

# Optimizing Decentralization of Management and Exploitation of Irrigation Works in Quan Lo-Phung Hiep Region, Mekong River Delta

Nguyen Duc Viet<sup>1</sup>, Nguyen Van Tinh<sup>1</sup>, Nguyen Tung Phong<sup>2</sup> and Dang Ngoc Hanh<sup>2</sup>

1. Directorate of Water Resources, Ministry of Agriculture and Rural Development (MARD), Hanoi 100000, Vietnam

2. Vietnam Academy for Water Resources (VAWR), Hanoi 100000, Vietnam

**Abstract:** In Vietnam as well as many countries which apply the irrigated agriculture over the world, the process of promoting the socialization trend in irrigation for the basic irrigation organizations, of which the main factor is water users, is very important. This paper aimed to optimize the decentralization of management and exploitation of irrigation works for water users, organizations in Quan Lo-Phung Hiep irrigation system of Mekong River Delta. The research has implemented a survey on 384 water users along four canals of level 2 of Quan Lo-Phung Hiep irrigation system under two sets of index: (1) water users' perception assessment of the irrigation works (14 indicators) and (2) assessment of the management efficiency in the irrigation works (six indicators). The research proposes the decentralization process from building. After determining the correlation coefficients, the multi-objective linear regression equation will be shown on six single objective functions. With the aim at achieving the highest efficiency in the management and exploitation of the irrigation works, there should be a shift in terms of the water users' perception of the irrigation works. These study results also demonstrate that about 65%-68% of the change in the indicators of the exploitation efficiency in the irrigation works is explained by some water users' perception indexes of irrigation works, including the quality of irrigation service and the output efficiency in agricultural production. By using the algorithm for multi-objective optimization problem, the optimal results in perception are determined. The input data is generated for the matrix supporting the decision making, and the decentralization of management and exploitation of irrigation works meets the three criteria, i.e., effectiveness, sustainability and flexibility.

**Key words:** Decentralization, irrigation management and exploitation, water user, irrigation services, Quan Lo-Phung Hiep, Mekong River Delta.

## 1. Introduction

Quan Lo-Phung Hiep is one of the five regions owning the largest irrigation system in Mekong Delta, serving the irrigated area for about 280,000 ha and 430,000 water users [1]. The water resource comes mainly from the tributaries of the Mekong River basin. The entire system has more than 100 km of the main canal axis, 426.2 km canals of level 1 and 28 gates which are used to prevent the saltwater and maintain the fresh water and hundreds of pumping stations [2]. The specific condition is that the irrigation works are in the form of open and semi-open states with the high connection, mixed in the various rivers; most of the

axis of canal is combined with the irrigation, water supply, deacidification, salinity intrusion prevention, etc.. Phat [3] reported that now Quan Lo-Phung Hiep irrigation system only has over 350 workers, who are directly managing the key irrigation works, with averagely one irrigation staff manages about 65 km of canal. In the irrigation system, the main canals and the channels of level 1 and level 2 are managed by one worker with 22 km and 36 km, respectively. Due to the insufficiency in human resources, many irrigation works in the Mekong Delta in general and the Quan Lo-Phung Hiep irrigation system in particular are not managed by the real managers. As a result, many degraded irrigation works with the waste and the serious water loss in the context of climate change and

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**Corresponding author:** Nguyen Duc Viet, Ph.D. candidate, research field: water resources engineering.

sea level rise are strongly impacting to Quan Lo-Phung Hiep region.

The urgent need of Quan Lo-Phung Hiep now is to promote the decentralization of management and exploitation of the irrigation works by state for the basic irrigation organizations (water users, water user organizations, service teams, households, etc.) in order to reduce the financial burden for the government, while ensuring the exploitation and use of the existing irrigation works efficiently and sustainably.

The decentralization of management and exploitation of the irrigation works based on the scientific basis is being mainly adopted, such as the area units (km<sup>2</sup>, hectare, etc.), the types of irrigation works (canals, drains, pumping stations, etc.) or the size of irrigation works (level 1, level 2, level 3 or on-farm) [4]. However, in fact, when the decentralization is applied to the areas of small-scaled irrigation works dispersed, like Quan Lo-Phung Hiep, there appears some disadvantages, such as (1) have not been consistent with the feature of irrigation work in the region; (2) have not included the market factors; (3) have not encouraged and promoted the socialization trend in irrigation; (4) have not been effective and sustainable [5].

