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Multiple Sources of Water for Multiple Purposes in Northeast Thailand

Frits Penning de Vries and Sawaeng Ruaysoongnern

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and
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Penning de Vries, F.; Ruaysoongnern, S. 2010. *Multiple sources of water for multiple purposes in Northeast Thailand*. Colombo, Sri Lanka: International Water Management Institute. 37p. (IWMI Working Paper 137). doi:10.3910/2010.208

/ water use / multiple use / water supply / rural development / farm ponds / surveys / simulation models / Thailand /

ISSN 2012-5763

ISBN 978-92-9090-725-1

Please direct inquiries and comments to: *iwmi@cgiar.org*

A free copy of this publication can be downloaded at www.iwmi.org/Publications/Working_Papers/index.aspx

Acknowledgements

We thank the leaders and members of the Farmer Wisdom Network in Northeast Thailand for inspiration and collegial cooperation. We also thank Dr. Prasnee Tipraqsa, University of Hohenheim, for translations of various documents written in Thai.

Project

This paper presents findings from the work carried out as part of the Multiple-Use Water Services (MUS) project.

The CGIAR Challenge Program on Water and Food (CPWF) provided financial and technical support for the MUS project, under their project entitled 'Models for Implementing Multiple-use Water Supply Systems for Enhanced Land and Water Productivity, Rural Livelihoods and Gender Equity (MUS)'.

Collaborators

The following organizations collaborated in the research conducted for this report.

International Water Management Institute

Khon Kaen University, Khon Kaen, Thailand.

Donors

Funding for the research carried out in this report was provided by the following organizations, among others, through the CGIAR Challenge Program on Water and Food (CPWF).

UK Department for International Development (DFID)

International Fund for Agricultural Development

European Commission

The views expressed herein do not necessarily reflect the official opinion of DFID, IFAD and the European Commission.

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Summary

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. A recent movement to construct ponds on farms increased the capacity to store water in a significant manner. It was observed that on homesteads with ponds, pond water was used for many purposes: mainly to irrigate crops and fruit trees, and for livestock or fish, and even in homes when water from cleaner sources was unavailable. With more diverse and productive activities, homesteads with ponds produce nearly all food they need, and probably enjoy a slightly higher income than those without ponds. Pond water is used even when ample piped water is available.

The optimal size of a farm pond depends on biophysical factors (weather, soil, crops) and even more on socioeconomic factors (prices, availability of labor, off-farm income). The aspirations of the household, expressed in goals and limitations, are also very important. It is argued that a simulation approach is required to help produce guidelines for construction of ponds on individual homesteads. The model BoNam outlined here comprises an integrated water balance of the plots on a homestead and the pond, and can simulate the consequences of various scenarios. Some results are presented in this paper.

A climate similar to that of Northeast Thailand is found in many tropical countries. Approaches to improve smallholder farming with ponds using information from this paper may be useful in other countries with pronounced wet and dry seasons.

IMPROVING THE WATER SUPPLY ON HOMESTEADS

Although there is usually ample water in the rainy season in Northeast Thailand there is a shortage in the dry season. Such shortages limit rural development. There are also other biophysical factors that limit rural development, such as low soil fertility, and socioeconomic factors, such as monopolies on farm inputs and produce. Although there is a general perception that drought is a key limitation (Srisuk et al. 2001), this paper focuses on 'water' since the relative importance of this limitation for rural development can be diminished. To improve the water situation on homestead farms it is necessary to know what sources of water are already available and how these are used and to understand which additional sources could be developed and which efficient and profitable uses could be promoted.

This paper will concentrate on *the hypothesis that the resource 'water' can be developed on many homesteads by construction of farm ponds; this can support more sustainable production systems, higher productivity and income, and greater well-being of the farm families.* There are four approaches to address this hypothesis: (i) ask the people concerned for their views, (ii) ask the national and international experts for their views, (iii) carry out and interpret a field survey, and (iv) use a model to simulate scenarios of water supply and water use. For this study we made use of all four: by listening to the Farmer Wisdom Network, by participating in an international project on multiple uses of water (Van Koppen et al. 2009), by carrying out a survey and by initiating a simulation model. It will be demonstrated that homesteads can benefit from more water and also that there is a gap in practical knowledge on how to achieve that with farm ponds.

The next chapter sketches the dynamic biophysical and socioeconomic background to water use and rural development in Northeast Thailand. It contains also the views of farmers, formulated through the Farmer Wisdom Network, on how more water and integrated farm management can bring progress, and views of experts on multiple uses of water.

The hypothesis is scrutinized in two chapters. In the first, results are presented of a survey to quantify the water situation for homesteads. Water from different sources (rainwater, public streams, homestead wells) is used for different purposes (domestic, livestock, supplementary irrigation), and an overview of what and how much is used for which purpose will make it easier to target interventions. The results of the survey are analyzed with respect to their potential to improve the water supply on homesteads with an emphasis on farm ponds and piped water. Farmers have identified ponds as an important feature of their farms and are testing different ways of using them. NGOs and local governments have started to supply piped water to homes as a means to improve the water situation. This community-level action is already widespread.

In the second chapter, the optimal size of ponds on homesteads is researched. There is insufficient experience with pond construction and the experimental approach is slow to produce guidelines for farmers or contractors on size, location and irrigation schedules. A modelling approach is called for. The first steps are presented in developing a new model to advise on optimal size of a pond in relation to the preferred farming style, location, weather and specific innovations.

THE CONTEXT OF FARM PONDS IN NORTHEAST THAILAND

Geography, Population, Development

Thailand is divided into five parts: North, Northeast, Central, East and South (Figure 1). This study focuses on the northeast. Its northern and eastern borders are formed by the Mekong River. All of its 19 provinces, 550 districts and some 29,000 villages are in the Mekong Basin. This region

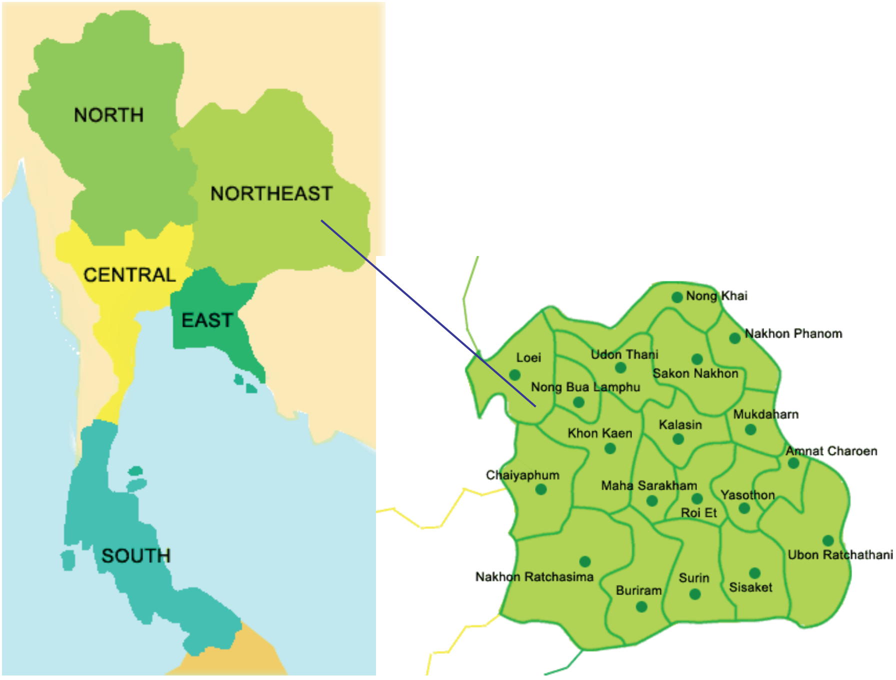

FIGURE 1. The five regions of Thailand and the 19 provinces in the Northeast. *Source*: Tipraqsa 2005.

consists of three subbasins of west-east flowing rivers that drain into the Mekong: the Kong, the Chi and the Mun. Thailand has three seasons: a hot and dry season (average temperature and relative humidity of 34 °C and 75%, respectively), a rainy season (29 °C, 87%) and a cool dry season (32 °C, 20%). The northeast is slightly cooler and drier than the other parts of the country. The potential evapotranspiration reaches almost 2,000 mm.yr^{-1} and rainfall ranges from 1,300 in the southwest to 1,900 mm.yr^{-1} in the north. Intensive rain occurs in 4–5 months but it has an erratic distribution that often causes local floods and droughts within the same year.

People cultivate rain-fed crops on most of the arable land. Rice paddies are common in the lowland areas. The rice crops, 1–2 crops per year, yield 2.7–3.7 t.ha^{-1}. Farms also annually produce 4–5 crops of vegetables, including bean, cabbage and onion that are often sold to middlemen. Some farmers produce and sell fish while others grow trees for convenience wood (e.g., teak, eucalyptus) for sale when cash is needed. In 2005, arable land accounted for 27% of the total area of which 7% was planted to permanent crops. Deforestation has occurred throughout the country. It has been severe in the northeast and has degraded the soil by the export of nutrients and by erosion (Ruaysoongnern 2001). Some farms pump water from wells but deep groundwater is often saline (Srisuk et al. 2001).

Thailand's population of 66 million has a low annual growth rate of 0.68%. Education is compulsory up to the age of 16 and the literacy rate is high. These conditions permit rapid development and economic growth.

Private titles to land for farmers are most common. Farm sizes in Northeast Thailand are generally modest due to the growing rural population and the custom of subdivision of the land among the owners' children. Land owned by a family consists of a garden plus fields around the house (homestead) and some fields with upland crops and/or rice paddy in land adjacent to the homestead or at some distance from it. There is little large-scale farming in the region. Statistics indicate that the average farm size is 2.5 hectares (ha), or about 0.5 ha per person: a comfortable size compared with that in many other Asian countries, but productivity per unit of land is modest. Many persons between 18 and 40 years of age have left their families and the rural areas for better education and employment in the cities. As a result, farmers are increasingly planting tree crops (fruit, rubber, convenience wood and energy), and cultivation is becoming less intensive.

