*Research article*

# The sustainability of the *muang fai* irrigation system of northern Thailand

**Arriya Mungsunti[1,2] and Kevin A. Parton[1,*]**

[1] Institute for Land, Water and Society, and School of Management and Marketing, Charles Sturt University, Bathurst, NSW 2795, Australia
[2] Center for Sustainable Development Goals Studies (SDGs Center), Padjadjaran University, Bandung 40132, Indonesia

* **Correspondence:** Email: kparton@csu.edu.au; Tel: +61-263657654.

**Abstract:** The research was designed to understand the factors that have sustained the use of a seven-hundred-year-old irrigation system (*muang fai*) in northern Thailand, despite the challenge of a new technology: pumping irrigation water from underground. There were two main objectives. The first was to assess whether the *muang fai* system is sustainable. The second was to determine the contribution of the *muang fai* to the groundwater sustainability in the study region. This second objective is related to the United Nation's Sustainable Development Goal 6 (SDG6), water security. The results show that membership of the *muang fai* is changing slowly and the system is inherently stable, even given various pressures that tend to work against it, such as the increasing average farm size. Also, although the *muang fai* conserves water relative to other forms of irrigation, there is adequate recharge in the majority of the region to render this contribution to sustainability of the watershed relatively small.

**Keywords:** traditional irrigation; groundwater; sustainability; Chiang Mai; Thailand

## 1. Introduction

At first sight, the *muang fai* irrigation system of northern Thailand seems like an anachronism. It is, after all, a seven-hundred-year old system. There are many alternatives available locally including small-scale pumping of water from underground that some farmers have adopted. Nevertheless, in northern Thailand the *muang fai* continues to thrive, and our study area is typical

with just less than half of the irrigated farms being members of the *muang fai*. Our previous work [1] examined the factors that led longan (*Dimocarpus longan)* farmers to be members of the *muang fai* in Sop Rong, Chiang Mai Province, rather than adopt modern pump irrigation methods. It showed that both farm characteristics and a number of economic and social factors influence participation in the *muang fai*. In this paper, we extend these results to investigate whether the *muang fai* is resilient to external threats, such as increasing average farm size, and also assess the contribution that it makes to the local groundwater system. These research issues are related to the United Nation's (UN) Sustainable Development Goal 6 (SDG6), particularly Target 6.3, with the indicator "proportion of bodies of water with good ambient water quality", Target 6.4 with indicators for "water use efficiency over time" and "level of water stress: freshwater withdrawal as a proportion of freshwater resources" [2].

In the earlier work, a logistic model [3] was used to explain what factors affected the likelihood of farmers joining the *muang fai*; and propensity score matching enabled first a comparison between returns per hectare on *muang fai* farms and those pumping water from underground, and second a comparison between water use on the two types of farms. The distance of the farm from the nearest canal is inversely related to membership. The size of the cultivated area is also a strong predictor of membership, with probability of membership first increasing with area and then reducing once a critical size of 0.95 ha has been reached. Wealthier farmers and those who have more experience tend to use pump irrigation, possibly because they have greater financial resources and/or access to credit to purchase the equipment.

The propensity score matching analysis showed that there is no statistical difference in longan yields between *muang fai* farms and farms pumping water from underground. However, profits per hectare were significantly higher on *muang fai* farms. Further investigation, including chemical analysis of the water, revealed that the surface water quality of the *muang fai* farms tended to be better and this resulted in the production of larger, higher quality fruit, resulting in the higher profits. Finally, the water use efficiency was higher on *muang fai* farms when measured either as $m^3$/ha, $m^3$/kg of fruit, or $m^3$/Bhat of fruit sold. Moreover, on a per hectare basis, the *muang fai* farms use between 43% and 50% less water than the farms pumping water from underground.

Hence our previous work has answered some questions, but two important ones remained unanswered. The first concerns the sustainability of the *muang fai* itself. Is it under pressure from alternative modern irrigation systems that will be adopted more rapidly in future? Our perspective in examining this first sustainability issue is different from that of Ounvichit [4]. He looked within the operating rules of the *muang fai* in an upland system to assess how it could cope with the challenges of water scarcity. In contrast, we have largely examined external factors impinging on the *muang fai* in a lowland area. The second issue examined in this article is the contribution of the *muang fai* to the sustainability of the local groundwater system. That is, do the members of the *muang fai* in aggregate consume less water than if they individually used pumps to collect irrigation from underground, and if there is a difference, is it of importance in sustaining the groundwater system? It

is these two questions——sustainability of the *muang fai* and sustainability of the groundwater system——that form the basis of the current paper.

Recent work in hydrology has focused on the issues of how to define and measure sustainability of groundwater systems [5–8]. This research has re-directed the emphasis from safe yield of a groundwater system to sustainability [5,9]. Safe yield focuses on how much water could be extracted from a system based on its hydrological characteristics. In contrast, sustainability is a far broader concept that at the same time addresses the groundwater system more holistically, but also means a massive step-up in complexity that makes measurability challenging. Nevertheless, the more holistic approach is closer to the SDG6 approach of the UN. Indeed, the UN carries the holistic perspective beyond water resources to a concern about the impact of water resources on development generally [10].

The World Commission on Environment and Development [11] (p. 41) defined sustainability as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". In a hydrological context, Loucks and Gladwell [12] (p. 30) extended this definition so that "Sustainable water resource systems are those designed and managed to fully contribute to the objectives of society, now and in the future, while maintaining their ecological, environmental, and hydrological integrity". Moreover, in working from these broad definitions, Maimone [7] (p. 809) suggests that "the idea that there exists a single, correct number representing sustainable yield must be abandoned. In fact, it may not be possible to completely address the full complexity of the concept of sustainability in many situations. Much can be gained, however, by an organized approach toward developing a working definition, coupled with an adaptive management approach". From this perspective, Maimone [7] goes on to expound various issues that need to be considered in developing such an adaptive management approach. These include an understanding of the spatial and temporal aspects, defining the appropriate scale of analysis and system boundaries, developing a water budget, risk management within a probabilistic approach, assessing likely changes in technology and recognizing the limits to our knowledge. In this context we have used as a basis the approach proposed by Ashraf et al. [13] to obtain a quantitative measure of sustainability of the groundwater system. This was augmented by observations on water quality.

