SELECTED APPROPRIATE DECISION SUPPORT TOOL FOR SUSTAINABLE RAIN-FED AGRICULTURE REFERENCED TO THE NEW THEORY OF HIS MAJESTY KING BHUMIBOL ADULYADEJ THE GREAT: A CASE STUDY OF KHAO WONG DISTRICT, KALASIN PROVINCE OF THAILAND

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A Dissertation Submitted in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy in Environment, Development and Sustainability
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เครื่องมือคัดเฉพาะเพื่อสนับสนุนการตัดสินใจที่เหมาะสมสำหรับพื้นที่เกษตรกรรมน้ำฝนอย่างยั่งยืนตามแนวทฤษฎีใหม่ของพระบาทสมเด็จพระมหาภูมิพลอดุลยเดชมหาราช บรมนาถบพิตร: กรณีศึกษา อำเภอเขาวง จังหวัดกาฬสินธุ์ ประเทศไทย

น.ส.อนุตรา วรรณวิโรจน์

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาศิลปศาสตรดุษฎีบัณฑิต
สาขาวิชาสิ่งแวดล้อม การพัฒนา และความยั่งยืน สหสาขาวิชาสิ่งแวดล้อม การพัฒนาและความยั่งยืน
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อนุตรา วรรณวิโรจน์ : เครื่องมือคัดเฉพาะเพื่อสนับสนุนการตัดสินใจที่เหมาะสมสำหรับพื้นที่เกษตรกรรมน้ำฝนอย่างยั่งยืนตามแนวทฤษฎีใหม่ของพระบาทสมเด็จพระมหาภูมิพลอดุลยเดชมหาราช บรมนาถบพิตร: กรณีศึกษา อำเภอเขาวง จังหวัดกาฬสินธุ์ ประเทศไทย. (SELECTED APPROPRIATE DECISION SUPPORT TOOL FOR SUSTAINABLE RAIN-FED AGRICULTURE REFERENCED TO THE NEW THEORY OF HIS MAJESTY KING BHUMIBOL ADULYADEJ THE GREAT: A CASE STUDY OF KHAO WONG DISTRICT, KALASIN PROVINCE OF THAILAND) อ.ที่ปรึกษาหลัก : รศ. ดร.ทวีวงศ์ ศรีบุรี

ประเทศไทยเป็นประเทศเกษตรกรรมซึ่งพื้นที่ทางการเกษตรของประเทศเกือบร้อยละ 80 เป็นพื้นที่เกษตรน้ำฝน สระน้ำประจำไร่นาซึ่งเป็นแหล่งน้ำขนาดเล็กแบบพึ่งพาตนเองด้วยการเก็บน้ำฝนสำหรับใช้ตลอดทั้งปีจึงมีความสำคัญอย่างยิ่งสำหรับเกษตกรในพื้นที่เกษตรน้ำฝน เกษตรกรเหล่านี้จึงจำเป็นต้องเลือกแผนการจัดการน้ำเพื่อการเกษตรที่ใช้น้ำฝนที่มีอยู่อย่างจำกัดในสระน้ำประจำไร่นาอย่างมีประสิทธิภาพและประสิทธิผลเพื่อตอบสนองความต้องการด้านต่างๆ ของครัวเรือน อันจะนำไปสู่เกษตรกรรมน้ำฝนที่ยั่งยืน การศึกษานี้จึงมีเป้าหมายที่จะคัดเลือกเครื่องมือเพื่อสนับสนุนการตัดสินใจที่เหมาะสมสำหรับพื้นที่เกษตรกรรมน้ำฝนอย่างยั่งยืนตามแนวทฤษฎีใหม่ของพระบาทสมเด็จพระมหาภูมิพลอดุลยเดชมหาราช บรมนาถบพิตร โดยใช้วิธีการวิจัยแบบผสมประกอบด้วยการทบทวนวรรณกรรม การสำรวจพื้นที่ การประชุมเชิงปฏิบัติการสำหรับการประเมินโดยผู้เชี่ยวชาญ การสัมภาษณ์แบบมีโครงสร้าง และการทำแบบสอบถามชนิดให้ผู้ตอบกรอกข้อมูลด้วยตนเอง นอกจากนี้ ยังได้ประเมินความสามารถในการใช้งานของต้นแบบเชิงแนวคิดของเครื่องมือเพื่อสนับสนุนการตัดสินใจโดยกลุ่มตัวอย่างในพื้นที่นอกเขตชลประทานของตำบลสงเปลือย อำเภอเขาวง จังหวัดกาฬสินธุ์ ซึ่งเป็นพื้นที่กรณีศึกษาของงานวิจัยนี้

ผลการศึกษาที่ได้คือเครื่องมือคัดเฉพาะเพื่อสนับสนุนการตัดสินใจซึ่งออกแบบมาโดยเฉพาะสำหรับเกษตรกรในพื้นที่เกษตรน้ำฝน องค์ประกอบต่างๆ ของเครื่องมือซึ่งประกอบด้วยการกำหนดปัญหา ข้อกำหนด เป้าหมาย หลักเกณฑ์สำหรับใช้ในการประเมิน และแผนทางเลือกในการจัดการน้ำเพื่อการเกษตร ได้จัดทำขึ้นให้สอดคล้องกับวัตถุประสงค์ในการทำการเกษตรของกลุ่มเกษตรกรกลุ่มนี้ อีกทั้งยังตั้งอยู่บนแนวคิดเรื่องเกษตรกรรมที่ยั่งยืนและทฤษฎีใหม่เพื่อให้สอดคล้องกับสภาพภูมิสังคมของเกษตรกรรมน้ำฝนแบบไทย แผนทางเลือกในการจัดการน้ำเพื่อการเกษตรได้รับการประเมินโดยหลักเกณฑ์ผ่านกระบวนการลำดับชั้นเชิงวิเคราะห์ (AHP) โดยแผนที่ดีกว่าจะได้รับเลือกและตรวจสอบความสมเหตุสมผลซึ่งผลที่ได้แสดงให้เห็นว่าแผนที่ได้รับเลือกสามารถสร้างสมดุลน้ำ สนับสนุนเกษตรกรรมแบบพึ่งพาตนเอง สร้างความพอเพียงในครัวเรือน และทำให้เกิดเกษตรกรรมน้ำฝนที่ยั่งยืน ผลจากการประเมินความสามารถในการใช้งานของต้นแบบเชิงแนวคิดของเครื่องมือเพื่อสนับสนุนการตัดสินใจพบว่าคุณลักษณะโดยรวมของเครื่องมือมีความสามารถในการใช้งานอยู่ในระดับดี คิดเป็นคะแนนเฉลี่ยรวม 4.26 คะแนน จากคะแนนเต็ม 5 คะแนน คุณลักษณะที่ได้คะแนนสูงสุดประกอบด้วยการสนับสนุนการตัดสินใจ ความน่าสนใจ การนำไปใช้ประโยชน์ได้จริง และการนำเสนอแนวคิด ในขณะที่คุณลักษณะที่ได้คะแนนต่ำสุดประกอบด้วยความถูกต้องแม่นยำและความเข้าใจง่าย ซึ่งคุณลักษณะเหล่านี้ควรจะต้องได้รับการพัฒนาเพื่อเพิ่มความสามารถในการใช้งานจริงของเครื่องมือและการยอมรับของผู้ใช้งานในอนาคต

สาขาวิชา	สิ่งแวดล้อม การพัฒนา และความยั่งยืน	ลายมือชื่อนิสิต ....
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KEYWORD: DECISION SUPPORT TOOL, SUSTAINABLE RAIN-FED AGRICULTURE, NEW THEORY, HIS MAJESTY KING BHUMIBOL ADULYADEJ THE GREAT

Anutra Wannaviroj : SELECTED APPROPRIATE DECISION SUPPORT TOOL FOR SUSTAINABLE RAIN-FED AGRICULTURE REFERENCED TO THE NEW THEORY OF HIS MAJESTY KING BHUMIBOL ADULYADEJ THE GREAT: A CASE STUDY OF KHAO WONG DISTRICT, KALASIN PROVINCE OF THAILAND. Advisor: Assoc. Prof. Thavivongse Sriburi, Ph.D.

Thailand is an agricultural country of which almost 80% of the total agricultural land is rain-fed. An on-farm pond, which is a self-reliant small-scale water source for harvesting the rainwater to be used for the whole year, becomes radical for farmers in this area. These farmers need to select the agricultural water management scheme which uses limited rainwater harvested in the on-farm pond efficiently and productively to fulfill their household needs, which will lead to sustainable rain-fed agriculture. Therefore, the study aimed to select an appropriate decision support tool for sustainable rain-fed agriculture referenced to the New Theory of His Majesty King Bhumibol Adulyadej The Great. This research applied mixed methods for collecting data, including desk review, field visit, workshops for the expert judgement, structured interview, and self-administrated questionnaire. The conceptual prototype of the tool was also tested for its usability with the sample group in the unirrigated area of Song Plueai sub-district, Khao Wong district, Kalasin province, which was the study area of this research.

The result of the study was the selected appropriate decision support tool which was purposely designed for farmers in the rain-fed area. Components of the tool, including problem statement, requirements, goal, assessment criteria, and alternative schemes were developed based on their agricultural operational objective as well as the concept of sustainable agriculture and the New Theory in order to make the tool compatible with topographical and sociological conditions of Thai rain-fed agriculture. Alternative schemes were evaluated by assessment criteria through the application of the AHP technique. The preferred scheme was selected and validated. The resulted showed that the preferred scheme was able to balance farm water demands and supply, promote self-reliant agriculture, ensure household self-sufficiency, and enhance sustainable rain-fed agriculture. The result of the field usability testing showed that the overall attributes of the conceptual prototype of the tool was good with the total score 4.26 out of 5 points. Attributes with the highest score included decision support, interest, applicability, and concept presentation. While, attributes with the lowest score were accuracy, ease of use, and learnability. Therefore, these attributes should be improved to enhance the tool functionality and user acceptance in the future.