According to the opinions of public administration by scholars, the decentralization of management can be established based on human behavior under the various approaches, such as perception and action. Besides, the water user is an integral part of an irrigation system [6]. Hence, one research hypothesis is the decentralization of management and exploitation of irrigation works for irrigation water users' organizations at community level based on the correlation between water users' perception and the management efficiency in the irrigation works. The constraint condition is the perception that must mean the impact on the efficiency of management and exploitation of irrigation works, including the quality of irrigation service and the output efficiency in agricultural production.

Today, the method using the optimal mathematical model is applied widely to select the best plans, bringing the most efficiency for supporting decision making. The fuzzy set theory with simple techniques, easy to use, will help to determine the highest point of awareness about irrigation works of water users and contribute to solve the problem of decentralization of management and exploitation of irrigation works for water users, organizations of Quan Lo-Phung Hiep irrigation system.

## 2. Material and Methods

### 2.1 Study Site

With the number of water users is 430,000 > 10,000, the expected error of 5% and reliability of 95%, so based on Cochran formula (1963) [7], the number of samples needed to be surveyed can be calculated by Eq. (1):

$$n = \frac{1.96^2 \times 0.5 \times (1-0.5)}{0.05^2} \approx 384 \quad (1)$$

To ensure the objectivity of the data, multi-stage sampling is employed. Four areas chosen in survey are four canals of level 2, namely, (1) Cai Nhuc-Cay Tram, (2) Pho Sinh, (3) Quan Lo-Nhu Gia and (4) Xang-Ca Mau (Fig. 1).

### 2.2 Methodology

Management and exploitation of irrigation works is only really meaningful, when it can demonstrate that the water users' perception has an impact on the exploitation efficiency. The process of determining the correlation between perception and efficiency is shown in Fig. 2 [1].

Two sets of indicators were built, including: (1) assessment of exploitation efficiency of irrigation works and (2) assessment of the perception of irrigation works. The detailed dependent variables ( $Y_i$ ) and independent variables ( $X_i$ ) are displayed in Table 1.

#### 2.2.1 The Correlation Analysis Method

With two variables  $X$  and  $Y$  having the same sample



**Table 1** Meaning of dependent and independent variables.

Dependent variable ( $Y_i$ )—exploitation effective	
$Y_1$	Effectiveness of repair and maintenance works
$Y_2$	Effectiveness of operation management
$Y_3$	Effectiveness of protection
$Y_4$	Assessing the quality of irrigation services
$Y_5$	Assessing the sustainability of irrigation management
$Y_6$	Effectiveness of production per unit of area
Independent variables ( $X_i$ )—water users' perceptions	
$X_1$	Awareness of head works
$X_2$	Awareness of channel levels
$X_3$	Awareness of points of water delivery
$X_4$	Awareness of regulation works
$X_5$	Awareness of owner of irrigation works
$X_6$	Awareness of water sources from irrigation system
$X_7$	Awareness of water fee
$X_8$	Awareness of water price consultation rights
$X_9$	Awareness of quality irrigation services based on fee
$X_{10}$	Knowing about operation of water distribution
$X_{11}$	Knowing about maintenance, repair and protection
$X_{12}$	Knowing about financial planning
$X_{13}$	Awareness of tidal sluices for water control, saltwater
$X_{14}$	Levels of readiness for financial participation

size ( $n$ ), Pearson correlation coefficients ( $r$ ) are calculated by Eq. (2):

$$r = \frac{\sum_{i=1}^n (X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum_{i=1}^n (X_i - \bar{X})^2 \sum_{i=1}^n (Y_i - \bar{Y})^2}} \quad (2)$$

where, the correlation coefficient ( $r$ ) value is from (-1 ÷ 1). If  $r < 0$ ,  $x$  and  $y$  are inverse correlation; if  $r > 0$ ,  $x$  and  $y$  are agreeable correlation.

### 2.2.2 The Multi-variate Regression Analysis Method

The purpose of multivariate regression analysis is to analyze the impact of the independent variables ( $X_i$ ) for each dependent variable ( $Y$ ), as linear Eq. (3):

$$Y = \alpha + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_n X_n \quad (3)$$

The condition for forming the linear regression Eq. (3) is of the same sample size ( $n$ ) according to Eq. (1), for independent variables  $X_i$  and one dependent variable  $Y$ .