A description of the study site at Sop Rong and its traditional *muang fai* irrigation system is contained in the next section. This is followed in Section 3 by a discussion of materials and methods. Here the importance of the study site is explained, together with an outline of data collection procedures and the research methods. Then results, discussion and conclusions are contained in the final three sections.

## 2. Study site

For more than 700 years, agricultural communities in northern Thailand have used a communal irrigation system called *muang fai*[1] [14]. This system developed from co-operation within families to co-operation at the village level and then on to co-operation between a number of village-level

---

[1] *Muang fai* is a traditional structure of irrigation system in many areas of northern Thailand. It is commonly managed by villages or groups of rice farmers. The size of *muang fai* depends on the typography of the location. The method of irrigation is to use channels to direct surface water from rivers or streams on to small areas of farmland. It is a type of surface or border irrigation system.

user groups [15]. As a consequence, the knowledge of how to manage agricultural water, which emphasizes self-reliance and co-operation among *muang fai* members, is ingrained in local culture [14]. Over many years, the villagers discovered how to manage the water system effectively. The outcome was a set of rules of operation that enabled distribution of water to each individual farm taking into account the intricate way in which farms were physically linked.

The study site, *muang fai* Sop Rong, is located in San Pa Thong district of Chiang Mai Province. It is on the west bank of the Ping River in northern Thailand, and supplies the twelve villages shown in Figure 1, Sai Mul, San Khok Chang, Mae Khong Tai, Mae Khong Krang, Rong Khut, Mae Khong Nua, Mae Ka, Pa Kuay,Mae Kung Noi, Dong Pa Sang, and Dong Khi Lek.At its nearest point, the study site is 18 km south-south-west of the city of Chiang Mai. The length of the main canal is 7.8 km, and the system supplies 937 ha of farmland, largely used in paddy and longan production. Figure 2 shows the permanent headwork structure [16].
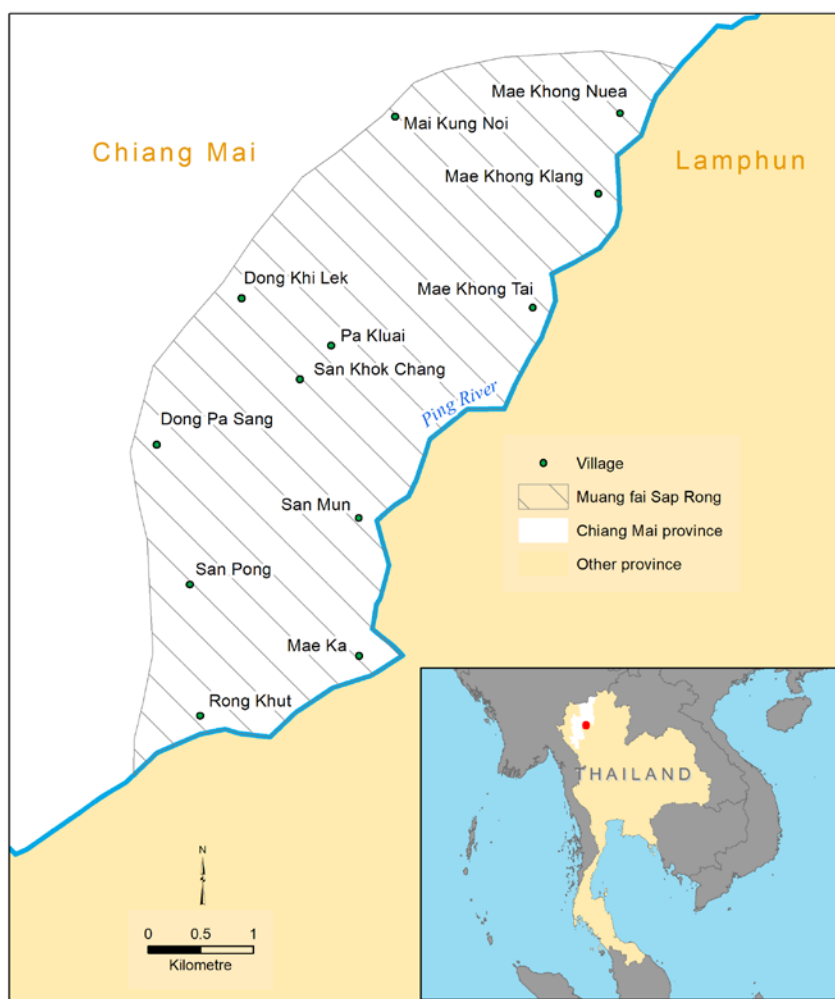


**Figure 1.** The study site of *muang fai* Sop Rong irrigation system.

Traditionally the headwork construction of the *muang fai* used locally found natural materials such as wood, logs and stones. Today, concrete construction, financed by government subsidy, has largely replaced these natural materials. During the planning phase of the *muang fai* construction,

various factors were considered. These included the gradient of the existing channel, the flow rate, seasonal variations in water depth, risk of flooding, and the water requirements of each farm in the system [17]. Figure 3 is a sketch showing the significant physical features. Water is diverted from a river, which is up to 20 metres wide, using weirs (*fai*) [18]. It then travels along major canals (*muang*), where a sluice gate (*tae*) is constructed to slow down the rate of flow and raise the level so that the water can be pumped on to cultivated areas [19].



**Figure 2.** The *muang fai* Sop Rong headwork area.

As explained by Mungsunti and Parton [1], only when water becomes limited does the water management of the Sop Rong irrigation system (our study site) switch to a set rotation schedule. The tail end villages extract the water first then the right to extract moves along to the head end village. If the water is not limited then normally the water is supplied constantly for any farmer to use. The irrigation system is closed once each year, usually in April, for cleaning and maintenance. Each farmer contributes labour for upkeep of the canals and pays a nominal annual fee. Annual fees are collected to cover any maintenance expenses and pay the *muang fai* manager (*kai-fai*), who is always a male farmer, each village *muang fai* leader, and any *muang fai* administrative staff [20].