Thailand is a lower middle-income industrial developing nation and is heavily export-dependent. Its free-enterprise economy has recovered from the financial crisis of 1997. The number of poor people declined by 2 million between 2002 and 2005 and poverty stands now at 10% of the population. Northeast Thailand is the poorest of the five regions. Hunger has been widespread in the past but is now largely eliminated. Agriculture, forestry and fishing contribute less than 10% to GDP but still employ 39% of the workforce. The distribution of income is relatively equitable (the Gini coefficient equals 42). The rapid economic growth before 1997, and again since 2002, has brought a widespread shift from rural towards urban lifestyles. There are still large differences in income, employment and well-being between cities and rural areas, but the latter are catching up fast.

Water Management and Development Problems

Economic development in Northeast Thailand in the 1960s and 1970s was mainly by exploitation and extraction of natural resources, in particular of soil fertility. People relied on ponds for drinking water and on natural water bodies for other domestic and agricultural purposes. In the 1980s, this was intensified by modernization and industrial processing. Even in the 1990s when value adding technologies were introduced farming was still based on extraction of natural resources. The 7^{th} National Development Plan (NDP) (1992–1996) and the 8^{th} NDP (1997–2001) promoted agricultural exports. Inevitably, degradation of land and water resources became widespread (Patanothai 1998; Bridges et al. 2001). An incoherent set of 13 laws regulates water management in the country which does not help improve this situation.

The decline in the quality of farmland and water resources in the northeast has caused a decline in productivity and subsequently in farm income and an increase in poverty. It has forced farmers to find off-farm employment, predominantly in cities. This emigration has created social problems associated with increased consumerism, reduced cohesion in families and communities, and a larger dependence on loans (Ruaysoongnern and Penning de Vries 2005).

Since the early and mid-1990s farmer organizations have promoted the adjustment of farming practices to reverse degradation (Ruaysoongnern and Suphanchaimart 2001). This adjustment often included the construction of a farm pond, crop diversification and recycling. The government supported the local communities with small-scale irrigation systems and some types of farm ponds. Yet, these were hardly used due to high cost and inappropriate design and placement on farms. In 2000, the Government of Thailand approved a program to provide revolving funds to villages for development initiatives (MOAC 2001) and in 2004 a program to dig 450,000 simple farm ponds. For the latter program baht (THB) 2,160 million ($65 million[1]) was available in the period 2005–2007, and provincial programs for new types of farm ponds were issued as more water was needed for rural development.

The provision of piped water to households is a recent development, and many villages have already been reached (2008) by programs. Primarily to promote rural health, an NGO, the Population and Community Development Association (PDA) has implemented piped water systems in over

[1] In this paper, $ means US$.

120 villages (18,000 households), provided loans to prefinance them and given training in financial management; micro-credit schemes effectively complement the formal bank facilities (D'Agnes 2000; Bepler 2002; PDA 2008). The government has begun to promote the expansion of community water supply systems as well. The water is extracted from reservoirs or large and deep bore-wells (10–50 m depth) and managed by local authorities as a community or government service (district level). Users pay a fee for the water they use. Nowadays, all villages and many of the farms near villages have electricity which allows them to use pumps to extract water from wells, ponds or canals.

VIEWS OF FARMERS AND EXPERTS ON WATER AND RURAL DEVELOPMENT

Farmer Networks and Ponds

As a way out of land and water degradation and declining incomes and food security, groups of farmers adopted integrated farming in the 1990s as their approach to farming. Integrated farming implies the diversification of outputs and inputs on the farms and on-farm recycling of 'waste.' It comprises livestock and often aquaculture. Water is a crucial element for integration: presence of ponds is typical of integrated farms. Such responses were possible due to a change in attitude towards farming and lifestyle and because of ample practical knowledge ('farmer wisdom') still residing in the communities. Integrated farming systems outperform the normal farming systems in all four dimensions of a multifunctional agriculture: food security, environmental functions, economic functions, and social functions (Tipraqsa 2005; Tipraqsa et al. 2007): after 5 years of integrated farming, biodiversity was higher, soils were richer in nutrients and had a higher water-holding capacity, and farm households had a higher income.

In response to the migration to cities and to heavy debts, some farmers returned to their rural homes 'to take back control over their lives.' With support from NGOs these farmers joined a Farmer Wisdom Network[2] (FWN). Together they analyzed their problems, assessed lessons learnt and identified potential alternatives and solutions. They identified two key problems: (i) degradation of community values, and (ii) unsustainable systems of agricultural production and use of water. In particular, opportunities for multiple uses of water (domestic and productive) from multiple sources (rain, roof runoff, farm run-on, groundwater, public surface water) were considered to be crucial for a path of development under their own control. Using household labor and limited financial resources, farmers started to develop integrated farming systems around farm ponds. Income generated from these diverse activities has been used to develop further water storage structures with support from government or research. Other farmers, feeling the same needs and constraints, joined and the movement 'snowballed,' particularly with the moral support of some of the nation's leading figures. The farmer groups and networks expanded from less than 100 leading farmers 15 years ago to currently a few thousand leaders and their active groups. The leaders of the FWN interact at national fora and with leading politicians (Figure 2).

Farmer organizations promote the construction of farm ponds, crop diversification and recycling to reverse ecological and economic degradation. The government financially supported local communities to construct small-scale irrigation systems and some types of farm ponds. Yet, these

[2] The Farmer Wisdom Network (FWN) is an umbrella organization that brings together several provincial and thematic farmer networks from Northeast Thailand.

FIGURE 2. Leaders of the Farmer Wisdom Network meet with the Prime Minister of Thailand (in the middle) in May 2005. *Source*: Sawaeng Ruaysoongnern.

were initially hardly used due to high cost and inappropriate design and placement on farms. But adapting these programs to accommodate bottom-up thinking in top-down planning allowed for contributions by farmers and other local people and facilitated responses to the economic crisis and water shortages. However, many planners and researchers initially lacked the agroecosystem's perspective necessary to understand sustainable and profitable farming (Tongpan 1988). Changing mental attitudes of organizations takes time and the slow development of the government sectors as a real partner in participatory activities still provides serious handicaps (MOAC 2001).

Water and Self-Sufficiency

The evolution in top-down and bottom-up thinking for rural development was stimulated strongly by His Majesty King Bhumibol Adulyadej of Thailand. He presented his New Theory in 1987 as a holistic approach to stimulate new thinking about water resource rehabilitation, integrated farming and community development (Ministry of Education 1999; LDD 2005). Figure 3 graphically shows the concept: diversification of production and resources, recycling, farm ponds, and conservation of natural resources (Box 1). Food processing was proposed to generate income from excess produce. In 1996, the concept was expanded with flood management in 'monkey cheeks,' which are spaces reserved to store excess water. The influence of the King as mentor of the Thai people is hard to overestimate. The concept comprises autonomy, moderation and risk management. Together, these lead to sustainable development, equitable growth and the protection of the moral values of responsibility, respect and self-restraint. The New Theory has been promoted through demonstration farms and has been researched in several agroecologies (Khao Hin Son 1999; Suwanraks 2000). The concept of a Sufficiency Economy was incorporated in the National Economic and Social Development Plan of 2002.

FIGURE 3. An image of a Thai farm according to the New Theory (*source*: Bridges et al. 2001).

BOX 1.

The New Theory on achieving self-sufficiency on farms.

The New Theory regards all aspects of life and production in an integrated way. It encompasses domestic work and expenditures, production of the staple crop (rice), vegetables, herbs (including those with medicinal uses), trees, poultry, cattle, fish ponds, small industries for food processing, and handicrafts. Instead of relying on a cash economy, it also revives the traditional economic system in rural communities: (i) stop buying what you can produce yourself; (ii) grow what sells best, (iii) share and give, as sharing makes happy and expands social capital; and (vi) barter and exchange to expand your resources. By '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.

Following the Sufficiency Economy concept and local initiatives, individual households have used opportunities to gain access to more water (rainwater harvesting, extracting from channels, piped water) and use it for various domestic and productive purposes. However effective these actions may have been for individuals, in 2004, they were still few in number and did not appreciably change the big picture of water use in Thailand.

The Water Ladder

Van Koppen et al. (2009)[3] made an inventory of sources and uses in several countries with the particular view to understand how and how much water is involved in domestic and productive activities. Their results show that across many countries, cultures and administrative systems, the uses with highest priorities are drinking and other domestic purposes (cleaning, sanitation, some livestock), then supplementary irrigation of kitchen gardens, and vegetable plots and other small-scale productive activities (making of bricks, brewing beer, commercial laundry), and last (only when ample water is available) irrigation of field crops which is a profitable option. This insight is summarized in a 'water ladder:' each step higher on the water ladder corresponds to more options for water-related activities (Table 1). These authors also turn this observation around: by providing homesteads with more water, families get more options for productive activities, gain more income and contribute to rural development. As a logical next step they promote development of water as a means to escape poverty (Van Koppen et al. 2006; Renwick et al. 2007). The water ladder provides this study with an international reference level to volumes of water at which additional activities can be undertaken.

TABLE 1. The Multiple-use water ladder (*source*: Van Koppen et al. 2006, 2009).