Field of Study:	Environment, Development and Sustainability	Student's Signature ....
Academic Year:	2018	Advisor's Signature ....

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INTRODUCTION

1.1 Rationale

A decision support tool comprises a wide range of systems, tools, and technologies, which help decision makers use data, documents, knowledge, communication technologies, and models to support a decision, complete decision process tasks, and solve sophisticated, complex, or simple problems (Power, 1997; Sprague, 1980). It is used for a wide range of natural resource management purposes, sustainable agricultural resource management in particular (Adham et al., 2016; Baker et al., 2001; Fülöp, 2005; Mendoza et al., 1999; Mendoza & Martins, 2006; Mendoza & Prabhu, 2000a, 2000b, 2003; Mysiak, Giupponi, & Rosato, 2005; Qureshi & Harrison, 2001). These subjects have multiple and conflicting objectives in nature, which requires consideration of social, economic, environmental, political, and technical issues in a structured framework for making a rational decision.

In the field of agriculture, the decision support tool helps decision makers manage agricultural resources to fulfill their needs; while, maintaining and enhancing the quality of the environment and conservation of natural resources. However, the main challenge for the achievement of the sustainable agriculture is in the rain-fed area where rainwater is the main water source for agriculture and thus it becomes an essential agricultural resource. This area accounts for more than 75% of the cultivated area in the world, houses one-third of people in developing countries, and produces around 60% of global food (Reddy & Syme, 2015). Without the water, crops and livestock die, people lose their income and go hungry, and the sustainability of rain-fed agriculture is threatened.

In Thailand, rain-fed agriculture covers almost 80% of the total agricultural land of the country (Ministry of Agriculture and Cooperatives [MOAC], 2017). The Land Development Department, the Ministry of Agriculture and Cooperatives, has tried to promote sustainable rain-fed agriculture in Thailand through the provision of more than 450,000 on-farm ponds to farmers in the rain-fed areas throughout the country since 2005 (MOAC, 2018). These on-farm ponds are a self-reliant water source which harvest the rainwater in the rainy season to be used as supplemental irrigation during dry spells and in the dry season. They enable these farmers use agriculture to live their lives for the whole year until the next rainy season and reduce their vulnerability to increasing climate variability and change (Adham et al., 2016; Ali, 2010; Critchley & Siegert, 1991; Oweis, Hachum, & Kijne, 1999; Oweis, Prinz, & Hachum, 2001, 2012; Pachpute et al., 2009; D. N. Pandey, Gupta, & Anderson, 2003; P. K. Pandey, Panda, & Panigrahi, 2006; Panigrahi, Panda, & Agrawal, 2005; Panigrahi, Panda, & Mal, 2007; Panigrahi, Panda, & Mull, 2001). However, these on-farm ponds only have a small storage capacity, which is on average 1,260 m^3 and there are no larger water sources to provide water in the dry season. Thus, it is necessary to select an agricultural water management scheme which uses the limited rainwater harvested in the on-farm pond efficiently and productively to fulfill social and economic needs of the household. It will enable the practice of sustainable agriculture in the rain-fed areas of Thailand.

A large number of criteria for the assessment of the sustainable agriculture were proposed to support decision makers to make a rational selection of the preferred alternative agricultural water management of the on-farm pond (Arab Forum for Environment and Development [AFED], 2011; Division for Sustainable Development. Department of Economic and Social Affairs [UN-DESA], 2016; Dumanski et al., 1998; McConnell & Dillon, 1997; Umanath & Rajsekar, 2013; United States Agency International development [USAID], 2015; Woltersdorf, 2010; Zhen & Routray, 2003). However, it is recommended that the assessment criteria should be locally specific, based on social, economic, and environmental contexts of each country (Hayati, Ranjbar, & Karami, 2010). Therefore, it is vital to take topographical and sociological conditions of the rain-fed agricultural areas of Thailand into account. His Majesty King Bhumibol Adulyadej The Great initiated the concept of the New Theory as a guideline for agricultural land and water management at the farm level. It is founded on topographical and sociological conditions of the rain-fed agricultural areas of Thailand. This concept was designed for small farmers who were poor and owned small pieces of land in the rain-fed agricultural areas of

Thailand (Chaipattana Foundation, 2014). They practice agriculture as small semi-subsistence or part-commercial family farms (McConnell & Dillon, 1997).

This research, therefore, is designed as a decision support tool for farmers in the rain-fed agricultural areas of Thailand to assess and propose a preferred agricultural water management scheme for the on-farm pond. This tool was developed through the disciplined decision-making process. The research selected the Analytic Hierarchy Process or AHP technique, which is widely applied as a decision-making tool (Adham et al., 2016; Baker et al., 2001; Fülöp, 2005; Mendoza et al., 1999; Mendoza & Martins, 2006; Mendoza & Prabhu, 2000a, 2000b, 2003; Mysiak et al., 2005; Qureshi & Harrison, 2001), as the multiple criteria decision-making techniques of the tool. Besides, it developed the assessment criteria of the tool based on the concept of the New Theory in order to make them compatible with topographical and sociological conditions of the rain-fed agricultural areas of Thailand. These criteria assessed the sustainability of agricultural water management schemes, in terms of the resource use efficiency, impacts on household self-sufficiency, and responsible long-term agricultural production. They render the decision support tool reliable and applicable, which enabled sustainable rain-fed agriculture in Thailand.

1.2 Research objective

- To select an appropriate decision support tool for sustainable rain-fed agriculture referenced to the New Theory of His Majesty King Bhumibol Adulyadej The Great

1.3 Research question

- How can farmers in the rain-fed agricultural area, who are small semi-subsistence or part-commercial family farms, make a rational and appropriate selection of the preferred agricultural water management scheme of the on-farm pond based on the concept of the New Theory of His Majesty King Bhumibol Adulyadej The Great?

1.4 Scope and limitations of the study

- This research mainly focused on rain-fed agricultural areas. It assumed that the rainwater was the only water source for agriculture in the study area. Whereas, the rainwater harvested in the on-farm pond was the only water source for supplemental irrigation during dry spells and in the dry season. Water from other sources were excluded.

- This research focused only on on-farm ponds with 1,260 m^3 storage capacity from the on-farm pond construction project in the unirrigated area of the Land Development Department, the Ministry of agriculture and Cooperatives. These on-farm ponds must harvest the rainwater from only two main sources which were rainfall and surface runoff. Besides, they must be able to collect the surface runoff flowing into the pond and store the harvested rainwater for the whole year.

- This research used secondary data from government agencies for devising agricultural water management schemes for the on-farm pond. These data were limited and average, so the schemes may not support extreme weather and climate events. Besides, data were specific and updated, to some extent, so the accuracy of the schemes may be reduced. However, it helped farmers devise their agricultural water management schemes without collecting all the required data by themselves.

1.5 Operational definitions

- **Decision support tool** is a wide range of systems, tools, and technologies, which helps decision makers use data, documents, knowledge, communication technologies, and models to support a decision, complete decision process tasks, and solve sophisticated, complex, or simple problems (Power, 1997; Sprague, 1980). For this research, the decision maker is an agricultural holder who makes a rational and appropriate selection of the agricultural water management scheme for the on-farm pond either by him/herself or receives the support from the decision supporters to interact with the decision support tool.

- **Sustainable agriculture** is the successful management of resources for agriculture to satisfy changing human needs, while maintaining or enhancing the quality of the environment and conserving natural resources (Food and Agriculture Organization of the United Nations [FAO], 1991). It comprises two key concepts; one is “needs”, especially for the poor and the other is “limitations of environment's ability” to meet both present and future needs. It is also vital to harmonize three core interconnected elements, which are economic growth, social inclusion and environmental protection (World Commission on Environment and Development [WCED], 1987).

- **Agricultural resource management** is the management of resources for agriculture in an individual farm unit, including soil, water, plant varieties and animal breeds, and techniques used in their production. It is a central tenet of the concept of sustainable agriculture (FAO, 1991). However, this research focuses mainly on the agricultural water management, since water is an essential and limited agricultural resource in the rain-fed areas. Without water, crops and livestock die, people lose their income and go hungry, and the sustainability of the rain-fed agriculture is threatened.

- **Rainwater harvested in the on-farm pond** is the rainwater which is collected during the rainy season and stored in the on-farm pond to supply water for farm activities during dry spells and in the dry season (Ali, 2010; Chaipattana Foundation, 2014). For this research, there are only two sources of the rainwater which are rainfall and surface runoff. Water from other sources are excluded.

- **Contingent drought** is a drought that occurs in the humid or sub-humid regions due to the irregularity and variability in rainfall. This kind of the drought may coincide with the critical growth stage of crops and affect crop productivity (AgriInfo.in, 2015). For this research, it is a drought that occurs during six months of the rainy season, from May to October. It is also called dry spells.

- **Seasonal drought** is a drought that occurs in the monsoon regions which are clearly defined as wet and dry seasons (AgriInfo.in, 2015). For this research, it is a drought that occurs during six months of the dry season, from November to April.

- **The New Theory of His Majesty King Bhumibol Adulyadej The Great** is a guideline for the agricultural land and water management at the farm level for small farmers who are poor and own a little land in the rain-fed areas of Thailand. These farmers practice agriculture as small semi-subsistence or part-commercial family farms (McConnell & Dillon, 1997). This concept is founded on the Sufficiency Economy Philosophy of His Majesty King Bhumibol Adulyadej The Great, which emphasizes self-reliance, self-sufficiency, and risk management. The New Theory consists of three phases (Chaipattana Foundation, 2014). However, this research focuses mainly on the first phase which is the New Theory farming practice. It helps farmers manage their limited agricultural resources sufficiently, rationally, and flexibly to fulfill their social and economic needs.