Each farmer member of the *muang fai* agrees to the rules and regulations of the system. On the rare occasions that the rules are violated, the monthly meeting of members hears the issue and decides on any penalty.Appendix B of Mungsunti and Parton [1] contains additional details on the rules governing the operation of the *muang fai*.

An important consideration was that the study site consists of two distinct zones, characterised by topography and soils [22]. The area to the east, which accounts for about 83% of the total, is a component of the central alluvial channel. This is "dominated by the deposition of sand and gravel transported under high energy conditions by the Mae Nam Ping River. Wells in this area are relatively shallow (average depth about 50 m). In most cases adequate yields with low drawdown (high specific well capacities) have been reached within the top 30 m of the sediment" [22] (p. 191). Hence this is an area that would in general support further development using groundwater supplies. One restriction to this is that because of a lack of continuous cover of clayey/silty sediments, the area is vulnerable to groundwater pollution, and hence could be reaching critical limits in relation to Indicator 6.3.2 of SDG6, the proportion of the water body with good ambient water quality.
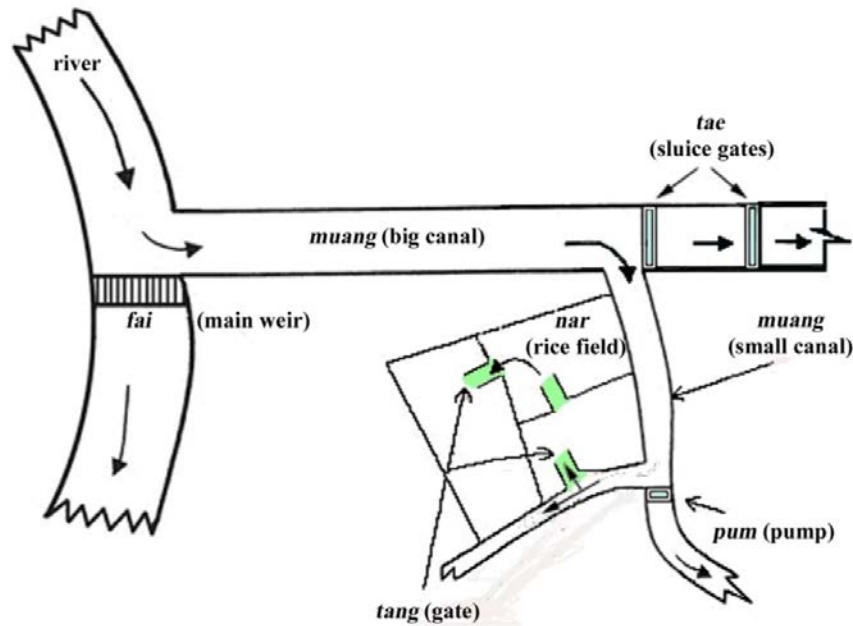
**Figure 3.** Design of a typical *muang fai* irrigation system. Source: [21].

The second area, to the west, comprising about 17% of the study region, is part of a zone of colluvial deposits. In this zone, there has been a relatively large lowering of the water table which "indicates that the recharge rate, especially in the deeper parts of the aquifer, is less than the abduction rate" [22] (p. 192).

## 3. Materials and methods

### 3.1 Significance of the study area

The communal irrigation system of *muang fai* Sop Rong was chosen for this study because it has been established for many generations. Even with the concrete headwork structure just mentioned, it still traditionally preserves certain physical features constructed of locally-found natural materials similar to the earliest period and operates according to long-established rules [23]. Thus the irrigation management is independent of government and in the hands of locals.

In the Sop Rong area there are both *muang fai* farmers and farmers who use the alternative method of pumping water from underground. The use of both technologies in the region was essential for our logistic analysis. Also, both groups of farmers are tending to use water for growing longan rather than paddy farming.

The sample frame was all longan farmers located in the 12 villages of *muang fai* Sop Rong. This sample frame was divided into two groups: *muang fai* members (MF) and non-members who are engaged in pumping irrigation water from underground (UG). The population data (Table 2) required to establish the sample frame were obtained from the Chiang Mai provincial office. The sampling interviews were not pre-arranged and were conducted at the farmer's house or elsewhere on the farm. The sampling continued until a minimum of 50% longan farmers had been interviewed, with a target of equal numbers of *muang fai* members and non-members. In total there were 929 longan farmers in the study region, of which 481 were surveyed, and of these 242 were *muang fai* members.

### 3.2 Survey instruments

As a preliminary step to designing the questionnaire, a number of qualitative interviews and focus group discussions were conducted with farmers in the study region. Most took place at a farmer's houses. The type of general information that was obtained included: area of different crops, quantity and costs of inputs, quantity of irrigation water used, availability of water, number of family members working on-farm and off-farm, and income from both agricultural and non-agricultural sources. Also discussed were any abnormal events during the previous season.

**Table 2.** Sample and population by village and type of irrigation.

| | Village | District | Total | Occupation | | Farmers | | Sample* | |
|---|---|---|---|---|---|---|---|---|---|
| | Name | Name | Pop | Farm | Non-Farm | Longan | Others | MF | UG |
| 1 | San Pong | Mae Ka | 79 | 64 | 15 | 61 | 3 | 1 | 34 |
| 2 | Sai Mul | Mae Ka | 173 | 56 | 117 | 43 | 13 | 6 | 10 |
| 3 | San Khok Chang | Mae Ka | 185 | 82 | 103 | 65 | 17 | 10 | 13 |
| 4 | Mae Khong Tai | Mae Ka | 182 | 89 | 93 | 76 | 13 | 36 | 3 |
| 5 | Mae Khong Krang | Mae Ka | 121 | 70 | 51 | 70 | 0 | 51 | 2 |
| 6 | Rong Khut | Mae Ka | 157 | 122 | 35 | 108 | 14 | 9 | 55 |
| 7 | Mae Khone Nua | Mae Ka | 103 | 55 | 48 | 53 | 2 | 36 | 6 |
| 8 | Mae Ka | Mae Ka | 127 | 63 | 64 | 56 | 7 | 7 | 23 |
| 9 | Pa Kuay | Mae Ka | 103 | 76 | 27 | 74 | 2 | 40 | 1 |
| 10 | Mae Kung Noi | Thung Tom | 241 | 115 | 126 | 105 | 10 | 12 | 14 |
| 11 | Dong Pa Sang | Ma Khun Wan | 225 | 123 | 102 | 104 | 19 | 10 | 43 |
| 12 | Dong Khi Lek | Ma Kham Luang | 173 | 118 | 55 | 114 | 4 | 24 | 35 |
| | | Total | 1869 | 1033 | 836 | 929 | 104 | 242 | 239 |

(* Sample of random longan farmers who were surveyed, MF and UG signify *muang fai* farmers and farmers who pump water from underground, respectively). Source: [24].