Service level	Volume		Water needs met	Examples of technologies: time, distance
	$l.cap^{-1}.d^{-1}$	$m^3.cap^{-1}.yr^{-1}$		
High-level MUS[a]	100–200	36.5–73	All domestic needs; vegetable garden, trees, livestock and small enterprises	House connections, large storage (roof water, run-on)
Intermediate MUS	50–100	18–36.5	Consumption, laundry, cleaning/ hygiene OK; vegetables, trees and/or small enterprises	House connections or frequent street taps; homestead wells
Basic MUS	20–50	7.3–18	Consumption OK; cleaning/hygiene low; basic livestock; fruit trees.	Round-trip < 5 minutes or < 200 m; roof water
Basic domestic	5–20	1.8–7.3	Consumption just OK; hygiene too low; no productive uses.	Round-trip 30 minutes, or 250 m–1 km
No domestic	<5	<1.8	Too low for basic consumption and basic hygiene	Round-trip > 30 minutes or > 1 km

[a]MUS = Multiple USes of water.

ACTUAL SOURCES AND USES OF WATER ON HOMESTEADS

On farms and in villages in Northeast Thailand, drinking water was traditionally obtained from public and private wells, ponds and streams. The volume of water was adequate to meet the domestic demand but had to be filtered or boiled. Low-lying areas cultivated with paddy rice received gravity irrigation from public streams and, more recently, from outlets from newly built large water reservoirs. A few home gardens received irrigation other than domestic wastewater because there were few water-lifting devices. Rainwater retained in the soil ('green water') provided the sole

[3] More specifically, the project was built on the hypothesis that integrated planning of community water supply for domestic and productive sources, though not yet common, is beneficial at the household, community and national levels.

source of water for upland crops. For about 50 years, roofs covered with sheets of corrugated iron have provided opportunities to harvest much cleaner water than what roofs with straw or leaves could yield. Use of jars, a more recent development, allows water storage for many months. This situation for homesteads may be described as 'basic MUS' (Table 1).

When more sources of water are available to households, more ways of benefiting from it become feasible. With the supply of two to five times more water, usually all needs for small productive activities can be met (Table 1). Additional sources can be found in three ways: powered pumps that lift water from wells or public surface water, farm ponds that retain runoff from nearby fields and piped water from the village.

Powered pumps overcome the effort of manual lifting of water for gardens and crops. Since the 1980s when small pumps with small combustion or electrical engines became affordable in Asia, uptake has been very significant in many countries. Small pumps are relatively easy to maintain, manage and transport. Engines that power 2-wheel tractors are also very popular and can power pumps directly. Digging of ponds and construction of dams to retain water in reservoirs have been promoted in Thailand since the 1990s. In recent years, piped water has become a common source of water for households in many villages.

How important are these sources in practice for the full system of water supply and use on the farm?

The Survey

In 2005, a survey was carried out in 130 households in the Buriram, Mahasarakam, Khorat and Yasothon provinces (Figure 1) to establish facts about homestead water. One group of 25–45 households was studied in each province. Groups formed themselves to create more benign and eco-friendly farms as a reaction against an earlier drive to maximize production and income and disregard environmental damage and social disruption. They did this by 'integrated farming,' attempting to become self-sufficient in resources through recycling and judicious use of main and by-products, and some by organic farming. Homesteads are owned by families who live on them.

Twenty households with a farm pond were chosen from each province to form one group, as well as five households that did not (yet) have a farm pond; the 4 x 5 no-pond farms are another group. Regular farms outside the FWN were not included in the survey.

About 180 features of each farm were recorded: the size of main plots and their crops, the numbers of cows and poultry, the sources of water and the periods when it is available, the quantity of water used (in volume or frequency of drawing on the source, use), the number of laborers and key implements on the farm, farm production by activity, home-consumption or sale, the income from the farm products and off-farm income, whether managed by man or woman, the level of debt and the degree of satisfaction with the lifestyle (social, cultural, health).

Data on the farms were not recorded completely uniformly so that quantities and activities cannot always be added or compared. There are large differences among the farms in almost any aspect including size, uses of water, income and equipment, even though the main activities on farms are similar.

Some characteristics of the farms are presented in Table 2. It is not possible to distinguish the group with no-pond farms from the group of farms with ponds on the basis of their characteristics because the variability in each group is large. It may be appropriate to speak of 'clusters' of farms with the suggestion that the clusters of pond-farms and no-pond farms have some overlap and that some farms of the no-pond cluster have more in common with pond-farms than with other cluster members.

TABLE 2. Averages of characteristics of the farms in our survey.

Case/Feature	Pond farms in Buriram	Pond farms in Mahasarakam	Pond farms in Khorat	Pond farms in Yasothon	No-pond farms
Farm size (ha; range)	1.2–3.5	1.5–5.5	1.4–5.0	0.5–4.5	0.5–7.1
Laborers male and female (owner + hired)	2.0+0.1	1.9+0.05	2.1+0	2.2+0.2	2.5+0.05
Produce	Vegetables, rice, fish, fruit	Vegetables, rice, fish, fruit	Vegetables, rice, fish, fruit	Vegetables, rice, fish, fruit	Rice, fruit, fish on some farms
Farm income (% of total)	80	50	70	60	50

Ambiguities in the answers to some of the questions in the survey, inconsistencies in the use of units and weaknesses in the definitions of some variables make out that statistical analyses would yield means and standard errors that seem relevant which, in fact, are not. Therefore, we preferred to use the more subjective measures of an eye-level average and a range of values within which the more reliable observations fall.

There is a tendency for the pond farms to have a slightly higher income and produce fish, but there are significant exceptions. The key point, however, is that there are differences in the sources and uses of water.

Sources and Uses of Water on Farms with Ponds

The group of homesteads with ponds shows an interesting picture of multiple sources and multiple uses (Table 3). Water from different sources is used for different purposes, driven by the specific requirements of quality and volume. Farms draw water from at least nine different sources and many farms use at least six of them simultaneously. These sources are:

- Rainwater harvested from roofs and stored in several large jars (3.5–5 m^3). Bottled water, though expensive, can be purchased from shops. Commercial tap ('piped') water from outside the farm is available at 70% of the farms in volumes of 25 to 250 m^3 annually. Piped water is easier to obtain and is available in larger volumes than water from wells and jars even though its quality for domestic use is (considered to be) inadequate without filtering or boiling.

- Shallow wells with buckets are still in use on 30% of the farms. Deep wells (boreholes of 10–30 m deep) are now common where electricity is available for pumps. Farm ponds retain water that flows from nearby fields. In public canals or streams, about 25% of the farms are close enough to allow water extraction. Runoff from nearby fields or roads helps about 25% of the farms to flood paddy fields; the importance of this source depends on the local topography. Rain wets the soil and provides the 'green water' for all cropped areas.

With respect to the uses of water, two categories of domestic uses and six categories of productive uses can be distinguished:

- Drinking water is available, usually from jars with stored rainwater and sometimes from purchased bottled water, while a few households sometimes use cleaned pond water. The water is of high quality throughout the year but the volume is limited.

TABLE 3. Sources of water (horizontally) and its uses (vertically) on integrated farms. The numbers show the average percentage of homesteads which use that source for a particular purpose. The sum is not equal to 100 when households do without a particular source or use it for more than one activity.

Sources and purposes	Jar (roof water)	Bottled water	Tap (piped water)	Shallow well	Deep well	Private pond	Public canal, stream	Run-on water	Green water
Drinking, cooking	100	6	7			6			
Other domestic			67	5	16	15			
Home garden			25	4	18	25			100
Vegetable garden			5		21	51			100
Livestock			5	5	10	63	2		
Fish				3	1	45	11		100
Fruit trees			1	1	6	34	61		100
Rice						3	26	34	100

- Other domestic uses (washing, laundry, sanitation) are piped water which is the preferred source, even though it has to be paid for, but water from wells and ponds is used as well.

- The home garden is irrigated with piped water or water from ponds or wells. Kitchen wastewater is recycled here. Herbs and a few vegetables are grown. This brings no income but avoids expenses for condiments, often more than one-third of the household expenses, and provides nutritious food. Home consumption, including sharing with friends and neighbors, has high priority.

- The vegetable garden is mostly watered from the pond or the well. Some of the vegetables are for sale or barter. About 60% of the farms have excess produce which is sold.

- Livestock get water from the pond or are supplied with water from the wells; small livestock (poultry) get piped water.

- Fish is either produced in special tanks or in the pond. Water, if needed, is taken from public sources.

- Fruit trees are usually not irrigated but when irrigated water comes from public sources or the pond.

- Rice paddies are not irrigated from ponds as the demand is too high. Irrigation, if possible, occurs from public sources or runoff.

Even though piped water was introduced to promote health in the first place, it appears to be used to supplement water from other sources for everything except drinking and irrigation of rice.

It is difficult to quantify the total volume of water used at each farm and our survey basically yielded only direct estimates for water consumption from jars and piped water. Together, these amount to at least 55 liters person^{-1} day^{-1} (lpd;100 $m^3.yr^{-1}$ per household). This is supplemented with water from ponds for gardens and from public canals for paddies. These sources were estimated to supply at least 25 and up to 1,000 lpd, the highest values on farms that also draw water from canals. The total consumption varies therefore from 80 to 1,000 lpd (150–1,800 $m^3.yr^{-1}$ per household). This corresponds with the 'high-level MUS' character of these homesteads (Table 1) where availability of water poses no limitation to small-scale productive uses. For unknown reasons, many homesteads in the Buriram Province consumed significantly more piped water than the average of the group of homesteads with ponds while those in Yasothon used significantly less than the average.

Sources and Uses of Water on Farms without Ponds

Water sources and uses on the no-pond farms are shown in Table 4. Most households are connected to a piped water distribution system. This volume supplements the water harvested from roofs and water drawn from wells and canals. Piped water appears to be used for all purposes in the homestead (except for irrigation of rice which requires too large volumes). The total use of water is estimated to vary from 70 to 500 lpd (140–900 $m^3.yr^{-1}$ per household). This places the no-pond households at the intermediate to high-level MUS (Table 1) where additional water would allow more productive uses.