### 2.2.3 Establishing Linear Multi-objective Optimization Function

The linear multi-objective optimization model on

the management and exploitation efficiency of the irrigation works is based on each linear regression equation between exploitation efficiency and water users' awareness of irrigation, then, a system of linear equations was set as Eq. (4):

$$f(Y) = [X_i; Y(Y_j)] \quad (4)$$

where,  $j$  is number of objective functions. Some boundary conditions for the variables in Eq. (4) were set as Eq. (5):

$$\begin{cases} g_k(X) (\leq, =, \geq) b_k, i = 1, 2 \dots m \\ X \in Z \subset R_n \end{cases} \quad (5)$$

where,  $g_k(X)$  represents the  $k$ th inequality constraint function,  $b_k$  is the value of the boundary conditions,  $m$  is number of inequality constraint functions,  $Z$  is the set of constraints and  $R_n$  is decision variables or design space [8].

With the desire to achieve the highest efficiency in the management and exploitation of the irrigation works,  $f(Y) \rightarrow \text{Max}$  of the multi-objective function was obtained.

### 2.2.4 Fuzzy Set Method

A classic approach but quite common to solve the multi-objective linear optimization problems is to use the fuzzy set theory [9].

Firstly, solving optimization problems for each single objective functions with the constraints was determined by the MATLAB software, and then, the fuzzy set functions for each target was identified using Eq. (6):

$$\mu[Y_j] = \frac{Y_j - Y_j^w}{Y_j^B - Y_j^w} \quad (6)$$

where,  $Y_j^B$  is the upper value,  $Y_j^w$  is the lower value.

The objective function was built in combination with the fuzzy set function as Eq. (7):

$$\mu = w_1\mu[Y_1] + w_2\mu[Y_2] + \dots + w_j\mu[Y_j] \rightarrow \text{Max} \quad (7)$$

where,  $w_1, w_2, \dots, w_j$  are the weights reflecting the importance of each fuzzy set function for the combined function according to the following conditions:

$$w_1 + w_2 + \dots + w_k = 1 \text{ or } 0 \leq w_1, w_2, \dots, w_j \leq 1.$$

Therefore, solving the multivariate objective function becomes the multivariate linear programming problem, which can be solved by simplex algorithm with the supporting tools, such as MULTIOPT, MATLAB, LINGO, etc..

### 2.2.5 The Matrix Method Supporting the Decision Making

The analytic hierarchy process (AHP) theory [10] is adopted in building the matrix supporting the decision making. One dimension of matrix is the hierarchy of the organizational type, the other one is the hierarchy of work levels (level 1, level 2, level 3 or on-field) of each irrigation work type (canals, drains, pumping stations, etc.). The water users' perception values of the irrigation works are considered the indicators.

Through the matrix supporting decision making, the decentralization point of management and exploitation will be suitably determined under the conditions of the irrigation works of each region and each locality.

## 3. Results and Discussion

On the basis of analyzing the correlation between 14 indicators of the water users' perception and each indicator of the set of management efficiency in the irrigation works (six indicators), there are six results correlated with the correlation coefficient from 0.65 to 0.68. This result leads to a same assumption with the research on Karacabey irrigation system, Turkey [6].

However, this is a new research study, and it has not identified whether the relationship line yet (power, quadratic, cubic, logarithmic, exponential or linear, etc.) is the most suitable one to describe the sample data. It is necessary to apply the multiple linear regression line (Fig. 3) and then choose the best line for description.

By applying Statistical Package for the Social Sciences (SPSS), the correlation results are described via six single linear regression models as Eqs. (8)-(13):

Effectiveness of repair and maintenance works:

$$Y_1 = 2.170 + 1.437X_1 + 1.873X_2 + 2.574X_3 + 1.012X_4 + 1.686X_5 - 0.249X_6 + 2.342X_7 + 0.221X_8 + 3.162X_9 \quad (8)$$

Effectiveness of operation management:

$$Y_2 = 0.395 + 1.023X_2 + 2.048X_3 + 0.575X_4 + 0.088X_6 + 0.030X_8 + 0.387X_9 \quad (9)$$

Effectiveness of protection:

$$Y_3 = 2.4 + 0.69X_1 + 0.070X_2 + 1.150X_3 + 0.230X_4 + 1.090X_8 + 0.612X_9 \quad (10)$$