After designing the questionnaire, the survey was carried out through direct interviews at farm locations in the *muang fai* Sop Rong area during the months of March and April, 2011. Before commencing the survey, the survey team was located in the study area. To minimise the costs of travelling and have easy access to data sources when it was necessary, a house was rented for two months for 15 enumerators to live in. After the survey each day, the team leader would examine the quality and number of the questionnaires completed. They would evaluate the results of the survey to maintain consistency, then make a plan for the next day.

By administering the questionnaire, information was collected on farm structure, land use, socio-demographic characteristics of the farm family, total family income and share from farming activities, reasons for adopting or not adopting *muang fai*, and farmers' opinions on *muang fai* management and administration. It was considered important to be able to include in the model variables for age, gender, marital status, education level, farming experience, size of farmland, distance to the closest canal, and social influences from neighbours.

## 3.3 Research methods

As described in Section 1, the earlier components of our work involved the use of logistic regression to explain the factors that affected the likelihood of farmers joining the *muang fai*, and propensity score matching to compare returns per hectare on *muang fai* farms and on farms pumping water from underground, and to compare water use on the two types of farms. The logistic model takes the form:

$$P(y = 1 \mid x_i) = P(y = 1 \mid x_1, x_2, \ldots, x_k) \qquad (1)$$

This is a binary response model in which $x_i$ denotes a set of explanatory variables, and the dependent variable y denotes a *muang fai* participation indicator, which takes the value of 1 if participation occurs and value of 0 if participation does not occur. The $x_i$ contained various farm and farmer characteristics such as farm size, age, gender, marital status, level of education, and other factors that affect participation. The results of this part of the earlier analysis are shown in Table 3, in which column 2 is the estimated equation (1), with the dependent variable being probability of membership of the *muang fai*.

The first part of the method of the current analysis was to use the estimated equation of Table 3 and project forward the three exogenous variables, farm size, expenditure per capita (as a proxy for income) and distance to the nearest canal, while holding all other exogenous variables at their mean level. The objective was to discover how probability of membership of the *muang fai* was likely to change over the next 10 years, and thereby assess its sustainability. The method entailed the following three steps. First, estimates were obtained of the expected increases in farm income and area of longan crop per farm. Second, these were combined with the model of Table 3 to estimate the impact of these two changes in reducing the probability of *muang fai* membership. Third, the model was used again to estimate the required reduction in average distance to the nearest canal to offset the effects of the above changes in income and size of longan area. Then the minimum length of canal to obtain this reduction in distance was estimated, by modelling various alternative new canal investments. Hence, the analysis shows the minimum required investment in canal construction to overcome the underlying trends in income and farm size and hence maintain the membership of the *muang fai* system.

Having considered the sustainability of the *muang fai*, the next part of the analysis was to examine the sustainability of the local groundwater system. When water is withdrawn from groundwater for irrigation rather than from surface water, "greater effects on the subsurface water balance are found, leading to significant depletion of groundwater in regions with low recharge rate and high groundwater exploitation rate" [25] (p. 957). In addition, in the location of our study, it has previously been shown that the *muang fai* members each withdraw between 4,200 and 5,635 $m^3$/ha per year less than those using pumps to collect underground water [1]. These results indicate that the *muang fai* may have an impact on keeping the groundwater system balanced. Not only does it withdraw less water, but each cubic metre of water withdrawn may have lower impact on the groundwater system.

A number of papers [5–8] clarify important issues when assessing groundwater sustainability, and they also provide some descriptive analysis of both sustainable and unsustainable groundwater systems. Quantitative methods to assist in measuring the impact on sustainability of changes like the shift from the *muang fai* to pumping irrigation water from underground are still being developed. For example, Gleeson et al. [6] move us closer to an operational approach. Their proposal involves the

three steps of setting mutigenerational goals of 50 to 100 years for water quality and quantity, backcasting from these goals to define the required shorter-term policies, and then implementation through adaptive management.

**Table 3.** Estimation results of logistic model of *muang fai* participation.

|  | Coefficient | Standard error | Marginal effect | Standard error |
|---|---|---|---|---|
| *Farm characteristics (explanatory variables)* |  |  |  |  |
| Log of distance to closest canal (m) | −0.293*** | 0.083 | −0.073 | 0.021 |
| Log of area of the main crops (rai) | 1.693*** | 0.406 | 0.423 | 0.101 |
| Squared of log area | −0.474*** | 0.140 | −0.118 | 0.035 |
| *Socio-economic characteristics* |  |  |  |  |
| Gender, 1=male 0=female | 0.339 | 0.301 | 0.085 | 0.074 |
| Log of age | 1.925** | 0.760 | 0.481 | 0.190 |
| Marital status, 1=married 0=otherwise | −0.461 | 0.355 | −0.114 | 0.085 |
| *Education* |  |  |  |  |
| Elementary | −1.378* | 0.793 | −0.320 | 0.160 |
| Junior secondary | −1.096 | 0.897 | −0.256 | 0.181 |
| Senior secondary | −1.031 | 0.884 | −0.244 | 0.185 |
| University | −1.083 | 0.938 | −0.253 | 0.189 |
| Log of farming experience (years) | −0.588*** | 0.215 | −0.147 | 0.054 |
| Log of expenditure per capita (baht/week) | −0.377** | 0.169 | −0.094 | 0.042 |
| Off farm work days/week | −0.031 | 0.044 | −0.008 | 0.011 |
| *Community characteristics* |  |  |  |  |
| Proportion of households in the village that are *muang fai* members (%) | 0.043*** | 0.006 | 0.011 | 0.001 |
| Constant | −4.831 | 3.429 |  |  |
| Log likelihood | −260.42 |  |  |  |
| Likelihood ratio | 123.73*** |  |  |  |
| Pseudo R-squared | 0.1920 |  |  |  |

Note: *** significant at 1%, ** significant at 5%, * significant at 10%. Source: [1].