In Table 4, the use of piped water seems to be more prominent on these farms than on the pond farms (Table 3). Closer inspection shows that this applies to relative, but not to absolute, values of consumption. The consumption of piped water is 25–150 $m^3.yr^{-1}$ on no-pond farms (but two nonintegrated farms used more than 400 $m^3.yr^{-1}$ of piped water for irrigation). This is about half the volume that homesteads with ponds consume. It appears that the absence of a pond is not compensated for by a higher intake of piped water.

TABLE 4. Sources of water (horizontally) and its uses (vertically) on no-pond farms. Numbers indicate the percentage of the households which use a particular source for a particular purpose.

Sources and uses	Jar (roof-harvested rain)	Bottled water	Tap (piped water)	Shallow well	Deep well	Private pond	Public canal, stream	Run-on	Green water
Drinking	100		50						
Other domestic			100	30					
Home garden			50	15	10				100
Vegetable garden			35	25			10		100
Animals (large)			20	5			10		
Fruit trees			5	20	5				100
Fish			5				5		100
Rice							15	35	100

Benefits of Farm Ponds

The main elements of the annual income of pond farms in the four provinces and those of no-pond farms are shown in Table 5. The comparison of the pond and no-pond homesteads suggests that those without a pond produce fewer vegetables and have no surplus to sell, and the same applies to animal products. The sale of fish from no-pond farms exceeds that from pond-farms, unexpectedly, but the average may be misleading as it results from two large fish farms next to public water sources. Rice for sale is an important product in all cases.

TABLE 5. Main elements of the annual income of pond-farms in the four provinces and of no-pond farms (in THB).[a]

Source of income	Buriram	Mahasarakam	Khorat	Yaso-thon	Average pond farms	Average no-pond farms
Vegetables, sale	11	0	4.5	5	5	0
Fruit, sale	2	1	1	2.5	1.5	3
Animal products, sale	8	17	10	17	13	1
Fish, sale	3.5	2	2.5	0.5	2	5.5
Rice, sale	24	7	26	10.5	17	12
Other	25	11	12	21	17	12
Farm income (sum)	73.5	38	56	56.5	56	33.5
Rice, vegetables, fish, fruit, animal products (in-kind)	21	15	20	21.5	19.5	8
Off-farm income	19	37	19	33	27	34
Total income	113.5	90	95	111	102	75.5
Savings	15	125[b]	17	17	16	22

[a] THB1.00 is approximately $35.00.
[b] This number is well beyond expectation due to two exceptionally high values that may be erroneous and is therefore not used to calculate the average.

Off-farm income amounts to 25–50% of farm income. This fraction tends to be larger on the farms without a pond. It consists of payments for part-time or short-time jobs of household members and, quite significantly, of remittances by family members. Eight of ten households have significant off-farm income. Twenty percent of the farms report no off-farm income but this does not signal poverty as it is consistent with the goal of self-sufficiency and well-being of farm households (these farmers report ample consumption of home produce). While there are differences in income between the four groups, the heterogeneity within the groups prevents us from concluding that these differences are significant.

Total income per homestead, including the value of home consumption, is over THB100,000 ($2,900) for farms with a pond, and one quarter less on farms without a pond. This is in agreement with the view that integrated farms have more opportunities for cropping due to their larger water availability. Their annual savings, however, appear to be similar and relatively high. About 10% of the households in both groups are ‘rich’ with an income several times the average from commercial rice or fish production. Income from no-pond farms is less diversified and slightly lower than that from pond farms. This implies that such farms are more vulnerable to drought and flooding. The pond farms are probably more resilient to ecological and economic pressures (Tipraqsa et al. 2007).

It is likely that a wider diversity of skills and knowledge is needed to successfully run a farm with a pond.

Management of farms and water is usually the joint responsibility (planning and execution) of men and women.

About other social and cultural values, it can be stated that households with homestead ponds were unanimous in stating their new way of farming is positive for their health, creates more time for social interaction, helps to learn and cooperate, and is appreciated as increased happiness and well-being. That this is also recognized by households that do not yet practice integrated farming can be concluded from the observation that the FWN has grown within 20 years from a few hundred members to well over hundred thousand farmers by 2008.

A SIMULATION MODEL FOR WATER ON THAI FARMS

Farm Structure

Pond design and the layout of fields merit specific attention given the importance of water and its role in spatial integration. The physical structure of 110 farms from members of the FWN was established. Nearly all of the homesteads have a vegetable garden in addition to land for the family house and sheds, and for rice, fruit trees and, sometimes, a plot with forest and medicinal plants and trees. There are large differences in layout, pond design and cropping patterns. Sizes, proportions of plots, choice of crop species and proximity to public water outside the farm are all highly variable. The farm area in our sample is 1–30 rai (0.2–5 ha) with a median value of 8 rai (1.3 ha). Some examples of layout of homesteads and ponds are presented below. Except for the presence of one or more ponds there seems to be no systematic difference between the clusters of homesteads with and without ponds, but that may be concealed by the large variability in design and use. On the pond farms, there were, on average, 4.6 different crop species (including fish) on nine plots, while there were fewer crop species (2.7 on average) on eight plots at the no-pond farms. Paddy rice usually covers more than 80% of the land on no-pond farms while the proportion is 60% or less on the farms with ponds. Rice crops receive supplementary irrigation water from surface runoff from nearby fields or roads (one crop per year) or are irrigated with water from a canal (one or two crops per year) but generally not from ponds.

The first example of the farm structure (Figure 4) shows an integrated farm with a pond. The farm area is 8 rai (1.3 ha). The pond covers about 2.5% of the area. The well and pond provide water for domestic and productive purposes. Rice is an important crop for household consumption and sale.

On homesteads without a pond, as shown in Figure 5, the picture is different. The roles of water from pipes and wells are more prominent but since volumes of water are smaller there is less productive use. The farm covers 14 rai in area (2.3 ha). Piped water services the house and is used, with domestic wastewater, for vegetables. Rice paddies receive water pumped from a nearby public canal.

Figure 6 shows another example of a farm with a pond. It represents a small farm without a connection to a piped water supply and with an area of only 3 rai (0.5 ha) of which 7% comprises a pond. Labor and water savings are achieved by growing specific tree species and by efficient drip irrigation. Intensive farming on a plot of 1 rai (0.17 ha) can provide food for a single household. Even though a farm of 0.5 ha is relatively small it provides ample income to purchase rice for domestic consumption.

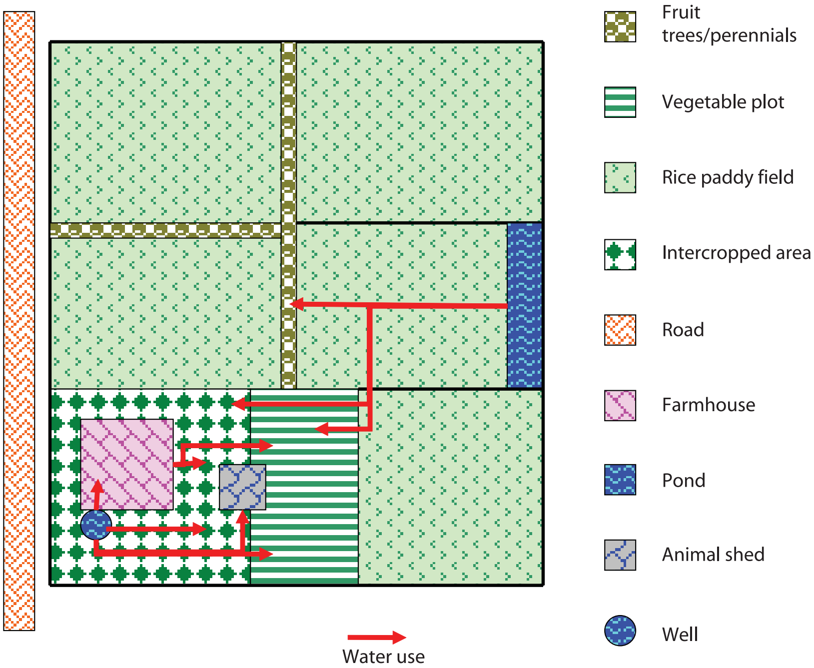

FIGURE 4. The layout of the farm of Mr. Sao Suriya of Buriram Province.

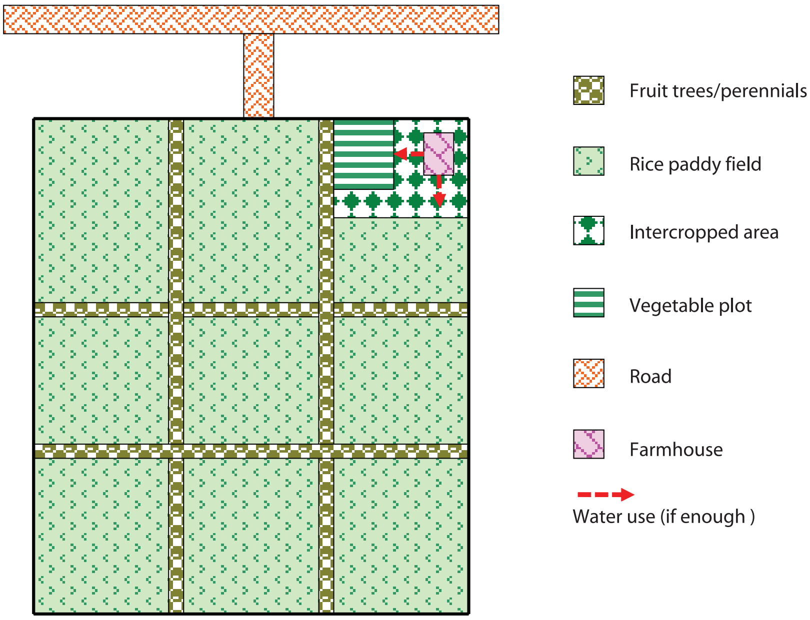

FIGURE 5. The layout of the farm of Ms. Amporn Malaisri in Nakhon Ratchasima Province.