- **Small semi-subsistence or part-commercial family farms** are a type of agricultural productions which aims to produce sufficient food for the daily household consumption and generate cash income for the purchase of non-farm produced foods, farm inputs, and other essentials throughout the year (McConnell & Dillon, 1997).

- **Land measurement in Thailand** is a specific land management system, which consists of rai, ngan, and square wah. They can be converted to a metric system, which is 1 square wah equals to 4 square meters; 1 ngan equals to 100 square wah, or 400 square meters, or 0.10 acre, or 0.04 hectare; and 1 rai equals to 4 ngan, or 1,600 square meters, or 0.40 acre, 0.16 hectare (Siam Legal International, 2017).

1.6 Expected Results

- The output of this research, which is the selected appropriate decision support tool for sustainable rain-fed agriculture referenced to the New Theory of His Majesty King Bhumibol Adulyadej The Great, can be used practically and effectively.

- The outcome of this study is that farmers understand, realize, and apply the concept of the New Theory for managing their agricultural resources sustainably.

- The findings of this research will benefit future research projects.

1.7 Significance of the work

This research proposed the selected appropriate decision support tool for sustainable rain-fed agriculture referenced to the New Theory of His Majesty King Bhumibol Adulyadej The Great. This tool promoted the agriculture 4.0 in Thailand by transforming the traditional farming into the innovative smart farming. It applied information and technologies for devising, assessing, and proposing the preferred agricultural water management scheme of the on-farm pond, which is productive and sustainable referenced to the New Theory. It helped farmers in the rain-fed agricultural area of Thailand, who are small semi-subsistence or part-commercial family farms, make a rational and appropriate selection of the agricultural water management scheme which enabled them to achieve sustainable rain-fed agriculture.

CHAPTER II
LITERATURE REVIEW

This chapter will be divided into four interrelated parts, starting from sustainable agriculture, the New Theory of His Majesty King Bhumibol Adulyadej The Great, agricultural water management of the on-farm pond, to the decision making. They are the fundamental concepts and theories of the selected appropriate decision support tool for sustainable rain-fed agriculture referenced to the New Theory of His Majesty King Bhumibol Adulyadej The Great, which is the topic of this research.

2.1 Sustainable agriculture

Sustainable development is defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". This definition is universally acknowledged. It comprises two key concepts; one is "needs", especially for the poor, and the other is "limitations of environment's ability" to meet both present and future needs. Besides, it is crucial to harmonize three core interconnected elements as presented in Figure 2.1, which are economic growth, social inclusion, and environmental protection (WCED, 1987).

Figure 2.1 Three core interconnected elements of sustainable development

Based on this concept, sustainable development in the agriculture, forestry and fisheries sectors is defined by the FAO as “the management and conservation of the natural resource base, and the orientation of technological and institutional change in such a manner as to ensure the attainment and continued satisfaction of human needs for present and future generations. Such sustainable development conserves land, water, plant and animal genetic resources, is environmentally non-degrading, technically appropriate, economically viable and socially acceptable” (FAO, 1989).

Consequently, sustainable agriculture is defined by the FAO as “the successful management of resources for agriculture to satisfy changing human needs, while maintaining or enhancing the quality of the environment and conserving natural resources” (FAO, 1991).

2.2 The New Theory of His Majesty King Bhumibol Adulyadej The Great

The New Theory is an alternative for sustainable agriculture and livelihoods. It is a guideline for agricultural land and water management at the farm level for small farmers, who are poor and own a little land in the rain-fed areas. This concept is founded on the Sufficiency Economy Philosophy of His Majesty King Bhumibol Adulyadej The Great, which emphasizes self-reliance, self-sufficiency, and risk management. It encourages farmers to manage their limited agricultural land and water resources sufficiently, rationally, and flexibly to fulfill their social and economic needs (Chaipattana Foundation, 2014).

2.2.1 The origin of the New Theory

The New Theory was initiated when His Majesty King Bhumibol Adulyadej The Great visited his people at Baan Kut Tor Kaen, Khao Wong district, Kalasin province, on 25th November 1992. It was a rain-fed agricultural area where farmers grew rice as their major crop since it was a major staple crop for Thai people. However, the yield was very low due to the water shortage. They were sensitive to the impact of the unpredictable rainfall pattern and dry spells. Therefore, it was necessary to harvest enough rainwater in the rainy season to be used as the supplemental irrigation during those periods. The concept of the agricultural land and water management was, then, initiated by dividing ten rais of land into three parts. The first three rais were an on-farm pond lined with a plastic for storing rainwater, the second six rais were for a rice cultivation, and the last one rai was for an accommodation and other purposes (OPM, 2008).

Later, the concept of agricultural land and water management of the New Theory was developed and experimented at the Royal-initiated Wat Mongkhol Chaipattana Development Project, Chalerm Phrakiat district, Saraburi province, on 25th January 1993. The premise was that, on the average, Thai small farmers owned 15 rais of land per household. The land was roughly divided into four parts (OPM, 2004b):

- **Rice field**

The first five rais are for growing rice which is the major staple food of Thai people. It is estimated that an average Thai consumes about 200 kilograms of rice per year. While, a family with 5-6 members consumes around 1,200 kilograms of rice per year. Thus, each family has to grow rice around five rais of land, with at least 240 kilograms of yields per rai, in order to have enough rice for the annual household consumption. It enables the household to be self-reliant and ensures the household food security. Besides, it reduces household expenses on food and increases household incomes from the sale of surplus food for household consumption (Ampol Senanarong, 2014).

However, it is recommended to grow rice only in the rainy season, not off-season. The rainwater harvested in the on-farm pond should be used in the most efficient way. Therefore, it is advised to grow local alternative crops based on local conditions, which require less water in the dry season (OPM, 2008). This practice of growing different crops in succession over the same piece of land in one calendar year, so-called multiple cropping, enables sustainable agriculture. It naturally increases soil nutrient recycling and soil organic matter, which improves plant growth and yields (AgriInfo.in, 2015a, 2015b). Moreover, it reduces crop specific pests and diseases which are often observed in monoculture (FAO, 2015).

- **Horticultural crops and perennial trees**

The second five rais are for growing horticultural crops and perennial trees, such as fruits, vegetables, herbs, and the like for daily household consumption. The surplus can be sold as another source of household income. Plants are selected according to soil conditions as well as local and market preference. However, perennial trees are given the precedence since they need less care and maintenance in the long run but yield regularly for the whole year. Their wood also can be used for general purposes, including firewood and construction. Besides, they give the shade and moisture to the area (OPM, 2011). Moreover, mixed farming sustains and satisfies as many needs of the household as possible (AgriInfo.in, 2015d, 2015e). It makes them self-supporting for the entire year. It also reduces market risks from solely depending on mono-cropping. Besides, it contributes to soil rehabilitation and fertility (OPM, 2008).

- **The on-farm pond**

The next three rais are for excavating the four-meter-deep pond, which can store around 19,000 m^3 of rainwater harvested during the rainy season. It is estimated that one rai of cultivated land normally requires around 1,000 m^3 of water. This amount of water is enough for year-round growing on five rais of major rice and alternative crops after the major rice cultivation as well as five rais of horticultural crops, which require around 10,000 m^3 of water per year. It is also enough for the domestic water use until the next rainy season. Therefore, the household need not rely on the irrigation system (Chaipattana Foundation, 2014).

Moreover, the on-farm pond can be used to raise aquatic animals and plants. Whereas, chickens can be raised above the edge of the pond for the daily household consumption. It reduces household expenses; while, the surplus can be sold to generate household income. However, it is recommended that water harvested in the on-farm pond should be mainly applied during dry spells. For the application in the dry season, it is necessary to have an agricultural water management scheme for the on-farm pond which balances farm water demands and supply, based on topographical and sociological conditions of the area (OPM, 2008).

In addition, each household should have more than one pond and divide them according to specific purposes, such as crop cultivation, household consumption, freshwater culture, and the like. In case that there are natural water sources or ditches in the farmland, it is recommended to enlarge them to store rainwater for farm activities throughout the year (Ampol Senanarong, 2014). The fertile topsoil from the pond excavation can be used for growing plants in other activities. Whereas, the lower level soil, which is less fertile, can be used to set up levees, vegetable patches, and garden plots. Moreover, the vetiver grass and perennial trees, which do not require much water, can be planted along the bank of the pond. They prevent bank erosion, conserve the humidity in the ground, and preserve organic substances in the soil. Meanwhile, the young leaves of the vetiver grass can be used to feed animals (OPM, 2008).

- **Accommodation and other purposes**

The last two rais are for accommodation and other purposes, such as livestock, mushroom cultivation, flower and ornamental plants, backyard garden, drying compost, roads, and other infrastructures (OPM, 2008).

If the land is larger or smaller than the said number, it can be divided into parts with a ratio of 30:30:30:10 for the most efficient and self-reliant land use. This ratio is only a rough formula that can be adjusted depending on topographical and sociological conditions of each area, such as the terrain, soil structure, the amount of the rainfall, cropping system, crop cultivation plan, the readiness of the farmer, the unity of the community, support from public and private sectors, and the like (Ampol Senanarong, 2014).

Eakawit Jornpradit (2007) applies the differential evolution method for optimizing the appropriate proportion of the on-farm pond to the rice field to horticultural crops and perennial trees to the accommodation, respectively, for 10-15 rai farmland in five regions of Thailand. He recommends that the appropriate ratio for the northern region is 35:45:10:10; for the northeastern region is 32:36:22:10; for the central region is 35:29:26:10; for the eastern region is 40:32:18:10; and for the southern region is 12:56:22:10. Whereas, Department of Agriculture, Misnistry of Agricutlure and Cooperatives, experimented with this ratio in 26 study areas throughout the country and found that the proportion of the on-farm pond tended to be less than or equal to 30%; while, other proportions tended to be equal to, or more than expected (Ampol Senanarong, 2014).