Assessing the quality of irrigation services:

$$Y_4 = 4.041 + 1.490X_2 + 1.369X_3 + 3.897X_4 + 0.552X_5 + 2.334X_7 + 1.139X_8 + 3.389X_9 \quad (11)$$

Assessing sustainability of irrigation management:

$$Y_5 = 1.278 + 0.113X_1 + 0.013X_2 + 0.017X_3 + 0.398X_4 + 0.231X_6 + 1.101X_8 + 0.258X_9 \quad (12)$$

Effectiveness of production per unit of area:

$$Y_6 = 2.581 + 0.040X_2 + 0.183X_4 + 0.039X_8 + 0.039X_9 \quad (13)$$

Consequently, after analyzing, it can be seen that linear is the most suitable to describe the existing data in the study.

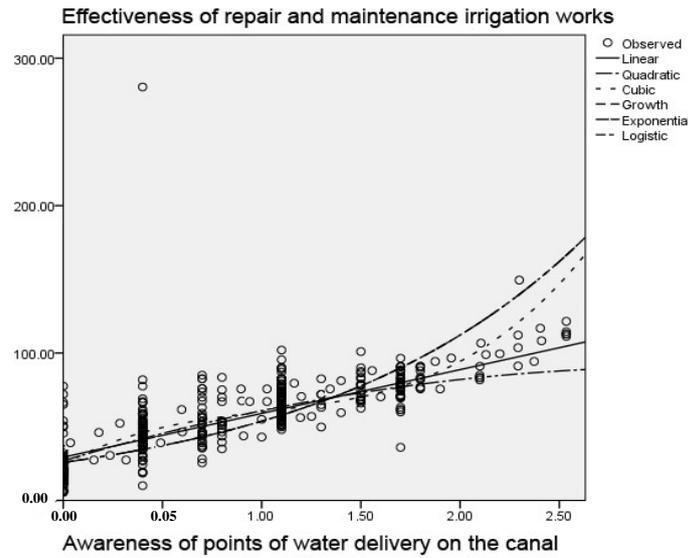


Fig. 3 Some regression lines between the perceptions and the management efficiency in irrigation works.

From six single objective functions Eqs. (8)-(13), the multi-objective function is built to reach the highest efficiency in the exploitation of irrigation works under the constraints conditions as Eq. (14):

Objective function:

$$f(Y) = [X_i; Y(Y_i) = u] \rightarrow \text{Max or Min } [-f(Y)] \quad (14)$$

where,  $u = w_1\mu[Y_1] + w_2\mu[Y_2] + w_3\mu[Y_3] + w_4\mu[Y_4] + w_5\mu[Y_5] + w_6\mu[Y_6]$

With  $w_1 = w_2 = w_3 = w_6 = 0.2$ ,  $w_4 = w_5 = 0.1$  and the constraints are as following:

$$\left\{ \begin{array}{l} 0.54 \leq X_1 \leq 3 \\ 1.16 \leq X_2 \leq 3 \\ 0.82 \leq X_3 \leq 4 \\ 1.78 \leq X_4 \leq 4 \\ 1.36 \leq X_5 \leq 4 \\ 0.80 \leq X_6 \leq 4 \\ 0.85 \leq X_7 \leq 4 \\ 1.13 \leq X_8 \leq 4 \\ 1.36 \leq X_9 \leq 3 \\ X_4 - X_7 \geq 0 \\ X_8 + X_9 - X_7 \geq 0 \\ X_1 \leq X_2 \leq X_3 \leq X_4 \end{array} \right.$$

The lower boundary values of the average value of water users' perceptions of irrigation works at the time of this study is 0.54, 1.16, 0.82, 1.78, 1.36, 0.80, 0.85, 1.13, 1.36 for  $X_i$ .

Solving the multi-objective functions with the constraint conditions according to the method of fuzzy set by MATLAB R2015a software, then the optimal results were obtained in Table 2 and Fig. 4.

Fig. 4 shows that the exploitation of irrigation works achieves the highest value when:

- (1) Water users are aware that the irrigation water source for agricultural production is from the system of irrigation works ( $X_5$ );
- (2) Water users know how to distribute water continuously from the level 3 channels to positions of getting water, especially the skills of self-resolve the conflicts that may occur during getting water ( $X_8$ );
- (3) Water users know how to self-maintain, repair and protect small irrigation works, infield irrigation ( $X_9$ ).