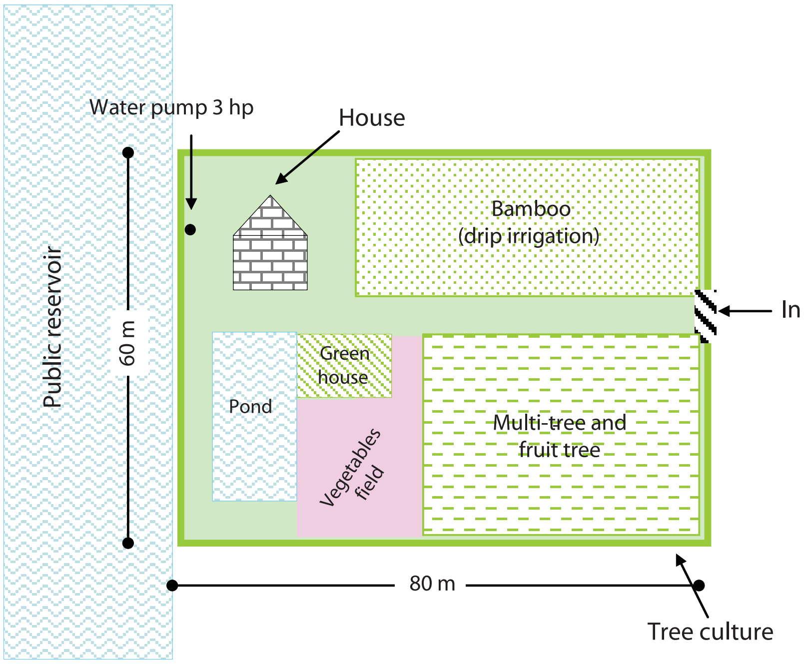

FIGURE 6. The layout of the farm of Ms. Suwaree Phasee in Buriram Province.

The homestead shown in Figure 7 does not have access to piped water. But intensive production on this small farm (1.5 rai = 0.25 ha) allows an adequate income. The large pond is filled by surface runoff from outside the farm. The pond occupies about 40% of the area and is used to breed fish. The rice plot is minuscule. Chicken and the household itself contribute to recycling of nutrients.

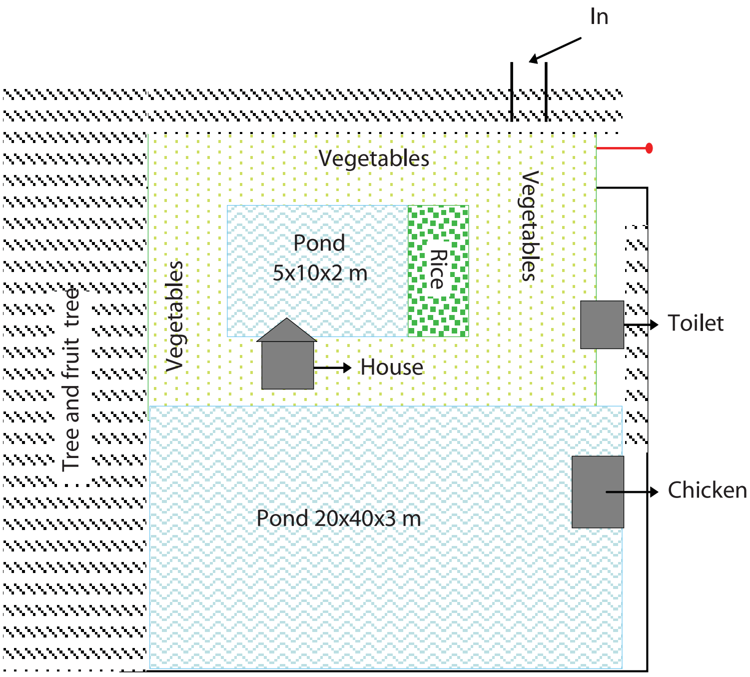

FIGURE 7. The integrated farm of Mr. Samrerng Yenram in Buriram Province.

A New Simulation Model

There is a wide range of pond sizes on actual farms, as illustrated in Figures 4–7. This suggests that there is no practical way to determine the optimum size. Indeed, farmers realize that more water is required for development of their farms and livelihoods and ask for guidelines to proceed with ponds. During an FWN workshop in the Kalasin Province, they formulated three pertinent questions (Box 2) that guided our activities.

BOX 2.

Three questions to scientists.

- What is the land-water resource ratio on farms for best productivity in different ecosystems?
- How to manage water for high water use efficiency for each crop species (for monocrops and in an integrated farming system)?
- What is the water productivity potential per farm in different parts of Northeast Thailand?

Source: FWN Workshop, Kalasin, 20 January 2004.

Several answers to the question about the land-water ratio, or relative pond size, have been given. The New Theory, for instance, suggests the value of 30% which would allow year-round irrigation. In trials, values of around 12% of the farm area have been reported as optimal (LDD 2005). In the past, the Land Development Department (LDD) used a fixed value of 1,260 m^3 as the target size. Not only do these numbers present too wide a range for farmers to choose from, but individual farms are also quite different due to features of soils, landscape and local climate, economic factors and the preferred farming style. However, the track record of new farms is still short (Tipraqsa 2005) so that farmers do not yet have sufficient experience to use the record as a guideline. For example, the pond shown in Figure 8 was dug without much guidance as to its location or size. Field trials can provide a way out and this route is taken by the LDD experiment station in Khao Hin Son. But trials should continue for 5–10 years and occur across the region to account for the variability of weather and differences in soils, and are therefore slow and expensive.

An alternative approach to identify the optimal pond size for individual homesteads, which is potentially much faster and cheaper, and with a wider range of answers, is simulation modelling. Farm modelling and analyses of results of carefully constructed scenarios are modern and flexible tools to help derive guidelines for construction of farm ponds. Modelling can support a nonspecialist with applicable knowledge. For instance, Croke et al. (2007) present significant impacts on land and water management due to support with modelling to local persons and organizations in Australia.

Is there a model published that could serve our purpose? A literature review yielded several models that address optimization and water on farms. These include SWB (Annandale et al. 1999), Tradeoff Analysis Model (Antle and Stoorvogel 2000), Dam Ea$y (Lisson et al. 2003), Planwat (Van Heerden 2004) and TechnoGIN-3 (Wolf et al. 2004) and an unnamed model by Kono (2001).

FIGURE 8. A newly dug farm pond in Mahasarakam Province.

Unami et al. (2004) presented a theoretical approach to farm pond design and suggested two strategies for farms with rice as the main product. A simulation model to optimize use of water for supplementary irrigation on US farms was published by Arnold and Stockle (1991). Lacombe et al. (2005) presented a multiagent model that represents objectives and constraints of smallholder rice farmers. However, these models do not provide all features required in our case, particularly those with respect to multiple uses of water, farming styles and weather-related risk on individual homesteads. We initiated the development of the farm simulation model BoNam (Thai for 'pond'), as shown in Figure 9. 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).

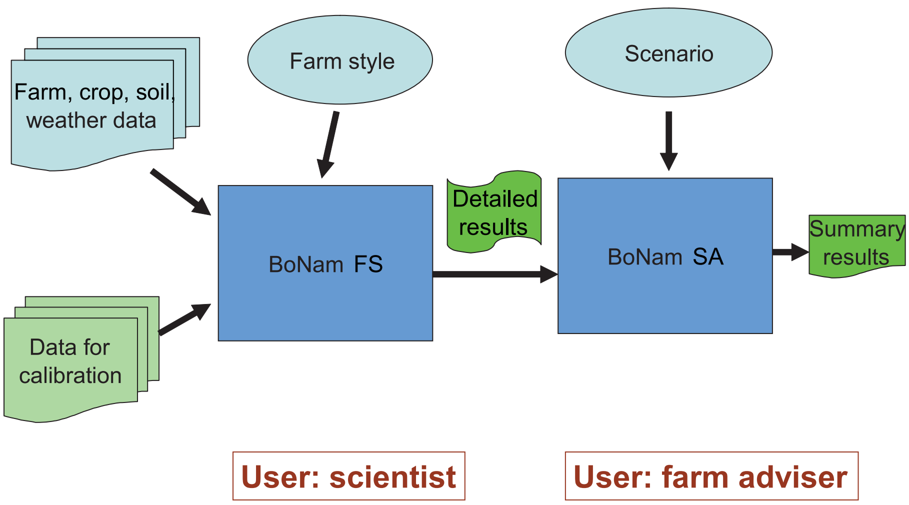

FIGURE 9. A diagram of the inputs required for BoNam and its products and users.

Even though simulation models are powerful tools, they are only components of a modelling approach. Other components include field research (to elucidate processes and relations and to evaluate performance) and calibration (i.e., resetting the values of state variables according to observed values). ‘No simulation without experimentation and *vice versa*.’ This paper presents an outline of the model.

BoNam-FS is used to produce results for different scenarios to determine the performance of the farm over a range of pond sizes in response to farming style, weather patterns or technological and management innovations. BoNam-FS was developed as a tool for scientists for in-depth analysis of farm water balances in existing or new scenarios. The detailed results can be analyzed with the spreadsheet BoNam-SA and summarized in graphs. This comprehensive output can be used by farm advisers.

BoNam simulates five farm sections: (i) the farmhouse, yard and the unplanted area surrounding the pond, (ii) the pond, (iii) the rice field(s), (iv) a plot with vegetables, and (v) 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.

Rainfall data were used for the individual years for Khorat (1995–2004), Khon Kaen (1987–1996), Ubon Ratchatani (1961–1969) and Nong Kai (1961–1969). The average annual rainfall at these locations increases from 1,345 via 1,522 and 1,673 to 1,984 mm (Figure 10). The potential evapotranspiration in Khon Kaen is 1,971 mm per year (Vudhivanich 1998). (Assuming that this value is a fair approximation for the entire northeast, the balance of precipitation and evaporation can be approximated by comparing the cumulative values with a straight line from the origin to 1,970 mm at week 52, as shown in Figure 10. This explains why droughts are common in the rainy season in Nakhon Ratchasima and Khon Kaen, while Nong Kai has the highest risks of flooding.) Weekly data averaged over 9 years were used to calculate temperature and evapotranspiration.