The full concept of water sources management of the New Theory was also initiated. It is called "large reservoir filling small reservoir, small reservoir filling pond". This concept shows the full capacity and potential of the New Theory as the most efficient rainwater harvesting system. It reduces risks from relying only on rainwater, which fills up the on-farm pond only once a year during the rainy season. Besides, it ensures that the rainwater harvested in the on-farm pond is enough for the dry season, even in years that the amount of rainfall is less than normal. In addition, this concept increases the total amount of the harvested rainwater of the country incredibly. The rainwater is stored not only in reservoirs; but also, in on-farm ponds (Chaipattana Foundation, 2014). However, when there are droughts in the areas that lack "large reservoir filling small reservoir, small reservoir filling pond", it is necessary to reduce the size of land for rice cultivation and use the remaining water for growing horticultural crops and perennial trees (Ampol Senanarong, 2014).

The full concept of the New Theory was developed in February 1995. It can be divided into three phases. The first phase is the above-mentioned, which is also known as the New Theory farming practice. It is a guideline for farmers to manage their limited agricultural land and water resources sufficiently, rationally, and flexibly to fulfill their social and economic needs. It enables them to, firstly, be self-reliant and subsist at an economical level through the production of enough food stuffs to live and eat throughout the year. It also lays a firm foundation for them to gradually raise their standard of living and finally live well and eat well. Besides, it helps them cope with both internal and external risks and uncertainties from extensive and rapid socio-economic and environmental changes, which leads to sustainable rain-fed agriculture (OPM, 2011).

The concept of the second phase is developed to unite individuals and households in the same area as groups or cooperatives. They are set up to collaboratively fulfill agricultural and common tasks in the community. These tasks include production, marketing, living conditions, welfare, education, and society and religious. These groups and cooperatives play an important role in solving local problems through joint actions. They also manage manpower in the community, which is a key factor for agricultural production, in order to help each other reduce labor expenses (Chaipattana Foundation, 2014). When they are strong, they can establish wide networks with other parties, including public and private sectors. It helps the micro economy grow in a stable manner with a fair income distribution, which strengthens both family and community institutions. Moreover, it enhances the ownership of the community to preserve their traditional customs and way of life as well as conserve their natural resources and environment as their capital for sustainable development in the future. It also increases the enthusiasm and capacity of the community to acquire more knowledge based on their local knowledge and wisdom (OPM, 2008).

Whereas, the concept of the third phase is added to cooperate with these groups, and the cooperatives with capital providers and external businesses. The cooperation with banks and private companies yields mutual benefits in trade, investment, and quality of life (OPM, 2008). It increases funds for investment. It also broadens and diversifies the occupational networks and economic activities of the community, which improves the quality of life of people in the community (Chaipattana Foundation, 2014).

It has been proved and broadly accepted in the academic arena and among farmers that the New Theory is the full cycle solution for agricultural problems, which leads to sustainable agriculture and livelihoods (OPM, 2008). However, this research studies only the first phase of the New Theory, which is the New Theory farming practice. It focuses on the farm level of an individual household whose agricultural production can be categorized as small semi-subsistence or part-commercial family farms. Their operational objective is to produce sufficient food for daily household consumption and generate cash income for the purchase of non-farm produced food, farm inputs, and other essentials throughout the year (McConnell & Dillon, 1997). It is relevant to the objectives of the first phase of the New Theory.

2.2.2 The fundamental concepts and theories of the New Theory

The New Theory is founded on development concepts and theories of His Majesty King Bhumibol Adulyadej The Great as shown in Figure 2.2, including Sufficiency Economy Philosophy, self-reliance, explosion from within, topographical and sociological approach, simplicity, and holistic approach (OPM, 2004b, 2008, 2011).

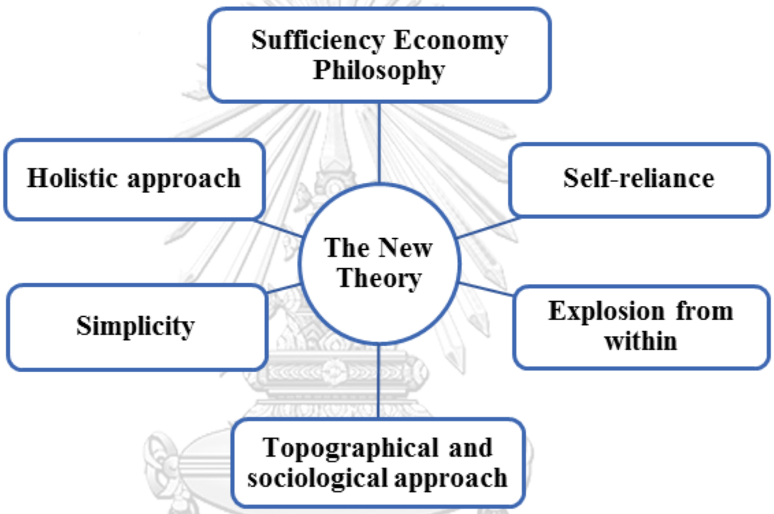

Figure 2.2 Fundamental concepts and theories of the New Theory

2.2.2.1 Sufficiency Economy Philosophy

The Sufficiency Economy Philosophy was initiated in 1974. It is the guiding path based on the middle way and mindfulness. It emphasizes the principle of moderation, reasonableness, and risk management, by using knowledge and virtues to live one’s life, as illustrated in Figure 2.3 (Chaipattana Foundation, 2014).

- **Moderation** is to avoid doing anything excessively or extremely and to realize one's own actual limitations.

- **Reasonableness** is to consider related factors carefully before taking any actions and to rationally anticipate expected outcomes from those actions.

- **Risk management** is to well prepare themselves to cope with any risks and changes by considering the probability of any future situation.

However, it also requires knowledge and virtue for making a rational decision and carrying out activities.

- **Knowledge** is to have knowledge in relevant fields, understand the relationship among them, and to use them carefully for planning and operating activities.

- **Virtue** is to be honest, patient, reserved, and intelligent in living one's life.

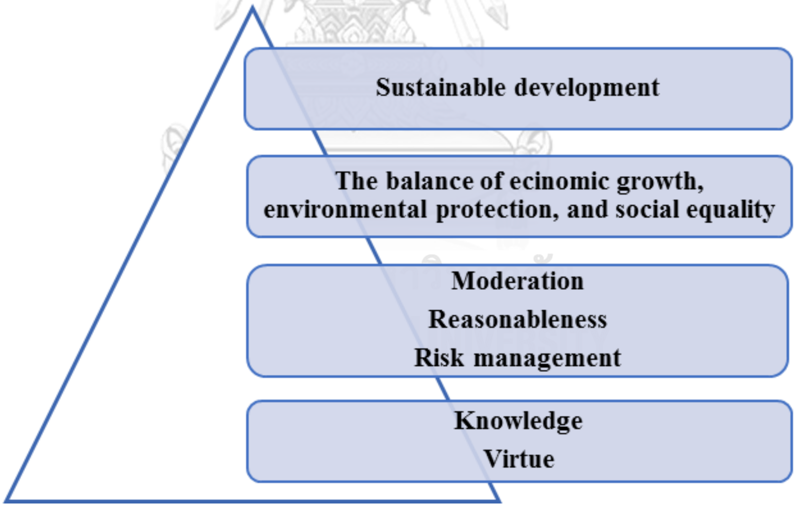

Figure 2.3 The concept of the Sufficiency Economy Philosophy

The Sufficiency Economy Philosophy is the fundamental concept of the New Theory. It encourages farmers to be self-reliant and manage their limited agricultural land and water resources sufficiently, rationally, and flexibly to fulfill social and economic needs. It lays a firm and sustainable foundation for people to cope with internal and external shocks and uncertainties from extensive and rapid socio-economic and environmental changes (OPM, 2008).

2.2.2.2 Self-reliance

Self-reliance is the ability to live by their own efforts freely and sustainably as well as adapting to changes in time. The goal of the New Theory is to enable people to be self-reliant sustainably. Therefore, it is necessary to improve their problem-solving skills and motivate people to be self-reliant by their free will (OPM, 2004b).

2.2.2.3 Explosion from within

Explosion from within is changes in one's attitude and behavior which occur when people realize benefits from the change and try doing it themselves. The successful application of the New Theory must come from individuals themselves. When they determine their own future, they can emerge into the development of the outer world with inner readiness (OPM, 2011).

2.2.2.4 Topographical and sociological approach

The topographical and sociological approach is concerned with each locality of the country having different and specific conditions as well as a unique way of life, customs, and tradition. The New Theory is designed to be flexible for the various topographical and sociological conditions of each locality. It does not adhere to academic or technical principles, which may be incompatible locally. Therefore, when applying the New Theory, it is vital to study well the conditions of the area to gain a true and deep understanding. It will respond to needs of local people accurately, which will lead to sustainable development (OPM, 2004b, 2008, 2011).

2.2.2.5 Simplicity

Simplicity is one of the outstanding characteristics of the New Theory. It simplifies complex problems about the agricultural land and water management and makes them comprehensible. It applies local wisdom and common sense for solving problems effectively and sustainably. It also uses simple and locally-available methods to manage environmental conditions so they become benefits systematically, effectively, and economically (OPM, 2004b).

2.2.2.6 Holistic approach

The holistic approach is to consider things as they are dynamic and linked to one another. The New Theory considers agricultural problems in a holistic and integrated approach. It comprises various agricultural activities for all year-round productions as a kind of mixed farming. These activities provide agricultural inputs for each other and make the best use of resources (AgriInfo.in, 2015d). They also reduce production costs as well as risks from adverse climate and the fluctuating prices of agricultural products. This approach, therefore, leads to the sustainability of the whole system and the conservation of natural resources (OPM, 2011).