The most straightforward method, and applied in a study geographically close to our own, is Koch et al. [26]. They accepted that there are many definitions of sustainable groundwater yield, but environmental and political constraints are important. This led them to a definition of sustainable yield based on Department of Groundwater Resources [27]. In the aquifers under consideration, this definition was "the maximum total pumping rate above the current pumping rate that ensures that the average piezometric head in each layer does not fall below a distance of 20 metres from the land surface in the next 20 years" [27] (p. 6). They then employed this constraint within a 3D groundwater flow model called MODFLOW. The outcome was an estimate of sustainable yield of 1.30 $m^2$/rai/day (7.80 $m^3$/ha/day) for the Upper Chiang Rai aquifer system of northern Thailand. This method provides one component (the water budget) of the sustainability approach proposed by Maimone [7].

An alternative method is proposed by Ashraf et al. [13]. This is the method that has been applied in our case study at Sop Rong. It is based on Equation 2.

$$R_T + H_{in} - ds/dt = D_T + H_{out} = F_n \quad (2)$$

Where $H_{in}$ and $H_{out}$ are human return flows and withdrawals, respectively; $R_T$ is total recharge (from precipitation, surface water and adjacent aquifers); $D_T$ is total discharge from the aquifer (to surface water, adjacent aquifers and evapotranspiration); $F_n$ is the net flux; and $ds/dt$ is change in storage; with all units in $m^3$/ha/day. These variables define the data requirements.

Next, normalised human inflow and outflow can be obtained, as in Equations 3 and 4, respectively.

$$h_{in} = H_{in}/F_n \quad (3)$$
$$h_{out} = H_{out}/F_n \quad (4)$$

Where $h_{in}$ and $h_{out}$ are normalised human inflow and normalised human outflow, respectively.

As shown in Figure 4, a system is natural-flow dominated if $h_{out} < 0.5$ and $h_{in} < 0.5$; surcharged if $h_{out} < 0.5$ and $h_{in} > 0.5$; human-flow dominated if $h_{out} > 0.5$ and $h_{in} > 0.5$; and depleted if $h_{out} > 0.5$ and $h_{in} < 0.5$.
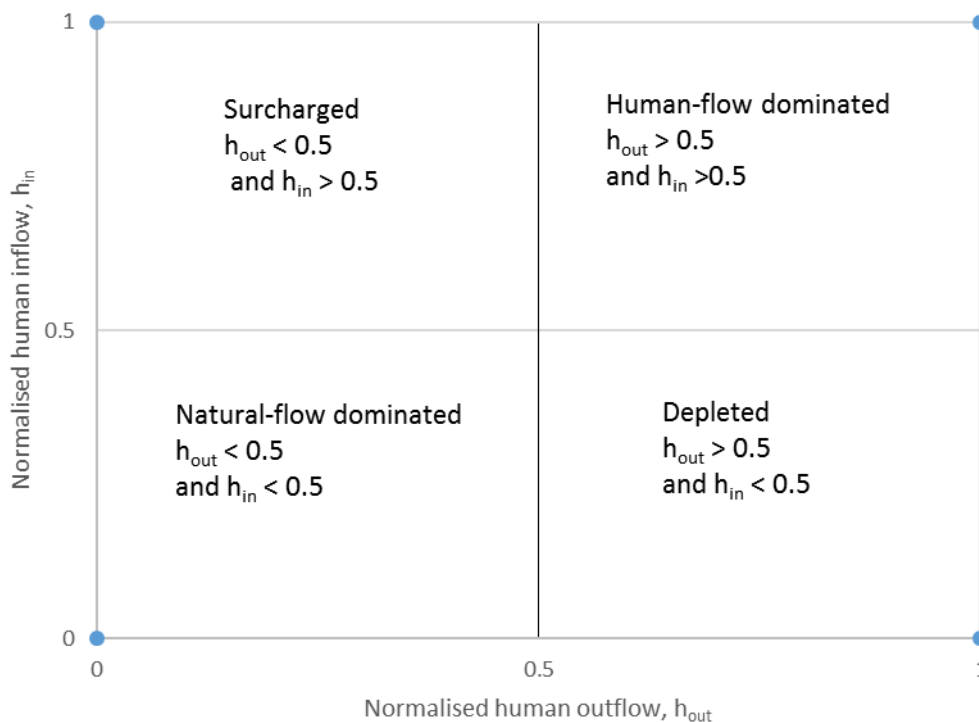


**Figure 4.** Matrix showing state of a groundwater system. Source: [13].

## 4. Results

To assess the sustainability of the *muang fai*, estimates were needed of the two exogenous variables, increase in household expenditure and change in area of longan crop. The expected expenditure increase over the next 10 years was equated with an increase in farm GDP of about 1.1 percent per annum between the fourth quarter of 2011 and third quarter of 2017 [28] compounded over 10 years. The outcome was an increase of 12.2 percent, which when inserted into the model of Table 3 resulted in a reduction of the probability of *muang fai* membership of 0.043.

The second exogenous variable was area of the main longan crop. In Thailand, production of longan fell slightly over the period from 2011 to 2016 on a roughly constant area [29]. Our interviews with farmers suggested that the area of longan in the study area was still increasing slowly. We used a value of 1% increase per annum for the analysis, which compounded over 10 years is about 10.5%. This resulted in a reduction of the probability of membership of the *muang fai* of 0.005 when inserted into the model of Table 3. The low values of both of these changes (i.e., less that a 5% change in aggregate probability of membership over a ten-year period) is an indicator of the inherent stability of the *muang fai* system.

Given that both of these changes resulted in a reduced probability of membership of the *muang fai*, the next step was to consider how membership probability could be sustained. One method is to construct additional canals so that distance to the nearest canal is reduced. Again, using the model of Table 3, it would require a reduction in distance of the nearest canal from an average of 57 metres to 49 metres to achieve the required offsetting increase in probability of membership of the *muang fai* of 0.048 (i.e. 0.043+0.005). These results are presented in Table 4.