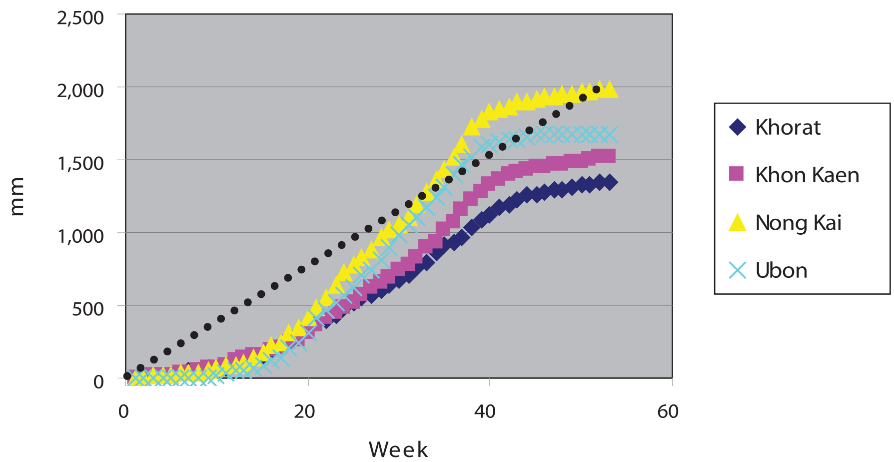

FIGURE 10. Average cumulative annual precipitation (in mm) for Nakhon Ratchasima, Nong Kai, Khon Kaen and Ubon and the linearized rate of potential evapotranspiration (dotted line).

Simulated crops have the physiological characteristics of both ‘lowland rice’ and ‘bean crops’ in their development and growth parameters (Penning de Vries et al. 1989). Target yields are set by farming style and reflect variety of choice and fertilizer level. Fish weight increases by 10% per week if ample feed is supplied (related to 'style'). The soil on the rice farm is characterized as 'clayey' and the soil on the vegetable plots as 'loamy' (Penning de Vries et al. 1989); both are common soil types in Northeast Thailand. Data from the soil map of Thailand cannot be used since the scale is too small. Soil fertility is addressed implicitly in parameters that specify the relative rate of crop growth. The landscape of the farm is characterized by runoff patterns between the plots. In the standard simulation there is no run-on water received from outside the farm. Drainage from the pond is set at a small fraction (0.005) of its contents per week.

Management of the farm in BoNam is characterized by choice of target yields of crops planted, irrigation levels, use of the soil amendments (e.g., bentonite) 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 different styles of managing a farm enterprise lead to quite different outcomes with respect to the 'best' results. Four styles are distinguished:

- Style A ('sustainability'): the solid, slightly conservative farmer[4] who makes sure that his farm is sustainable, that his family has always adequate rice and that he seeks stability. This farmer may have no children who see their future in agriculture.

- Style B ('income'): the farmer who seeks maximum benefit and does not mind the associated risk since he can borrow money to buy input for the next season and has a financial buffer to buy food. Mostly commercial and input-intensive production: irrigation, fertilizer, labor.

- Style C ('scientist'): the curious, enterprising farmer who tries out new methods for water distribution, new crops, etc. This style is characterized by adopting the most efficient ways of doing things.

- Style D ('low input'): the farmer seeks to minimize farm work and monitoring because he has off-farm income, prefers a more relaxed life, or has no partner on the farm.

Style A is the most common in Northeast Thailand, and a significant number of farmers aim for style B; style C is probably rare, while style D may become more prominent as many farmers get older. About 20 parameter values and settings in BoNam are affected by 'style,' e.g., if a farmer goes for a relaxed style of farming, this will be reflected in selected crop species, target yield levels, and absence of fish production.

BoNam-FS is built in the language SIMILE (Muetzelfeldt and Massheder 2003). 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. 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. To keep

[4] Since farming is planned and executed by people of both sexes, either jointly or separately, the term 'farmer' is employed for both sexes.

the total area of the farm constant, a change in the size of the pond is compensated for by a change in the size of the paddy rice field. The optimal size of a pond is found by comparing the results of repeated simulations for relative sizes ranging from 0.0 to 0.3.[5]

The actual simulation model consists of 15 modules: one for the water balance of each of five farm plots (which might consist of a single field or a field of several plots at different locations), one for each of the three productive activities (vegetables, rice and fish), one for strategic decisions on the farm layout, one for operational decisions in management, one for time management, two for weather and price data, and two to track simulated farm performance (water balance, income, etc.) and annual totals.

How crops, soils and ponds 'respond' to management and weather is calculated during each simulation cycle for a short interval of time (one week). All states are updated with their rates of change at the end of each interval. Calculations are repeated hundreds of times until the simulation period is completed.

Model Performance

Studying the dynamics of individual variables in great detail is required in the initial phases when the model is being built and tested: a comprehensive set of outputs could include weekly or monthly values of the soil relative to water contents in the cropped plots, levels of water stress in the crops, crop dry weights, and runoff between fields and from the farm, and the water level in the pond. This level of detail is not pursued further in this paper.

Users of simulation results need simple indicators of how the farm is doing. We chose five indicators of farm performance:

- Annual farm gross income ($THB.yr^{-1}$) from sales of rice, vegetables and fish.
- Number of weeks per year that a pond is dry as a measure of risk.
- The quantity of irrigation water applied ($m^3.yr^{-1}$) to measure how much more water the pond actually made available.
- The water use efficiency (income gained per unit of irrigation water).
- The quantity of runoff from the farm ($m^3.yr^{-1}$) to see the consequences for neighboring farms and water management at large.

For an illustration of the type of summary results of the BoNam model, the model was run for one location (Khon Kaen) with relative pond sizes from 0.0 to 0.3 with all other input data constant and all management parameters set at default values for a subsistence style of farming (A). Results (Figure 11) show that for 'average' rainfall years (probability 50%) a pond of 0.09 of the farm surface area is optimal for the indicator 'income;' in wet years, the pond should be 0.12 of the area; in drier years 0.07 is optimal (a 'wet year' being defined as a year which brings rainfall

[5] The size of a pond is its ratio to the surface area of the farm, e.g., a pond size of 0.3 means the pond size is 0.3 of the surface area of the farm.

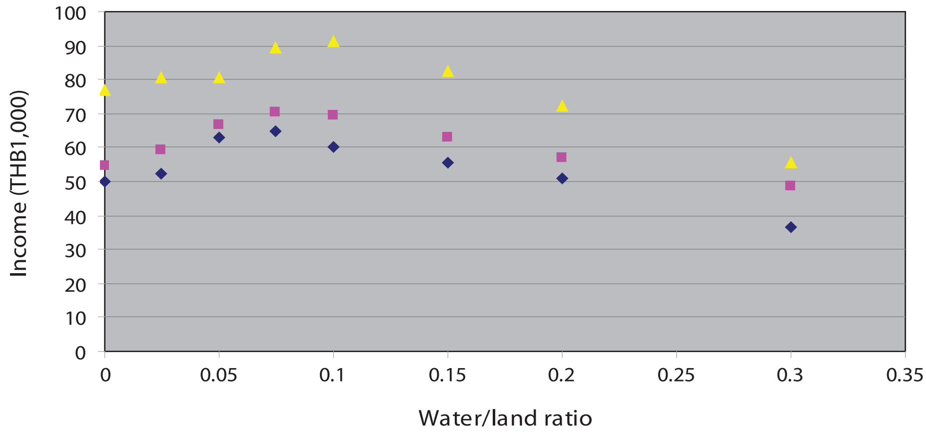

FIGURE 11. The relation between pond size (fraction) and farm income (THB) in Khon Kaen for farm style A in the 'best' years (triangles, 1 in 4 years is better), 1 of 2 years (circles), and in the 'worst' case (diamonds, 1 in 4 years is worse).

surpassed only once in 4 years, and a 'dry year' as one with rainfall surpassed 3 times in 4 years). The spread between the upper and lower values is a measure of the interannual variability in weather. Slightly irregular patterns in the graphs are due to nonlinear processes, such as failure due to drought or a second crop.

Figure 12 shows the indicator 'runoff' for the same case. The optimum value (i.e., the least runoff) suggests an optimum size of 0.07 in average years, 0.05 in dry years and 0.13 in wet years. These values are different from those for the indicator 'income.' The minimum volume of water to runoff (about 500 m^3) is floodwater from paddy rice fields that exceeds their storage capacity.

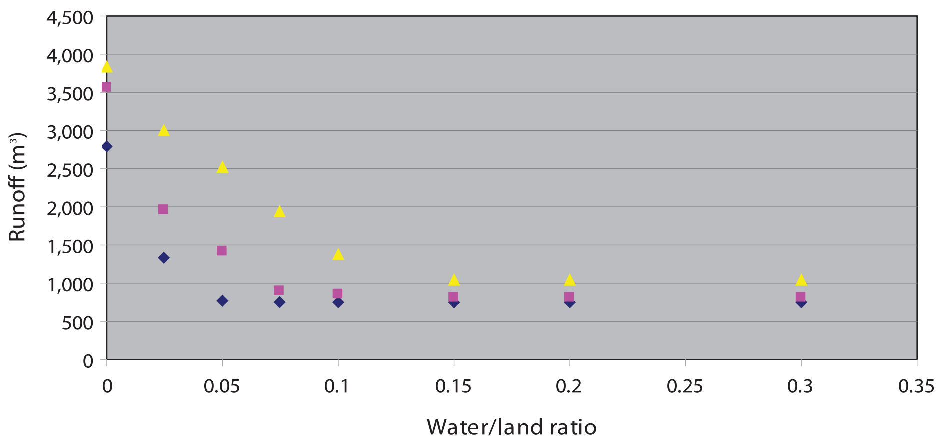

FIGURE 12. The relation between pond size (fraction) and farm runoff (m^3) for the same case as in Figure 11 in the 'best' years (triangles, 1 in 4 years is better), 1 of 2 years (circles), and in the 'worst' case (diamonds, 1 in 4 years is worse).