2.2.3 The New Theory as an approach for sustainable development

Tangon Munjaiton, Supa Kreetibut, and Orawan Prukchatsiri (1999) believe that the full application of the New Theory is compatible with the agricultural production system in Thailand. It will enable sustainable development in every level, from the individual and household level to the national level, as demonstrated in Figure 2.4. The first phase of the New Theory, the New Theory farming practice, lays a firm and sustainable foundation for the individual and household. It is a kind of mixed farming which comprises various agricultural activities, both crops and livestock. These activities provide agricultural inputs for each other and use natural resources efficiently. They reduce production costs and risks from adverse climate and the fluctuating price of agricultural products, which leads to sustainable intensification and sustainable agriculture at the farm level.

Moreover, these agricultural activities provide enough and various foods with nutrients for each household. It makes people self-reliant and healthy as well as reduces the hunger rate of the country. Besides, it increases decent jobs in rural areas, which reduces the workforce migration from rural areas to urban areas and any social problems. It also strengthens the family relationships since there are a lot of work on the farm throughout the year.

Furthermore, the on-farm pond of the New Theory farming practice can mitigate the severity and damage from floods in the rainy season and droughts in the dry season. It collects rainwater and floodwater drainage to relieve water shortage in the dry season, which also increases the effectiveness of rainwater harvesting and consumption of the country. Besides, it conserves water-related ecosystems and increases the humidity in the soil. Planting trees also increases the humidity in the atmosphere and initiates rain. (OPM, 2008).

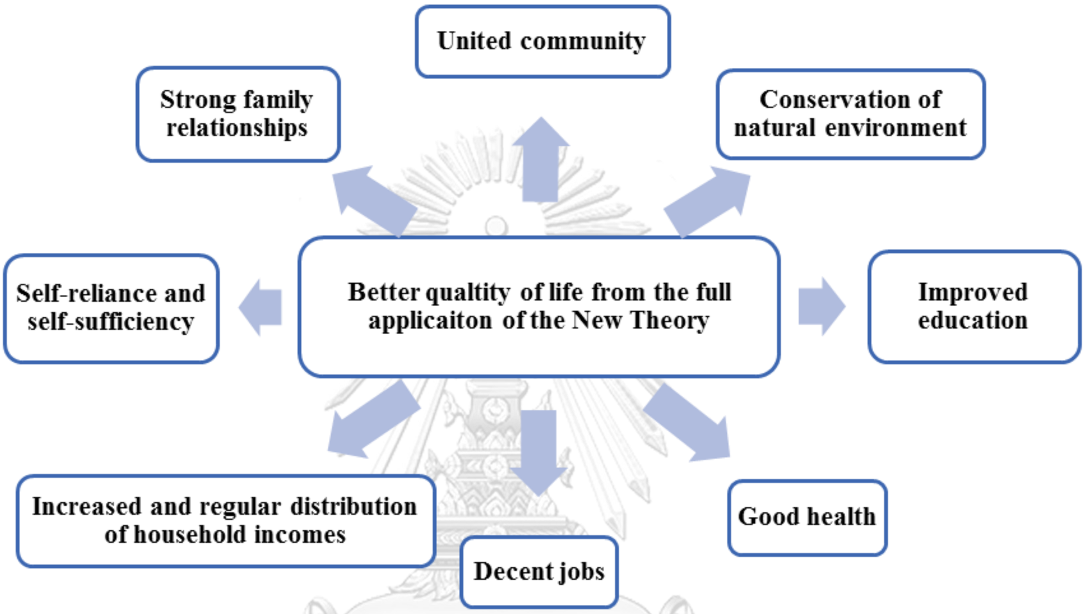

Figure 2.4 The New Theory and the quality of life
Source: Tangon Munjaiton et al. (1999)

2.3 Agricultural water management of the on-farm pond

A small storage facility, like an on-farm pond, is radical for the pursuit of sustainable agriculture in rain-fed areas where rainwater is the only water source. The water demands in these areas are still unmanageable since they lack available natural and man-made water sources and a supplemental irrigation system. Besides, its geographical conditions are not suitable for constructing large-scale water collectors (Ali, 2010).

However, the on-farm pond has a small storage capacity and lacks a larger water source to obtain water in the dry season. Therefore, it is necessary to devise an agricultural water management scheme of the on-farm pond, which balances farm water demands and supply. The scheme should be devised based on topographical and sociological conditions of each area. Besides, it should optimize farm water productivities in all aspects, including economic, social, and environmental, which ensures sustainable rain-fed agriculture in Thailand.

2.3.1 Water supply in the rain-fed agricultural area: The on-farm pond

The New Theory gives importance to the rainwater harvesting for agriculture (OPM, 2011). In general, a rainwater harvesting system comprises three main components, which are a catchment area, a storage facility, and a target area (Oweis et al., 2012). In the rain-fed area, water is stored in a storage facility, like an on-farm pond, can be harvested only from the rainfall and surface runoff from the catchment area. Therefore, the sustainability of rainwater harvesting largely depends on the timing and amount of rainfall. While, the harvested rainwater is applied for productive purposes in the target area, mainly as supplemental irrigation for crop production during dry spells in the rainy season and in the dry season (Oweis et al., 1999). Hence, it is necessary to collect enough rainwater for farm activities throughout the year, until the next rainy season.

Rainwater harvesting system is an effective and economical response to dry spells and droughts. It improves yields and reliability of the crop production by reducing risks from the water deficit, especially in the critical growth stages of plants. It also offers the opportunity to grow higher-value crops (Critchley & Siegert, 1991; Fox, Rockstrom, & Barron, 2005; Ngigi et al., 2005; Oweis et al., 1999; P. K. Pandey et al., 2006; Panigrahi et al., 2005; Panigrahi et al., 2007; Roy, Panda, & Panigrahi, 2009). Besides, it provides environmental benefits. It reduces environmental degradation as well as conserves soil and water resources through the improvement of the vegetative cover and the reduction of desertification (Oweis et al., 2012).

2.3.1.1 The on-farm pond

The on-farm pond is a kind of surface or ground storage where water is collected on the ground surface by digging the ground inside the farm boundaries. It is a self-reliant water source for the household in the rain-fed area. It stores surplus rainwater during the rainy season or from the heavy rainfall events as well, as some, or all runoff from the adjacent catchment area for later use. It enables plant growth during dry spells in the rainy season and crop production in the dry season (Panigrahi et al., 2007). The ideal on-farm pond should provide enough water to meet needs at the lowest cost per unit of water supplied.

- **Geometry of the storage**

The size of the on-farm pond is small, ranging in capacity from 1,000-500,000 m^3. It is determined by the amount of water needed to be stored and used, the supply capacity, the cost of construction and maintenance, the potential profit from the crop production, and the available finance of the farmer (Oweis et al., 2001, 2012). Whereas, the geometry of the pond depends on specific topography and environment of each area. For example, in the unirrigated area where farmers rely only on rainwater, the pond should be deep enough to reduce the evaporation. While, in the irrigated area or in the area where there is a continual water supply, the geometry of the pond can be more flexible or reduced to make room for other purposes (OPM, 2004b, 2008, 2011). However, it is found that the size of the storage facility tends to decrease when the size of the field area increases (P. K. Pandey et al., 2006; Roy et al., 2009).

Water harvested in the on-farm pond is mostly lost through evaporation as well as seepage and percolation, which account for 30-50% of the total collected water. The time and the volume of water held in the storage also affect the amount of water lost. The amount of water lost through evaporation varies from 0.1-0.3 m^3 per day, relying on the evaporation rate and the exposed surface area of the pond. Whereas, water lost through seepage and percolation ranges from 0.03-0.4 m^3 per day, depending on the soil type of each area, methods and materials used for the construction and maintenance, water depth, and field management practices (Ngigi et al., 2005; Oweis et al., 2012; Panigrahi et al., 2007; Panigrahi et al., 2001; Roy et al., 2009). In the high rainfall area, the impact of seepage and percolation losses is more obvious in the dry season when the total rainfall is much less than the seepage and percolation rate (Srivastava, 2001). It is also found that the amount of water, ranging from 2-5 mm per day, is lost through breaches of the lining material (Panigrahi et al., 2005; Panigrahi et al., 2007).

Therefore, it is recommended that rainwater should be collected in a small surface area but deep storage in order to reduce the loss of productive land and evaporation (Panigrahi et al., 2007). The soil examination and technical advice from officers are also required before the pond excavation (OPM, 2008).The New Theory estimates the depth of the pond based on the premise that the daily evaporation causes a loss of one centimeter per day when there is no rainfall. If there is no rainfall for 300 days, the water level in the pond will drop around three meters per year (OPM, 2011). However, in cases where there is an adoption of crop-fish integration system, the depth of water stored in the pond must be at least 1.2 meters for fish cultivation (P. K. Pandey et al., 2006). Thus, the geometry of the pond should be at least a four-meter depth of trapezoidal shape and the surface of the pond should be a rectangle rather than a square in order to reduce the evaporation (OPM, 2008). Besides, it is advised that the pond should be covered by either roofing with locally available materials or planting non-fruiting passion varieties (Ngigi et al., 2005). Whereas, floating covers and surface layers can reduce evaporation losses by 50% (Ali, 2010; Panigrahi et al., 2005).

In addition, many researchers suggest that, in the area with sandy loam and sandy soils, the storage should be sealed with locally available materials. It maximizes water use efficiency and reservoir capacity as well as minimizes seepage and percolation losses (Fox et al., 2005; Ngigi et al., 2005; P. K. Pandey et al., 2006; Panigrahi et al., 2007; Panigrahi et al., 2001; Roy et al., 2009; Srivastava, 2001). Lining materials include masonry, concrete, rubber tarpaulin, UV resistant, durable plastic sheet, and compaction or self-sealing (Fox et al., 2005).