The next step is to estimate the length of extra canal that would be required to reduce the average distance of the nearest canal by approximately 8 metres. The positioning of the extra canal sections is shown in Figure 5. This would require about an extra 860 metres of canal to be constructed.

**Table 4.** Impact on the probability of *muang fai* membership of various changes in exogenous variables.

| Change | Impact on probability of *muang fai* membership |
| --- | --- |
| Expected increase in expenditure of 12.2% | −0.043 |
| Expected increase in area of main longan crop | −0.005 |
| Required reduction of average distance to nearest canal of 57 to 49 metres. | +0.048 |

With respect to assessing the contribution of the *muang fai* to the sustainability of the groundwater system of the region, the method is to estimate the normalised human inflow, $h_{in}$, and normalised human outflow, $h_{out}$, that would occur with and without the continuation of the *muang fai* irrigation system. In the without case, it is assumed that all the members of the *muang fai* switch to pumping irrigation water from underground. Hence the changes in the normalised inflows and outflows provide an estimate of the impact on groundwater sustainability.

Using our own data augmented by Margane and Tatong [22] we estimated the different withdrawal rates, $H_{out}$, by farmers within the *muang fai* and farmers using irrigation water pumped from underground. The mean withdrawal rate by *muang fai* farmers was 2.43 m³/rai/day (14.59 m³/ha/day), whereas those using pumps withdrew 4.91 m³/rai/day (29.41 m³/ha/day). These are both higher than the 1.30 m³/rai/day (7.80 m³/ha/day) for the Upper Chiang Rai system estimated by Koch et al. [26], but unlike our study, this was for an upland basin system. The annual aggregate quantity of water withdrawn from the Sop Rong system under the present irrigation structure is about 6.55 million cubic metres per year. This would increase to approximately 8.88 million cubic metres per year if all *muang fai* farms used underground water instead. Given that agricultural yields would be unchanged [1], this shows that the existence of the *muang fai* improves the SDG6 indicators of water use efficiency (Indicator 6.4.1) and freshwater withdrawal as a proportion of freshwater resources (Indicator 6.4.2).
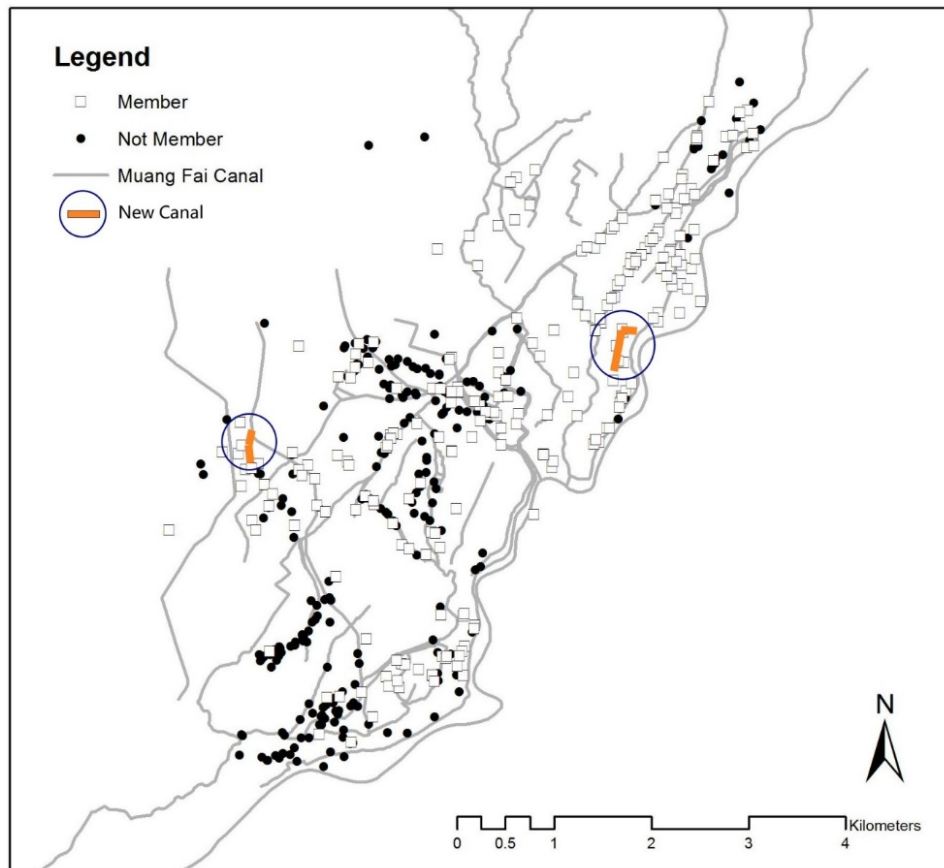
**Figure 5.** Location of the new canal sections needed to sustain the membership of the *muang fai* at the current level.

As noted in the section on the study site, the region consists of two distinct zones (east and west), characterised by topography and soils [22]. This meant that in the analysis that follows these two zones had to be assessed separately. The current state of the groundwater system can be described by estimating the initial normalised human inflow and initial normalised human outflow for the two areas of the study (eastern and western) at Sop Rong. This resulted in the initial points on the left-hand of each line shown in Figure 6. In both the eastern and western areas of our study site, the groundwater system is currently natural-flow dominated. As such it can be considered to be sustainable. Then by calculating the aggregate additional water that would be withdrawn by switching from the *muang fai* to entirely irrigation pumped from underground, together with linked subsequent effects, new estimates can be made of the normalised human inflow and normalised human outflow. These are shown by the right-hand ends of the two lines in Figure 6 (with arrows). In this way the lower of the two lines shows the transition as we move from the *muang fai* to underground irrigation for the eastern component of the study site, and the upper line the transition for the western component. In the case of the eastern component, the outcome is to remain natural-flow dominated, whereas the western area moves to become human-flow dominated. Hence, while both transitions result in a less sustainable outcome, the shift in the eastern area, which accounts for 83% of the total area, is marginal. In becoming human flow dominated, the western area is more concerning. However, the fact that the much larger eastern area remains natural-flow