The optimum for the indicator 'volume of pond water for irrigation' shows yet another pattern (Figure 13): the single optimum value of 0.08 applies to dry and medium years, but in wet years almost double the size is optimal.

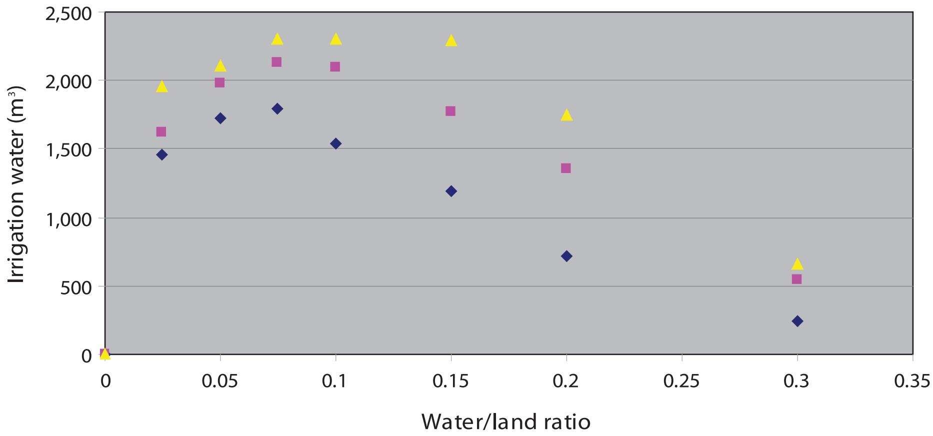

FIGURE 13. The relation between pond size (fraction) and the amount of water for irrigation (m^3) for the same case as in Figure 11 in the 'best' years (triangles, 1 in 4 years is better), 1 of 2 years (circles), and in the 'worst' case (diamonds, 1 in 4 years is worse).

For the indicator 'number of weeks dry' the optima are similar to those of other indicators: close to 0.10 and between 0.07 and 0.15, depending on the rainfall (Figure 14). In addition, the pond is dry for at least 1–2 weeks in wet years but for several months in a dry year.

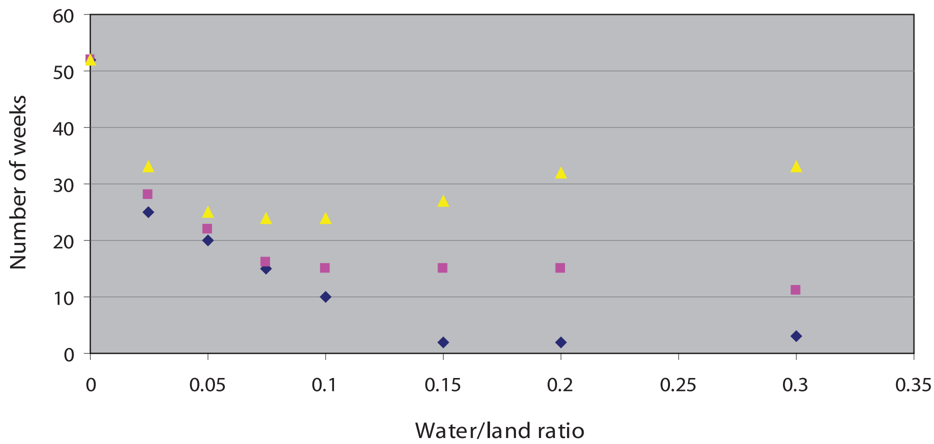

FIGURE 14. The relation between pond size (fraction) and the number of weeks that the pond is dry for the same case as in Figure 11 in the 'best' years (triangles, 1 in 4 years is better), 1 of 2 years (circles), and in the 'worst' case (diamonds, 1 in 4 years is worse).

For the above example of a farmer who has subsistence of family and farm on top of his priority list, the optimum size of the pond appears to be around 0.09 of the farm area. It is important to note that the optimum pond size for the individual indicators is not the same. Moreover, the 'best years' for reducing runoff are different from the 'best years' for the 'minimum number of dry weeks.' Hence, here is another 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.

A First Response to the Questions

Let us now turn to answer the questions the farmers posed (Box 2). How 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 determined for four locations: Khorat, Khon Kaen, Nong Kai and Ubon for which the precipitation patterns were shown in Figure 10. Results are given in Figure 15.

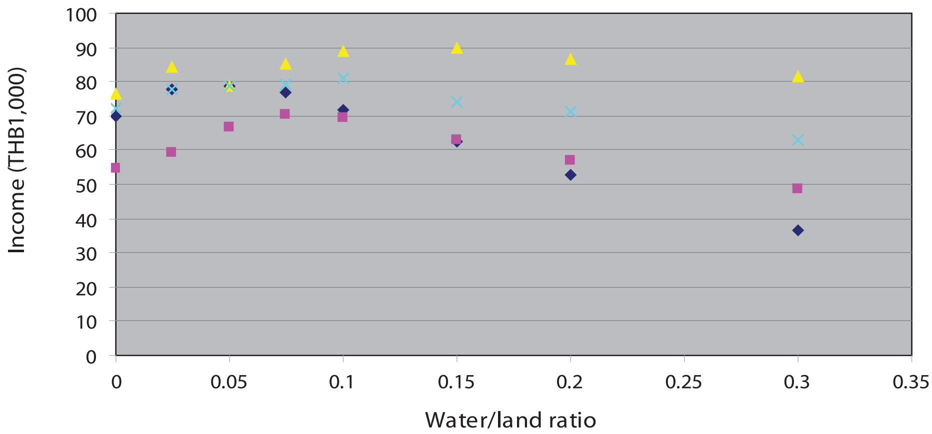

FIGURE 15. The relation between pond size (fraction) and gross farm income (50% probability) for farming style A as a function of location: Nongkai (triangles), Ubon (crosses), Nakhon Ratchasima (diamonds) and Khon Kaen (squares).

For simplicity, judging only the indicator 'farm income,' one sees a rather flat response with an optimum of 0.1–0.15 in the wettest region (Nong Kai) while in the second wettest area (Ubon) the response is not that strong. 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 Khorat, on the other hand, there is an optimum water/land ratio of around 0.05. So the model confirms that the optimum size of a pond is different per location. It also suggests (data not shown) that the pond needs to be up to twice the size at the wetter locations if preventing runoff is important.

The question 'how to manage water for high water use efficiency?' (Box 2) 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. Figure 16 shows how farm gross income depends on the farming style A, B, C or D in Khon Kaen for the relative pond size 0.10 (recall that expenses for farm inputs are not yet deducted). Unsurprisingly, style C (the farmer who aims at modern scientific farming) provides the highest results and style D (the farmer who has farming as a second priority) the lowest. In this case, the model has quantified the difference that we had intuitively expected.

Finally, a few comments about the question 'what is the ecological potential in the region?' (Box 2). The ultimate 'potential production' of agricultural and horticultural crops is directly related to the amount of solar radiation that they intercept. Growth rates of 200 kg dry matter per ha and per day are achieved by many species of crops under intensive management and in full sunlight. For example, rice farming in such conditions can yield 8 $t.ha^{-1}$ and more (e.g., Egypt

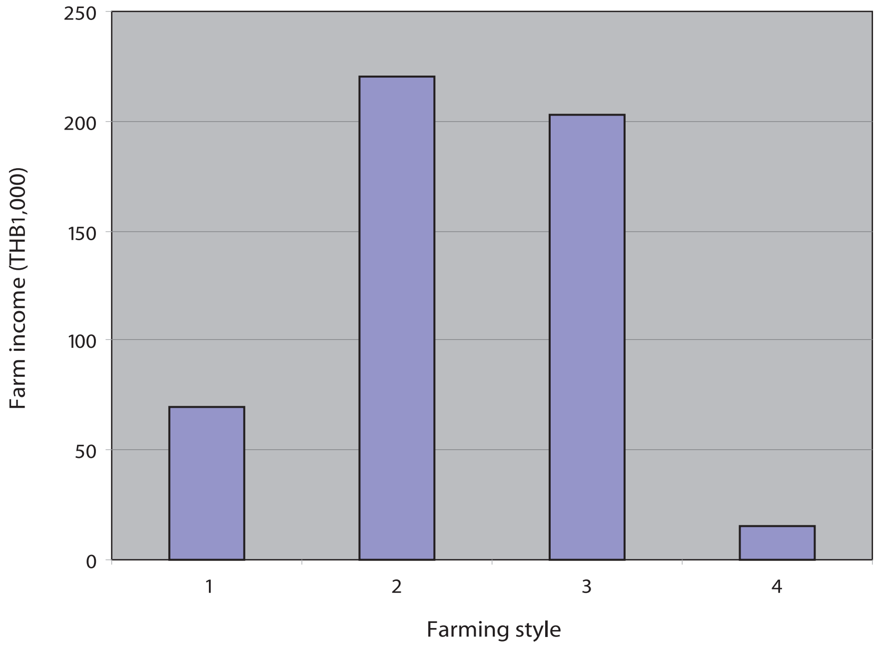

FIGURE 16. The farm gross income is shown in relation to the farming style in Khon Kaen. '1' stands for style A, '2' for B, '3' for C and '4' for D.

has a national average of 10 $t.ha^{-1}$). Still, the current average rice yield in Thailand is below 3 $t.ha^{-1}$ (IRRI 2008) because farming is much less intensive. To raise the yield levels and achieve the ecological potential there are many elements that need to be addressed such as at the technical level, factors like the crop calendar and crop choice, fertilizer application and nutrient recirculation in combination with soil improvements, irrigation and other elements, and markets and prices at the socioeconomic level.