- **Storage capacity**

The storage capacity of the on-farm pond relies on rainfall characteristics and distribution, the available runoff volume, cropping system, crop water requirements, field management practices, the pattern of water withdrawal from the pond, and storage dimension (Roy et al., 2009). The total depth of the pond must cover the amount of water lost through evaporation as well as seepage and percolation. It also needs to meet the minimum volume of water required for purposes and periods of water use, especially in the critical growth stages of plants (Oweis et al., 1999; Oweis et al., 2001, 2012; Panigrahi et al., 2001; Srivastava, 2001). The storage capacity of the on-farm pond can be calculated by Equation 2.1.

$$V = \frac{A_1 + A_2 + \sqrt{A_1 A_2}}{3} \times h$$

Where:
V is the storage capacity of the on-farm pond in m^3
$\mathbf{A_1}$ is the top dimension of the on-farm pond at the ground level in m^2
$\mathbf{A_2}$ is the bottom dimension of the on-farm pond in m^2
h is the depth of the on-farm pond in m

Equation 2.1 Basic formula for calculating the storage capacity of the on-farm pond
Source: Prime Minister's Office (2004a)

Moreover, the volume of evaporation loss from the on-farm pond during six months of the dry season, from November to April, can be calculated by Equation 2.2.

$$Evp. = \frac{E \times RA}{2000}$$

Where:
Evp. is the volume of evaporation loss from the on-farm pond in m^3
RA is the wetted surface area in m^2
E is evaporation in mm.

Equation 2.2 Basic formula for calculating the volume of evaporation loss from the on-farm pond
Source: Prime Minister's Office (2004a)

Meanwhile, the volume of seepage loss from the on-farm pond during six months of the dry season, from November to April, can be calculated by Equation 2.3.

$$SL = \frac{S \times RA}{2000}$$

Where:

SL is the volume of seepage loss from the on-farm pond in m^3

RA is the wetted surface area in m^2

S is seepage in mm.

Equation 2.3 Basic formula for calculating the volume of seepage loss from the on-farm pond
Source: Prime Minister's Office (2004a)

Values of provincial evaporation and seepage in Thailand are provided by Office of the Decentralization to the Local Government Organization Committee (OPM, 2004a).

Although, the on-farm pond helps farmers reduce risks from the variation of intra-seasonal or inter-seasonal distribution of rainfall, particularly in the rain-fed area. They may be not willing to allocate a part of their cultivated land to store water if the value and fertility of the land is high (OPM, 2011). Besides, techniques required for the effective construction of a functional on-farm pond are too specific and complicated for farmers to do by themselves. For instance, the fertile topsoil received from digging the pond should be used for growing plants in other activities. While, the lower level soil, which is less fertile, should be used to set up levees, vegetable patches, and garden plots (OPM, 2008). It is also advised to control the erosion in the catchment area and install a silt-trap before the runoff flows into the storage in order to minimize siltation which reduces the storage capacity (Oweis et al., 2001). Furthermore, initial expenses for the pond excavation is too expensive for farmers to afford. Therefore, both the public and private sectors should assist farmers with these difficulties. Whereas, farmers are still responsible for their own routine expenses, including the continuous maintenance after the construction (Chaipattana Foundation, 2014).

2.3.1.2 The implementation of rainwater harvesting

Not all areas are appropriate for harvesting rainwater. Different topographical and sociological conditions of each area influence the successful implementation of the rainwater harvesting. These include climate, hydrology, precipitation patterns, topography, soil and plant characteristics, water requirement patterns, alternate water source, available materials and labor, indigenous knowledge about rainwater harvesting, acceptability of water harvesting concepts, and local socio-economic factors (Oweis et al., 2012). Therefore, it is important to select a suitable area for constructing an on-farm pond which not only maximizes water use efficiency and storage capacity, but also minimizes evaporation and seepage losses. There are some parameters identifying suitable areas for rainwater harvesting.

- **Rainfall characteristics**

The most important characteristics of rainfall for the rainwater harvesting are intensity, duration, frequency, and magnitude. Rainfall intensity is the amount of rainfall in a given time over an area. While, rain duration is a period that the rain falls. Frequency of rainfall is the distribution of rainfalls over a given period. Whereas, magnitude of rainfall is the total amount of rainfall at a point over a given period. Rainfall intensity and duration are necessary for determining the volume of available rainwater for harvesting (Oweis et al., 2012). For instance, rainstorms with high intensities generate high surface runoff even of short duration, since the raindrop impact clogs the soil pores. (Critchley & Siegert, 1991). Therefore, a thorough assessment of rainfall-runoff potential of a certain area is radically required (Panigrahi et al., 2001).

- **Topography and soil characteristics**

Topography and soil characteristics, including land slope, surface structure, infiltration and percolation rates, and soil depth and texture, strongly impact the runoff yield of the rainwater harvesting. Generally, soil can be grouped into three types as below (Critchley & Siegert, 1991).

- **Sandy soils** are coarse textured soils with sand predominant. Their infiltration rate is around 25-50 mm per hours.

- **Loamy soils** are medium textured soils with silt predominant. Their infiltration rate is around 12.5-25 mm per hours.

- **Clayey soils** are fine textured soils with clay predominant. Their infiltration rate is around 7.5-12.5 mm per hours.

It is recommended that the rainwater harvesting system should be on low quality or nonproductive land. However, the soil should be neither saline nor sodic. Soil porosity is also critical for designing a rainwater harvesting system. It allows water to infiltrate and affects the water storage capacity and water flow in the soil layers. Ideally, the soil in the catchment area should have a high runoff coefficient with a low infiltration rate. While, the smaller size of the catchment increases the runoff efficiency, which is the volume of runoff per unit of area (Oweis et al., 2012). Whereas, the suitable soil for rainwater harvesting should not be sandy since its infiltration rate is higher than the rainfall intensity. However, soil surface sealing can reduce infiltration and increase runoff (Critchley & Siegert, 1991).

For the land slope, steep and short slopes generate more runoff than gentle and long slopes as the water is exposed to infiltration and evaporation in a shorter duration. It is suggested that the suitable slope of an area for rainwater harvesting should be less than 5%, which will distribute more regular runoff (Critchley & Siegert, 1991). On the contrary, the construction of the on-farm pond should be located at the corner or center of the farmland in the gentle slope area. It uses gravity for water to flow to all points of use which minimizes the cost of pumping and conveyance for irrigation. Therefore, government officers with field skills and experience should help farmers identify the most suitable locations for constructing the on-farm pond (Ampol Senanarong, 2014). Geographic Information Systems or GIS is also useful for marking the storage location (Oweis et al., 2001, 2012).

- **Runoff characteristics**

In order to design the rainwater harvesting system, it is important to calculate the quantity of runoff. It is the proportion of the rainfall depth which is generated by rainstorms in a given catchment area when the entire area is contributing runoff. The surface runoff is generated when the rainfall intensity exceeds the infiltration capacity of the soil; while, surface puddles and other depressions are filled. The infiltration capacity of the soil is related to physical conditions of each catchment area. These include rainfall intensity, soil type, texture and structure, inclination, the antecedent soil moisture content, and vegetation (Critchley & Siegert, 1991). Runoff on the small area, less than 12 km^2, can be determined by the rational method in Equation 2.4:

$$Q = fCIA$$

Where:

Q is the peak flow rate in m^3 per second

C is the dimensionless runoff coefficient

I is the average rainfall intensity in mm per hour

A is the area in km^2

f is the conversion factor which is 0.278 for km^2

Equation 2.4 Rational method for calculating the quantity of runoff
Source: Ali (2010)

The runoff coefficient from a rainstorm over the catchment area can be calculated by Equation 2.5:

$$C = \frac{Total\ depth\ of\ runoff\ in\ mm}{Total\ depth\ of\ rainfall\ in\ mm}$$

Equation 2.5 Basic formula for calculating the runoff coefficient
Source: Critchley and Siegert (1991)

The runoff coefficient is not a constant factor. It depends on characteristics of the rainfall, physical conditions of a certain catchment area, and the antecedent moisture condition of the soil. It is recommended that at least two years of rainfall and runoff data of the specific catchment area are required for designing the water harvesting system (Critchley & Siegert, 1991). Table 2.1 shows values of general runoff coefficient for various combinations of ground cover and slope, applied for the rational method.

Table 2.1 Runoff coefficients for the Rational Formula

Type of drainage area	Runoff coefficient, C
Concrete or asphalt pavement	0.8-0.9
Commercial and industrial	0.7-0.9
Gravel roadways and shoulders	0.5-0.7
Residential – Urban	0.5-0.7
Residential – Suburban	0.3-0.5
Undeveloped	0.1-0.3
Berms	0.1-0.3
Agricultural – Cultivated fields	0.15-0.4
Agricultural – Pastures	0.1-0.4
Agricultural – Forested areas	0.1-0.4

Note: For flat slopes or permeable soil, lower values shall be used. For steep slopes or impermeable soil, higher values shall be used. Steep slopes are 2:1 or steeper.

Source: Michigan.gov (2017)

- **Socioeconomics and infrastructure**

Socioeconomic conditions of the area are a key factor for the successful implementation of rainwater harvesting. Each area has different local conditions and needs which influence unique design requirements and usages of the rainwater harvesting system (Oweis et al., 1999). These include crop production plans, farming systems, financial resources, cultural behaviors, the attitude of farmers towards the introduction of rainwater harvesting concepts, the background knowledge of farmers about rainwater harvesting, the ability of farmers to operate and maintain the rainwater harvesting system, available materials and labor, and land property rights (Oweis et al., 2012).

Land ownership and rights of use issue can influence farmers to implement rainwater harvesting. Farmers who lack land tenure may not be willing to invest in rainwater harvesting structures on land which does not belong to them (Critchley & Siegert, 1991). While, existing infrastructures in a certain area are important for planning the rainwater harvesting system (Oweis et al., 2012). The ability of farmers to operate and maintain the system as well as the cost and availability of materials and skilled labor in the area also affect the adoption of more sophisticated water harvesting systems (Fox et al., 2005).