dominated suggests that the overall impact on groundwater sustainability at Sop Rong of the transition away from the *muang fai* is small.
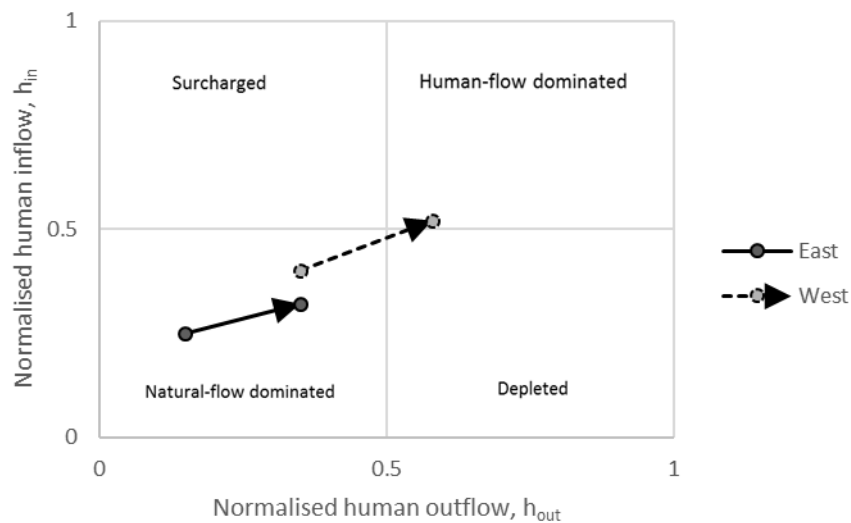


**Figure 6.** Effects on the Sop Rong irrigation area of transition from *muang fai* into irrigation water pumped from underground.

Of course these quantitative results focus on only one aspect of sustainability emphasised by Maimone [7], developing a water budget. Margane and Tatong [22] provided further qualitative data in terms of an assessment of groundwater vulnerability to the risk of contamination. This reveals that the Sop Rong area is medium to high risk and that "waste disposal and uncontrolled handling of potential contaminants should be avoided" [22] (p. 197). This especially applies to the more populated, eastern area adjacent to the Ping River. In summary, any transition away from *muang fai* irrigation towards irrigation based on pumping water from underground is only likely to directly affect the 17% of the area in the west of our study site, and even here the move would not be into a zone of depletion, but into a zone of human-flow domination. In the remainder of the study site, quantitative sustainability would be maintained by the high recharge rate. A qualitative issue would remain for the east of our study site because of the high groundwater vulnerability of the area in relation to the risk of contaminants. This would only be increased in a minor way by the transition away from the *muang fai*, but a cautious approach still needs to be taken whenever an existing risk of contaminants is increased.

## 5. Discussion

While we had made some progress previously in determining the factors that influence farmer's decisions to participate in the *muang fai* irrigation system, additional work described in this paper was needed to assess the sustainability of this traditional irrigation system. Also it was considered important to analyse the contribution of the *muang fai* to the sustainability of the local groundwater system. This is particularly pertinent to improve water use efficiency and reduce water stress within Targets 6.3 and 6.4 of the UN's SDG6 objectives.

The research findings indicated that a farmer's participation is inversely related to the farm's

distance to the closest *muang fai* canal. *Muang fai* membership was also shown to be inversely related to a farmer's economic status. A direct relationship was found between participation and proportion of villagers who were *muang fai* members. The relationship with size of farmland was found to be non-linear with participation probability first increasing with farm size, but then decreasing after some point.

Overall these results point to both the reasons for persistence to the present day of the *muang fai* irrigation system, but also to a future that may challenge its sustainability. There is a tension between positive and negative influences on *muang fai* membership. Our earlier work observed that membership of the *muang fai* was concentrated in some villages of the study area and no other villages that had very similar socio-economic and demographic profiles and were similar distances from the *muang fai* canal [1]. This membership concentration seemed to be the influence of a social network of the type also observed by Ounvichit [4]. However, this positive influence of the social network of *muang fai* communities may be facing increasing pressure as farms become larger and farmers wealthier, because it is clear that the wealthiest farmers with main crop areas in excess of about 1 ha are tending to use irrigation water pumped from underground. As time proceeds, some farmers may become convinced that their interest is to transition to pumping water from underground.

The analysis presented here indicates first that the above influences are slow moving and hence those factors are a small threat to the sustainability of the *muang fai*. Combined with Ounvichit's [4] observation that the internal operation of the *muang fai* enables it to be resilient in the face of reduced water supplies, these results provide some assurance for the continuance of the *muang fai* system.

A further result is that extending the canal system to encourage membership can overcome the negative influences on membership of increasing incomes and cultivation size. Government can fully or partially subsidise the investment in the new canals to make the *muang fai* water accessible. In such circumstances, an additional important element would be to educate farmers by demonstrating both the *muang fai* technology and the benefits of its outputs such as higher sales prices for the crops.

The second area of the study investigated the influence of the *muang fai* Sop Rong on the sustainability of the local groundwater system. While the literature points to many components of sustainability [5–9], the focus here was largely on quantity of groundwater use relative to recharge. In this context, the *muang fai* Sop Rong has a positive impact by conserving water. However, only in a small area of the study site is the critical quantitative limit of groundwater being reached. The results suggest that overall the *muang fai* reduces withdrawals by about 2.33 million cubic metres per year compared with pumping irrigation water from underground. However, this contributes in only a minor way to the sustainability of the local groundwater system. If all farmers in the *muang fai* moved to pumping irrigation water from underground then only for 17% of the area would there be a switch from a natural-flow dominated system to a human-flow dominated one with consequent recharge challenges. The other 83% may continue to be vulnerable to various risks of groundwater contamination, but would remain natural-flow dominated. Hence, the contribution of the *muang fai* Sop Rong to the UN's SDG6 indicators can be summarized as: (a) a small increase in the proportion of the body of water with good ambient water quality (Indicator 6.3.2); (b) an improvement in water use efficiency (Indicator 6.4.1); and a reduction in the level of freshwater removal as a proportion of freshwater resources (Indicator 6.4.2).