With respect to water, one option to increase the ecological potential of farms is to retain more 'green water.' This can be achieved by adding bentonite to the soil (it raises fertilizer efficiency and soil water-holding capacity significantly; Noble et al. 2000, 2004). It will allow the farmer to make better use of the natural rainfall and allow him to get closer to the local potential production. The model was rerun for the same situations as in Figure 11 and simulated the presence of bentonite. Outcomes of simulations are shown in Table 6. It shows that the amount of water for irrigation increases because the 'green water' function of the soil is much enhanced, and that the ponds are dry for fewer weeks per season because less irrigation water is needed. (These benefits of bentonite relate to the improved water-holding capacity of the soil

TABLE 6. Optimum pond size in Khon Kaen (style A, 50% probability of precipitation) without bentonite (as in Figure 11) and with bentonite mixed into the topsoil. Columns 2 and 4 show the values of the indicator at mid-range. Columns 3 and 5 show the range of the relative pond sizes where 90% or more of the value is attained.

Indicator	Regular farms		With bentonite	
Income	THB70,000	0.08–0.11	THB75,000	0.06–0.095
Irrigation water used	1.500 m^3	0.085–0.10	1,700 m^3	0.06–0.10
Farm runoff	360 m^3	0.10–0.14	360 m^3	0.06–0.14
Dry periods per year	14 weeks	0.10–0.16	8 weeks	0.06–0.14

and are only modest. The main benefits expected of this soil amendment and seen in preliminary trials are in the prevention of leakage and in recycling of nutrients, aspects that are not dealt within the BoNam model.) To judge the value of the changes, one has to consider that a 50 t application of bentonite costs THB50,000 (Noble, pers. comm. 2004, Bangkok) but it will work for many years afterwards. At least, one of the farmer networks has experimented with bentonite in their fields but results have not yet been reported.

Another option to increase water retention and crop production at the farm is lining of ponds to prevent seepage. Its effect appears to be relatively small. The reason is that the simulated rate of deep drainage is rather low (0.5% w^{-1}, or about 5-15 mm w^{-1}) and it is much smaller than evaporation (about 35 mm w^{-1}). Seepage losses might be significantly larger if the soil is sandy or has cracks and holes and the effects on sealing will then be larger as well. Knowledge of the rate of loss of water in specific cases is crucial for a proper simulation of farm and pond performance. It has been observed in some cases that the soil water table was actually high enough to replenish water taken from the pond. To simulate this feature and for calibration appropriate data from actual homesteads are required.

The shape of the pond has not been mentioned so far even though farmers are interested in this feature. The shape of the pond (oval, rectangular) or one large one or multiple small ones, will not affect the simulations much and any choice will not affect the results significantly. Practical advice, therefore, is to identify a shape in agreement with landscape (lower parts of the farm and following the landscape). A factor that farmers can influence is shading of the pond. This leads to a reduction of wind and insolation and hence of surface evaporation that is higher than the increase in transpiration by the shade trees.

Discussion

There is significant uncertainty in other and input-value parameters, as is usual for the farm model of a cropping system. Metselaar (1999) demonstrated the significance of parameter inaccuracy in predictive modelling, and showed that calibration is indispensable before practical results can be obtained. On-farm observations and interactive sessions with farmers are essential for further development.

One particular uncertainty is in the use of averaged weather data. Nonhebel (1994) found that the use of monthly averages instead of daily values may lead to overestimation of yields by 50% (unirrigated) to 15% (fully irrigated crops). Since our time interval is one week, the error is smaller but possibly still significant.

Before application of the model in specific situations it will be necessary to supply the relevant input data (weather, soils, farmscape, farm management data). In many cases, it will also be necessary to calibrate some of the key parameters, such as the rate of leakage of the pond, upwelling in low parts, and run-on from, and runoff to, neighboring grounds.

BoNam computes gross income of the farm (2004 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.

BoNam is a complex model that needs a skilled scientist to adapt it further to answer farmers' questions in full and to produce sets of realistic scenarios. How to select the pond size that fits best a particular farm from these scenarios requires no particular modelling skills but it has not yet been tested in practice. Yet, BoNam can already be used to guide ideas about pond construction.

It provides answers with respect to optimum size given a fair approximation of local conditions and farm management. It can also be used to guide crop management when the farm already has a pond of a given size.

Implementation

For results of models to be used in practice, action is required at the local and the national level: at the local level where advice is to be tailored to individual farms and training to be provided for optimal use of the pond, and at the national level where it should be adopted and adapted. A model is not like an engine that is produced in the factory and can be used straightaway after purchase. It needs to be adopted by a national partner who will look after its tuning to local conditions, provide crucial parameters that characterize local conditions, and employ trained local advisers in its use. In the case of BoNam, it may be expected that BoNam-FS is useful for the national science partner, and BoNam-SA for both the latter partner and the local farm advisers or FWN members (Figure 9). Results of the modelling exercise with earlier versions of BoNam were of interest to the Land Development Department (Penning de Vries et al. 2005), which is the Thai government science partner for pond construction, but they have not yet been taken up.

In FWN, a network of farmers exists that is willing to evaluate model performance and take up and promote any useful advice. The networks have already transformed the water use patterns and national policies to support those activities with small loans and by sharing knowledge in workshops and demonstrations. Their activities include local research to identify indigenous water resource rehabilitation and resource management technologies, research proposal screening for end-user participation, participatory technology development, biodiversity promotion, carbon sequestration, community forest management, and agroforestry. Network farmers are keen to try suggestions for improvements. For example, when IWMI suggested the use of bentonite and other clay-based materials, farmers organized field and pot tests and exchanged visits.

To promote self-sufficiency through integrated farming and multiple uses of water Learning Centers for Economic Self-Sufficiency were created by the farmer networks and the Bank of Agriculture And Cooperatives (BAAC) supported by the Ministry of Agriculture and Cooperatives. Already 36 such centers were operational in 2008 and 100 more were planned across the region by 2009, and together they will be instructing about 100,000 farmers per year. Concepts from BoNam as well as crucial results can be transmitted through the Learning Centers. A first round of interactions about BoNam with FWN members took place at a Learning Center in Buriram in 2004.

CONCLUSION AND RECOMMENDATIONS

In areas where water from the rainy season can be stored for productive activities in the dry season, such as supplementary irrigation of crops, construction of farm ponds can provide the required storage capacity in an effective manner. Water from ponds serves multiple purposes: various domestic uses if rainwater harvesting or piped water is insufficient, and irrigation of crops and trees, livestock and fish.

Determining the optimal size of a pond for a particular homestead is not a trivial task. A modelling approach is required to produce guidelines for construction of ponds and water management. Results produced with a model need to be communicated effectively to farmers. Existing farmer networks can be a vehicle for such communication in Northeast Thailand.

The climate of Northeast Thailand is characterized as 'tropical savannah'[6] in the updated Köppen-Geiger classification of climates (Peel et al. 2007). The tropical savannah is the second most common climate type and covers large parts of Asia, Africa and South America or 11.5% of the global area (ibid.; Figure 17). While this study addresses the situation in Northeast Thailand,

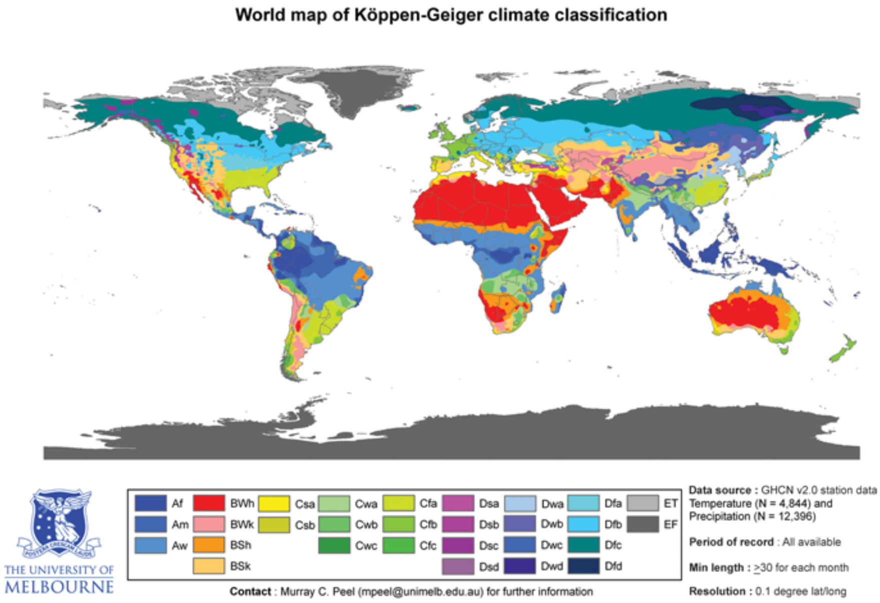

FIGURE 17. The updated Köppen-Geiger world map of climate clasification (from Peel et al. 2007). Results of this report are relevant for the Tropical Savannah (Aw) climate type that is widespread in the tropics.

similar problems of carrying over water from the wet to the dry season and of designing ponds occur in other regions with a tropical savannah climate. Results presented here could therefore be used as a basis for an approach to improved water supply on homesteads in other countries.

[6] The Tropical Savannah (Aw) climate is where temperature of the coldest month is over 18 °C and precipitation in the driest month is less than 4% of the annual total. The driest month in Northeast Thailand (January) receives less then 20 mm out of a mean annual precipitation of around 1,600 mm, while the coldest month (January) has a mean temperature of 24.5 °C.

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ISSN 2012-5763
ISBN 978-92-9090-725-1