By the time of the survey in 2014, the potential development of water users at community level in Quan Lo-Phung Hiep is from level 1 to level 5 as follows:

Level 1: individual households or water user;

- Level 2: irrigation services group;
- Level 3: co-operative group using water;
- Level 4: water user organization;
- Level 5: inter-commune irrigation management.

Thus, each type of different irrigation management organization model will also have different requirements in terms of awareness of water users, applying the matrix method supporting decision making on decentralization for each type of work with various specific tasks as shown in Table 3.

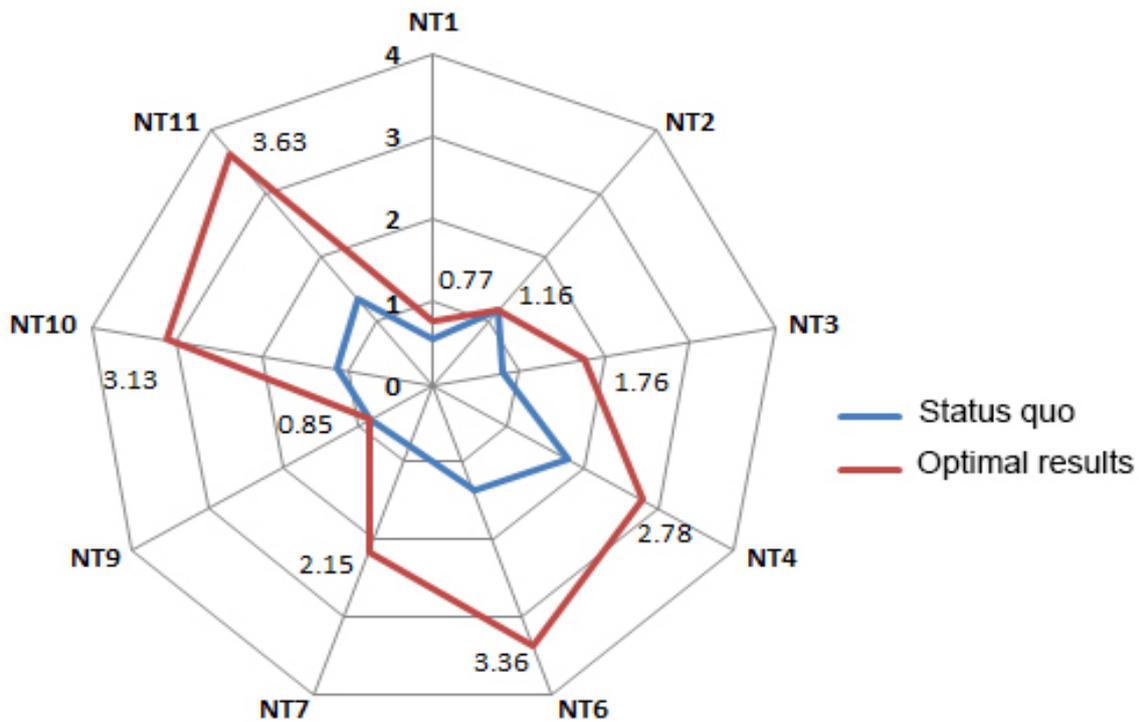
The proposed decentralization of management and exploitation of irrigation works in Table 3 will help

the policy makers related to irrigation management in decision making of decentralization irrigation works in line with the capacity of water users of Quan Lo-Phung Hiep irrigation system.

Specifically in Table 3, for the task of managing the irrigation work (task 1) with the average perception index of 2.0, water users can perform the management of level 3 canals and infield. However, with the task of operating and distributing water (task 2), water users have average awareness level reaching 2.5. Thus, it can be said that they can perform this task, even adding canals of level 2.