## 6. Conclusions

Two main research questions were answered in this study. First, the *muang fai* Sop Rong was shown to be resilient to the external challenges facing it. Although there are various pressures that tend to work against the *muang fai*, such as the increasing average farm size, membership is changing slowly and the system is inherently stable. Even without government support, probability of membership is unlikely to fall by more than 5% over the next ten years. Second, the *muang fai* system in the area does conserve groundwater to make the Sop Rong watershed more sustainable. However, only in one small location, representing some 17% of the total area, is groundwater reaching critical quantitative limits where the system would switch from natural-flow dominated to human-flow dominated if the *muang fai* was replaced by underground pump irrigation. Nevertheless, the *muang fai* Sop Rong does contribute to the UN's Sustainable Development Goal 6, in particular Indicators 6.3.2, 6.4.1 and 6.4.2.

Finally, it must be acknowledged that there is an important limitation in the research presented here. While the focus has been on sustainability, we would be the first to admit that when assessing the sustainability of a system like *muang fai* there are many aspects, including cultural, economic, environmental and social. For example, the *muang fai* is a social institution that carries with it important aspects of cultural heritage. These have not been considered in our assessment, which has focused mainly on environmental issues. We must leave for future research the challenges of considering and balancing these other different types of impacts.

## Acknowledgements

## Conflict of interest

All authors declare no conflicts of interest in this paper.

## References

1. Mungsunti A, Parton K (2017) Estimating the economic and environmental benefits of a traditional communal water irrigation system: The case of muang fai in Northern Thailand. *Agric Water Manage* 179: 366–377.
2. United Nations (UN) (2016) Sustainable Development Goal 6: Ensure availability and sustainable management of water and sanitation for all. Available from: https://sustainabledevelopment.un.org/sdg6#targets
3. Zhou S, Herzfeld T, Glauben T, et al. (2008) Factors Affecting Chinese Farmers' Decisions to Adopt a Water-Saving Technology. *Can J Agric Econ* 56: 51–61.
4. Ounvachit T (2011) Equal water sharing in scarcity conditions: the case of Chaisombat Muang Fai Irrigation System in Thailand. Paddy and Water Environment 9: 325–332.

5. Alley W, Leake S (2004) The Journey from Safe Yield to Sustainability. *Groundwater* 42: 12–16.

6. Gleeson T, Alley W, Allen D, et al. (2012) Towards Sustainable Groundwater Use: Setting Long-term Goals, Backcasting, and Managing Adaptively. *Groundwater* 50: 19–26.

7. Maimone M (2004) Defining and Managing Sustainable Yield. *Groundwater* 42: 809–814.

8. Zhou Y (2009) A Critical Review of Groundwater Budget Myth, Safe Yield and Sustainability. *J. Hydrol.* 370: 207–213.

9. Alley W, Reilly T, Franke O (1999) Sustainability of Ground-Water Resources. US Geological Survey Circular 1186. Denver. Available from: https://pubs.usgs.gov/circ/circ1186.

10. Ortigara, A R C, Kay, M, Uhlenbrook S (2018) A Review of the SDG6 Synthesis Report 2018 from an Education, Training, and Research Perspective. Water 10: 1353. Available from: https://www.mdpi.com/2073-4441/10/10/1353

11. World Commission on Environment and Development (1987) Our Common Future. New York: Oxford University Press.

12. Loucks D, Gladwell J (1999) Sustainability Criteria for Water Resource Systems. Cambridge: Cambridge University Press.

13. Ashraf B, AghaKouchak A, Alizadeh A, et al. (2017) Quantifying Anthropogenic Stress on Groundwater Resources. *Sci Rep* 7: 12910.

14. Surareks V (1986) Historical Development and Management of Irrigation System in Northern Thailand. Bangkok: Chareonwit Printing.

15. Wichienkiew A, Sattayawattana C, Panitchayakul P, et al. (2003) Water Resource Management: Muang Fai Tradition. In: Jammarik S, Sattayawattana C, editors. *Local Community Right of Original Indegenous Lanna: Case Study of Lua, Lou, Pakakayor (Karen) Communities in Nan, Chiang Rai, and Chiang Mai Provinces*. Bangkok: Nititham. pp. 120–130.

16. Ounvichit T, Wattayu S, Masayoshi S (2008) Participatory Management Structure of Large-Scale People's Irrigation System: The Case of the Soprong Muang Fai System, Northern Thailand. *Southeast Asian Studies* 46: 145–162.

17. Na-Tarang E (2001) Local Knowledge of Lanna. Bangkok: Ammarin Printing and Publishing.

18. Falvey L (2001) Sustainable Technologies in Thai Agriculture. *ATSE Focus* 115: 53.

19. Lertwicha P, Wichienchai A (2003) Village Community of Mae Karn River Basin. Bangkok: Tarn Punya Education.

20. Surareks V (2006) Muang Fai Communities in Northern Thailand: People's Experiences and Wisdom in Irrigation Management. *J Dev Sustain Pract* 1: 44–52.

21. Surareks V (1998) The Muang Fai Irrigation System of Northern Thailand: Historical Development and Management. *Tai Culture* 3: 37–48.

22. Margane A, Tatong T (1999) Aspects of Hydrogeology of the Chaing Mai-Lamphun Basin, Thailand that are important for Groundwater Management. *Zeitschrift fuer Angevandte Geologie* 45: 188–197.

23. RID (2003) Royal Irrigation Department Database. Chiang Mai: RID.

24. Chiang Mai Provincial Office (2010) Chiang Mai Provincial Population Report. Chiang Mai: Chiang Mai Provincial Office.

25. Leng G, Huang M, Tang Q, et al. (2014) Modeling the Effects of Groundwater-Fed Irrigation on Terrestrial Hydrology over the Conterminous United States. *J Hydrometeorol* 15: 957–972.

26. Koch M, Arlai P, Lukjan A (2012) Modeling Investigation on the future Permissible Yield in upper Chiang Rai Aquifers System. *Procedia Eng* 32: 69–76.

27. Department of Groundwater Resources (2009) Groundwater Resources Assessment in the Kok River Basin. Bangkok: Thai Government.
28. IEconomics.com (2017) Thailand–GDP from Agriculture. Available from: https://ieconomics.com/thailand-gdp-from-agriculture.
29. Win H (2017) Analysis of Tropical Fruits in Thailand. Available from: http://ap.fftc.agnet.org/ap_db.php?id=818.