegetable crops that can be specified in the model with their key constants are shown in annexe 2 and 4.

As recommended by Frits et al., 2005, Crop death due to drought or pest invasion is not yet included in the model. This model is not designed to deal in a dynamic manner with fertilizers. The approach is followed that the farmer chooses target yield and it is assumed that he/she will adjust the fertilizer applications accordingly. The target weight for a crop can be chosen between 30% and 90% of the potential yield.

Modules Plot4_soil_veg and Plot3_soil_rice.

The soils are basically unsaturated soils in which water is drained from top to lower layer. For the rice and the vegetable plot, 3 layers are considered: the top, middle and ground water layer. Water is supplied by rain and irrigation, and leaves by evaporation and transpiration. Surface runoff occurs when more water arrives than can infiltrate. These parameters of soil properties can be justified to run the model (see Appendix, TableA6.5).

Module Area_ manager

This module deals with the choice of the size of the pond (and consequently that of the vegetables plot). This is a key one for farm design and major investment study.

The 'area manager' is a simple function that keeps the total equivalent to 1 ha (or another value). Plot 4 (vegetables) is the one that becomes smaller when the pond area expands (Figure 2), which can be achieved by adjustment of a 'slider'. In our work, a default value is 0-0.35 ha or 0-35% for sensitivity analysis.

Module Farm_manager

This submodel deals with all tactical management decisions: which crops to grow, when to plant and harvest, how to irrigate. The farmer actively manages crops on the plots 3 (vegetables) and 4 (rice). Management options include: setting the target yield (which implies in reality: choosing and executing the right variety, fertilizer strategy), planting dates, irrigation method. A key choice is that of species and target yield.

A weakness here is that the same level of water stress applies for a full week, where in reality this level fluctuates rapidly. Frits et al,. 2005 mentioned that weeds are not considered: their area coverage and water consumption are assumed to be small. While this may be realistic from the point of view of a water balance, the implications for labor requirements are not counted.

For soil management, we deal only with irrigation. For irrigation methods, we choose either 'full irrigation' or none at all. Full irrigation for the vegetable and the irrigation water is drawn from the pond; when the level in the pond falls below 1,000 mm, irrigation is halted. There is no management practice specified to alter soil surface characteristics (such as surface storage or evaporation). This minimum of 1,000 mm is chosen due to fish culture. From the survey, all pond farmers raise fish and keep the minimum of water level for fish culture. There is no irrigation for rice in our simulation.

Model produce prices

Prices. Income from vegetables and from rice is set equal to the yield multiplied by the price per kilo dry weight, estimated at 15 THLAK (thousand LAK) kg-1 for beans and 1.5 THLAK (thousand LAK) kg-1 for paddy rice (in 2010-2011 market prices according to the survey. Fish brings 20 THLAK (thousand LAK) kg^{-1} live weights on the local markets (survey, 2012 on market prices of pond fish for 2010, 2011 and 2012).

Module weather manager

The key variables for the water balances are rainfall and potential evapotranspiration (ET0), while temperature is also important for crop growth. The climatic data is obtained from the Provincial Meteorological Offices for 2004-2012. ET0 is the value that refers to the evaporation of a short grass surface that is not short of water. It is either measured in a Class A pan or obtained by calculation according to the Penman-Monteith equation (according to FAO, 2004, website). The climatic situations are described in section 3.2 (see above).

The default data set is a series for Champasack of 9 years (2004-2012) that are characterized by rainfall, temperature and evapotranspiration. Average annual rainfall is 1,969 mm. For temperature only a single time series is used, with week values equal to the average daily mean value of these years. For rainfall and evapotranspiration, we use the weekly values for the simulation as recommended by the model. From figure 6.4 and 6.5, Savannakheth is drier than Champasack province.

Module time_manager

Time is kept by the model during a simulation process in units that are interpreted here as weeks. Time = 0 gives weekno=1. Once the number of weeks goes over 52, another 'year' is added and the count restarts from 1.

In our simulation of pond water level, a set of climatic data starts from 15 July of year 1 and ends up at 15 July of another year. This simulation helps to compare with the actual data from the station 4 (see Appendix, Figure A6.4).

For all scenario analysis, the weather variable is from 1 January to 31 December of each year. So, the 'wet season' is a term used to identify planting times and is a reflection of average weather rather than current. It is defined as the period between the 27th week until the 2nd week of each year.

Module farm_performance

The BN model suggests that the performance of the farm is measured in a limited set of indictors. Two illustrative indicators are the level of water in the reservoir, reflecting the balance of rain and runoff on the one hand and of irrigation and drainage on the other, and the biomass of vegetable and rice crops.

Module Annual_Results

The module 'annual results' derives annual values from the cumulative ones in Farm Performance. Data per year are computed for the period 1 July – 30 June of the following year, that is: from the start of the major growing season until the next.