**Table 2 Comparing the results of optimization of water users' perception of irrigation works at the time of this study.**

Awareness	Status quo	Optimal result	Proposed
NT1 = $X_1$	0.54	0.77	1
NT2 = $X_2$	1.16	1.46	1
NT3 = $X_3$	0.82	1.76	2
NT4 = $X_4$	1.78	2.78	3
NT6 = $X_5$	1.36	3.36	3
NT7 = $X_6$	0.80	2.15	2
NT9 = $X_7$	0.85	0.85	1
NT10 = $X_8$	1.13	3.13	3
NT11 = $X_9$	1.36	3.63	4



**Fig. 4 The graph of awareness optimizing trend of irrigation works of water users.**



(Table 3 continued)

Optimize decentralization of management and exploitation of irrigation works for water users, organizations in Quan Lo-Phung Hiep												
Proposed tasks		Task 3: protection, monitoring and tracking the quality of the water in irrigation system										
Score	Type of works	Canal				Sluice				Pumping station		
	NT requirements	NT2, NT6, NT11 (average value = 2.67)				NT3, NT4, NT11, NT13 (average value = 2.25)				NT11, NT14 (average value = 2)		
	Value of awareness	[NT2 = 1; NT6 = 3; NT11 = 4]				[NT3 = 2; NT4 = 3; NT11 = 4; NT13 = 0]				[NT11 = 4; NT14 = 0]		
	Proposed value (highest average value)	Primary canal	Secondary canal	Third canal	On-farm canal	Prevent salty, keep sweet	Sluice at the primary canal	Sluice at the secondary canal	Sluice at the on-farm canal	Big pump station	Makeshift pump station (100-300 ha)	On-farm pump (5-100 ha)
0	Household	<<-□---	■	■	■	<<-□-----□-----□-----			■	<<-□---	■	■
1	Services group	<<-□---	■	■	■	<<-□-----□-----		■	■	<<-□---	■	■
2	Co-operative group	<<-□---	■	■	■	<<-□-----□-----		■	■	<<-□---	■	■
3	WUOs/ WUAs	<<-□---	■	■	■	<<-□-----□-----		■	■	<<-□---	■	■
4	Inter-commune	□	□	□	□	□	□	□	□	□	□	□
Proposed tasks		Task 4: maintenance and repair of irrigation works										
Score	Type of works	Canal				Sluice				Pumping station		
	NT requirements	NT6, NT8, NT9, NT11, NT14 (average value = 2)				NT6, NT8, NT9, NT11, NT13, NT14 (average value = 1.33)				NT8, NT11, NT14 (average value = 1.33)		
	Value of awareness	[NT6 = 3; NT8 = 0; NT9 = 3; NT11 = 4; NT14 = 0]				[NT6 = 3; NT8 = 0; NT9 = 1; NT11 = 4; NT13 = 0; NT14 = 0]				[NT8 = 0; NT11 = 4; NT14 = 0]		
	Proposed value (highest average value)	Primary canal	Secondary canal	Third canal	On-farm canal	Prevent salty, keep sweet	Sluice at the primary canal	Sluice at the secondary canal	Sluice at the on-farm canal	Big pump station	Makeshift pump station (100-300 ha)	On-farm pump (5-100 ha)
0	Household	<<-□-----□-----		■	■	<<-□-----□-----□-----			■	<<-□-----□-----		■
1	Services group	<<-□-----□-----		■	■	<<-□-----□-----□-----			■	<<-□-----□-----		■
2	Co-operative group	<<-□-----□-----		■	■	<<-□-----□-----□-----			■	<<-□-----□-----		■
3	WUOs/WUAs	□	□	□	□	□	□	□	□	□	□	□
4	Inter-commune	□	□	□	□	□	□	□	□	□	□	□

■: type of irrigation are proposed for decentralization of management and exploitation for water users, organizations; □: task or service delivery points; <-----: responsible for performing state management related to irrigation works.

#### 4. Conclusions

By the measuring scale with Cronbach's Alpha index ( $\alpha$ ) and the correlation with the Pearson index ( $r$ ), it can be seen that there are only nine out of 14 cognitive assessment indicators of water users which really have positive influence on the efficiency of exploiting irrigation works, with Pearson index ( $r$ ) value ranging from 0.65 to 0.68.

The outputs of the optimization problem of irrigation perception are inputs for the matrix supporting decision making. Based on each specific task, each type of irrigation work will be distributed corresponding to the potential development of irrigation management organizations at the local level in Quan Lo-Phung Hiep.

However, in reality, there is always more than one base to contribute to improve the efficiency of management and exploitation of irrigation works, such as seed, plant breeding, cultivation techniques, fertilization regimes, local culture, market factors, etc.. Therefore, it is necessary to have further studies to overcome the limitations of this study.

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