Culture, level of education, familiarity with the technology, perceptions, and awareness of the need for changes also influence the adoption of the rainwater harvesting. Existing indigenous knowledge about the rainwater harvesting in the area is a solid foundation for farmers to adopt, since they know that the adoption is financially advantageous for their crop production (Fox et al., 2005; Ngigi et al., 2005; Oweis et al., 1999). In addition, many researchers have proved that the adoption of the rainwater harvesting system is economically viable (Fox et al., 2005; Ngigi et al., 2005; P. K. Pandey et al., 2006; Panigrahi et al., 2005; Panigrahi et al., 2007; Panigrahi et al., 2001). However, an economic analysis of rainwater harvesting is still required when considering the adoption of rainwater harvesting. It needs to take all costs, both fixed and variable costs in the entire processes, including the initial cost, operation cost, and maintenance cost, into account. It helps compare between the required water quantity and benefits from additional crop yields. These attractive benefits of the rainwater harvesting must be clearly explained (Oweis et al., 2001). Furthermore, micro credit schemes or forms of subsidy to finance the construction, operation, and maintenance of the system may encourage farmers to apply the system (Oweis et al., 2012; Panigrahi et al., 2001).

2.3.2 Farm water demands

There are three major types of farm water demands, which are water for the household consumption, rearing livestock, and crop cultivation. It is recommended, in the dry season or when the water is scarce, domestic water use is the priority for the water allocation. The remaining is then provided for rearing livestock and crop cultivation, respectively (OPM, 2004a).

2.3.2.1 Water requirement for household consumption

Domestic water uses vary with climatic conditions, life style, culture, tradition, diet, technology, and wealth (Gleick, 1996). For the household living in the rural area of Thailand, it is estimated that 80 liters per person per day is required in order to meet basic needs (Watcharin Chetananon, 2009).

2.3.2.2 Water requirements for rearing livestock

Daily water requirement for rearing livestock varies significantly among animal species, which can be generally categorized as below (Watcharin Chetananon, 2009).

- **Cattle** consumes 50 liters per unit per day
- **Swine** consumes 20 liters per unit per day
- **Poultry** consumes 0.15 liter per unit per day

2.3.2.3 Crop water requirements

The main purpose of rainwater harvesting for agriculture is to supply water required for the crop production. Crop water requirement is the total amount of water that a crop needs throughout the growing season to compensate for water lost through the evapotranspiration. Evapotranspiration is the transpiration of the plant and the direct evaporation from the soil and plant surface, which occur simultaneously. It is used for determining supplemental water requirements for the crop production. It differs among plants and varies over the growing season due to different plant cover and climatic condition (Critchley & Siegert, 1991; Oweis et al., 2012). Crop water requirement is estimated from a disease-free crop, with the full production potential, which grows in a field under general soil conditions with adequate soil water and fertility (Doorenbos & Pruitt, 1977).

There are a wide range of factors influencing plant growth, including physical, climatic, and biology of the area (Oweis et al., 2012). Critchley and Siegert (1991) explain that climatic conditions and crop type are two main factors which influence crop water requirements. Whereas, Ali (2010) also adds soil and management factors as another two main factors.

- **Climatic conditions**

Climatic factors, including sunshine, temperature, humidity and wind speed, affect water requirements of a crop. Crops grown in different climatic zones have different water requirements. For example, a certain crop grown in sunny, hot, dry or windy climate requires more water than those grown in cloudy, cold, humid, or calm climates. Whereas, the growing period of a certain crop in a cold climate is longer than those in a hot climate (Critchley & Siegert, 1991).

- **Crop type**

Each crop type needs a different amount of water. They have a different duration of total growing season. Short duration crops have 90-100 days of total growing season; while, long duration crops have 120-160 days of total growing season. Whereas, perennial crops have the duration of total growing season for many years. Therefore, vegetables and cereals consume water for short growing seasons; while, trees need water throughout the year. Each crop type also has different daily water needs of a fully-grown crop. Besides, it has a different sensitivity to drought. Crops with low drought resistance suffer greater reductions in yields than those with high drought resistance (Critchley & Siegert, 1991).

- **Soil**

There are some soil aspects which influence plant performance, such as texture, structure, depth, fertility, salinity, infiltration rate, available water capacity, and the like (Oweis et al., 2012). For instance, soil texture influences other soil characteristics, including infiltration rate and available water capacity. Whereas, soil depth influences soil capacity to store water as well as provide nutrients and moisture for plant growth (Critchley & Siegert, 1991).

The ideal soil for plant growth, in terms of nutrient supply, biological activity, as well as nutrient and water holding capacities, should be deep, loamy, and sufficiently permeable to allow adequate moisture to reach the crop root zone. Besides, it needs to have a good soil structure and high content of organic matter. Its depth should be more than 0.5 meters to support plant growth during prolonged dry periods; while, more than one meter is ideal. Moreover, its available water holding capacity values should be around 100-200 mm per meter. The water stored in the crop root zone reduces the evaporation and seepage losses (Critchley & Siegert, 1991; Oweis et al., 2012).

Crop water requirements can be measured directly from the field experimentation. It can also be estimated indirectly from the weather data and the predetermined crop coefficient values, which reduces the difficulty in obtaining accurate field measurements. (Doorenbos & Pruitt, 1977). Equation 2.6 presents the basic formula for calculating crop water requirements or crop evapotranspiration.

$$ETc = Kc \times ETo$$

Where:
ETc is water requirement or evapotranspiration of a given crop in mm per unit of time
Kc is crop factor or crop coefficient of a given crop for the particular growth stage
ETo is reference crop evapotranspiration in mm per unit of time

Equation 2.6 Basic formula for calculating crop water requirements or crop evapotranspiration
Source: Ali (2010)

Reference crop evapotranspiration or ETo is the rate of evapotranspiration from a hypothetical reference crop. The assumption is that the crop is 12-centimeter height, a fixed crop surface resistance is 70 s m^{-1}, and albedo is 0.23. It is similar to the evapotranspiration from an extensive surface of uniform height green grass which grows actively without any water shortage and completely shading the ground (Smith, Allen, & Pereira, 1998). It is expressed in millimeters per day and represents the mean value over the period of time (Doorenbos & Pruitt, 1977).

Scientists and specialists have developed many evapotranspiration estimation methods. However, FAO recommends that the FAO Penman-Monteith method is more consistent in estimating ETo than other methods. This method is also recommended as the standard method by the International Commission for Irrigation and Drainage and the World Meteorological Organization. It takes almost all climatological factors which influences ETo into account. These include temperature, humidity, solar radiation or sunshine hour, and wind speed. Besides, it is valid for estimating reference and crop evapotranspiration in a wide range of locations and climates (Smith et al., 1998). Equation 2.7 is the basic formula for calculating reference crop evapotranspiration.

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}$$

where

ET_o reference evapotranspiration [mm day^{-1}],
R_n net radiation at the crop surface [MJ m^{-2} day^{-1}],
G soil heat flux density [MJ m^{-2} day^{-1}],
T mean daily air temperature at 2 m height [°C],
u_2 wind speed at 2 m height [m s^{-1}],
e_s saturation vapour pressure [kPa],
e_a actual vapour pressure [kPa],
e_s - e_a saturation vapour pressure deficit [kPa],
Δ slope vapour pressure curve [kPa °C^{-1}],
γ psychrometric constant [kPa °C^{-1}].

Equation 2.7 FAO Penman-Monteith equation
Source: Allen et al. (1998)

Crop factor or crop coefficient or Kc is the ratio of the actual evapotranspiration to the reference evapotranspiration of a disease free crop which is grown in a large field and received adequate water. (Doorenbos & Pruitt, 1977). It shows the effect of crop characteristics on crop water requirements. Values of crop coefficient vary with crop types, growth stages of a crop, percentage of ground crop cover, growing season, climatic conditions, management system, frequency of rainfall or irrigation, and method of ETo estimation (Ali, 2010; Doorenbos & Pruitt, 1977). Equation 2.8 is the basic formula for calculating crop coefficients.

$$Kc = \frac{ETc}{ETo}$$

Where:

ETc is crop evapotranspiration at various growth stages

ETo is reference crop evapotranspiration at various growth stages

Equation 2.8 Basic formula for calculating crop coefficient
Source: Allen et al. (1998)

The growing season of a crop can be divided into different growth stages according to evapotranspiration. Each crop has a different sensitivity to water stress in different growth stages. Each growth stage also has different value of crop coefficient. Generally, there are ten major growth stages in the life cycle of crops, which are germination, seedling, tillering, stem elongation or jointing, booting, heading, flowering or anthesis, milk, dough, and ripening (Ali, 2010). Critchley and Siegert (1991) categorize them into main four growth stages, which are:

- **The initial stage** when the crop needs little water
- **The crop development stage** when the crop needs more water
- **The mid-season stage** when the crop water requirement reaches its peak
- **The late-season stage** when the maturing crop consumes less water

However, the length of each growth stage varies with crop types and climatic conditions of a certain area. Oweis et al. (2012) explain that there are two critical growth stages in which the water availability is necessary to plant growth. They are the plant establishment and the reproductive stage.

In general, crop water requirements are easier to determine than water requirements for trees. Trees have a very high sensitivity to moisture deficit during the establishment stage. Their drought sensitivity declines when their root systems are fully developed. The critical stage for most trees is in the first two years of seeding or sapling establishment (Critchley & Siegert, 1991). Moreover, it is difficult to examine the total area exploited by the root zone in the different stages of root development until a seedling grows into a mature tree. However, as a rule of thumb, it is estimated that the area exploited by the root system is equal to the area shaded by the canopy of the tree at noon (Critchley & Siegert, 1991; Oweis et al., 2012).

Values of crop water requirement, reference crop evapotranspiration, and crop coefficient of a wide range of crops, which are cultivated in Thailand, are calculated by various evapotranspiration estimation methods, including the FAO Penman-Monteith method, and provided by the Royal Irrigation Department (MOAC, 2011).

2.3.3 Field management practices for agricultural water use efficiency

Water use in agriculture is still inefficient. It is necessary to improve water use efficiency in agriculture through good field management practices and farming conditions. These include planning the coincidence between rainfall periods and water use periods to use rainfall more beneficially and optimize the storage capacity of the on-farm pond, planning crop production with proper irrigation, fertilizers, and improved seeds, selecting suitable crop types, producing various and higher-value crops, diversifying agricultural systems, improving the irrigation system and irrigation scheduling, improving the soil fertility, and reducing the evaporation loss (Ali, 2010; Arab Forum for Environment and Development [AFED], 2011; Hayati, Ranjbar, & Karami, 2010; Oweis et al., 2012; Panigrahi et al., 2001; Sharma, Molden, & Cook, 2015; United States Agency International development [USAID], 2015). There are some critical factors, related to field management practices, which affect the water use efficiency in agriculture.

- **Crop type**

Types of crop influence irrigation water requirements. It is recommended to select economic crops with low daily water needs and short growing seasons. It is also advised to select crops which perform well under anticipated conditions to reduce risks from crop failure. In general, local and annual crops as well as perennial trees should be prioritized since they are best adapted to the local environment. Improved drought-tolerant crops and varieties are also encouraged since they still survive even when the irrigation system fails.

- **Irrigation scheduling**

Irrigation scheduling is influenced by the water availability in the crop root zone, the amount of water consumed by crops since the last irrigation, growth stages of the crop, soil moisture content, and local climatic conditions. It is found that small and timely irrigation with soil nutrient management enhances water use efficiency by 10-25%. Therefore, it is necessary to plan the irrigation schedule to match with crop water requirements at each growth stage.

- **Irrigation methods**

Generally, there are three main irrigation techniques, which are surface or gravity irrigation, sprinkler irrigation, and drip irrigation. Surface irrigation is widely applied since it is the easiest and cheapest method. However, it is also the least efficient method since less than 10% of water is used by the plant. Sprinkler irrigation is costlier due to pressurized water requirement. Nevertheless, with low energy precision application, this method is efficient at 95% and saves around 20-50% of energy costs, compared to the conventional one. Drip irrigation is highly efficient since it drops water to the crop root zone. This method has different levels of sophistication and cost. It increases yields up to 100% with water saving up to 40-80%. It is recommended to apply irrigation techniques that optimize water use efficiency. Improving the water distribution system also enhances water use efficiency. For example, lining the canal surface reduces seepage losses; while, putting the canal underground decreases evaporation losses.

- **Soil enhancement measures**

Improving soil fertility enhances soil water availability for crops and water use efficiency. It is recommended to ask government officers for advice and soil capacity surveys. There are a wide range of soil enhancement methods. For instance, proper field leveling reduces runoff from surface and sprinkler irrigation. Furrow diking also reduces runoff and collects water. Moreover, residue management and conservation tillage in the field with sprinkler or drip irrigation reduce runoff and surface evaporation. They also increase organic matter and water holding capacity of the soil. Besides, mulching and shading impede the solar radiation which reduces soil water evaporation. Whereas, mulching also hinders water vapor from the soil surface.

2.3.4 Agricultural water productivity

Agricultural water productivity is developed from the term "water use efficiency" to measure productions from water used. It is the ratio of the net benefits from agricultural activities to the amount of water consumed to produce these benefits, including food, nutrition, income, jobs, welfare, livelihood, and sound ecology, at less social and environmental cost per unit of water used. Its concept is to produce more with less water and improve social, economic, and environmental output per unit of water use (International Water Management Institute [IWMI], 2014).

It is vital to improve agricultural water productivity since it can reduce poverty and improve the quality of life of poor farmers through better food and nutrition as well as more income and employment. Besides, it can fulfill increasing demands for food and changing diet patterns of a growing, wealthier, and increasingly urbanized population. Productive use of agricultural water also reduces costs of crop cultivation, energy requirements for water withdrawal, and needs for additional land and water resources. Moreover, it ensures water availability for environmental uses and climate change adaptation. These enable sustainable development in the rain-fed agricultural areas in various but interrelated aspects, as presented in Table 2.2.

Table 2.2 Relevant sustainable development goals and targets to the productive use of harvested rainwater

Relevant sustainable development goals: SDGs	Relevant targets
Goal 1. End poverty in all its forms everywhere	**Target 1.1** Reduce poverty **Target 1.5** Build the resilience of the poor and reduce their vulnerability to climate change and other economic, social, and environmental shocks
Goal 2. End hunger, achieve food security and improved nutrition and promote sustainable	**Target 2.1** Reduce hunger and ensure safe, nutritious, and sufficient food all year round

Relevant sustainable development goals: SDGs	Relevant targets
agriculture	**Target 2.2** Reduce malnutrition **Target 2.3** Increase agricultural productivity and incomes of small-scale food producers **Target 2.4** Provide sustainable food production systems and resilient agricultural practices that increase productivity and production, maintain ecosystems, enhance adaptive capacity to climate change, and improve land and soil quality
Goal 4. Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all	**Target 4.4** Provide information and communications technology skills and decent jobs
Goal 6. Ensure availability and sustainable management of water and sanitation for all	**Target 6.4** Increase water-use efficiency, ensure sustainable water withdrawals and supply, and reduce water scarcity in the agricultural sector
Goal 12. Ensure sustainable consumption and production patterns	**Target 12.2** Use natural resources efficiently **Target 12.a** Enhance scientific and technological capacity for sustainable patterns of consumption and production
Goal 13. Take urgent action to combat climate change and its impacts	**Target 13.1** Enhance resilience and adaptive capacity to climate-related hazards
Goal 15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss	**Target 15.3** Improve degraded land affected by drought

Source: United Nations (2017)

Office of the Royal Development Projects Board evaluated the on-farm pond construction project based on the New Theory farming practice. They did a survey with households acquiring the on-farm pond and found that these households gained various advantages from the on-farm pond. These social, economic, and environmental benefits enabled them to be self-reliant and have a better quality of life. However, it also found that 45% of respondents still faced water shortage problems, mainly due to dry spells and various kinds of crop cultivation. Besides, there were other factors affecting the sufficiency of the rainwater harvested, including crop types, size of farmland, field management practices, rainfall characteristic and hydrology of the area, and storage capacity of the on-farm pond (OPM, 1999).

Whereas, Land Development Department, Ministry of Agriculture and Cooperatives, which is the major government agency for the provision of on-farm ponds, has also implemented the on-farm pond construction project in the unirrigated areas since 2005. The standard storage capacity of the pond is 1,260 m^3 (MOAC, 2017a). This project has been benefiting at least 450,000 households in the rain-fed agricultural areas throughout the country (MOAC, 2018a). Office of Agricultural Economics, Ministry of Agriculture and Cooperatives, has evaluated the project and found that 25% of the on-farm ponds in the survey could not supply enough water. It was mainly due to dry spells and the incompatibility between the size of the on-farm pond and the size of the farmland (MOAC, 2016a).

This problem hinders the pursuit of sustainable development in the rain-fed agricultural areas of Thailand. Therefore, it is necessary for farmers to select the agricultural water management scheme of the on-farm pond which balances farm water demands and supply as well as optimizes farm water productivities in all aspects. The application of the multiple criteria decision-making technique for assessing the sustainability of alternative schemes will help them make a rational and appropriate selection of the preferred one, which enables them to be self-reliant and improve their quality of life, sustainably.

2.4 Decision making

Harris (2012) defines decision making as the study of identifying and selecting alternatives based on the values and preferences of the decision maker. It is necessary to identify as many alternatives as possible and to select the one with the highest probability of success or effectiveness and which best fits with goals, desires, lifestyle, values, and the like. Whereas, Lunenburg (2010) describes decision making as a process of making a choice from a number of alternatives to meet a desired result. It consists of three key elements which are the selection of a choice from a number of alternatives, a complicated process of selecting a choice from options, and an expectation from the mental activity in which the decision maker is involved to reach a final decision.

However, human error from personalities, attitudes, prejudices, and a self-interest bias of an individual decision maker also influence the selection of choices (Harvey, 2007). Besides, complex environmental and limited information processing make rational decision-making impractical for human beings (Schwartz et al., 2002). Therefore, it is necessary to have a decision support tool in order to help the decision maker conduct rational decision-making in practice.

2.4.1 Decision support tool

A decision support tool is a wide range of systems, tools, and technologies, which helps decision makers use data, documents, knowledge, communication technology, and models to support a decision, complete decision process tasks, and solve sophisticated, complex, or simple problems (Power, 1997; Sprague, 1980). It applies a disciplined and transparent decision-making process with adequate supporting information and recommended alternatives for improving the quality of the decision making. It enables decision makers to analyze and better understand the problem, consider alternatives systematically, and make a rational decision (de Kok & Wind, 2003; Harvey, 2007).

2.4.2 The rational model

The rational model, so-called the rational choice theory or the optimizing decision theory, believes that decision makers have well-ordered preferences and acquire full detailed information about their alternatives, outcomes, and decision criteria. Besides, they can discriminate among all possible alternatives by using a single scale of preference, value, or utility through a consistent and systematic process for making an optimal decision. It makes them completely rational and enables them to select the optimum choice which maximizes the solution to the problem (Lunenburg, 2010; Pavitt & Curtis, 2001; Schwartz et al., 2002).

According to the rational model, Baker et al. (2001) propose an eight step disciplined decision-making process as presented in Figure 2.5. It is simple, clearly defined, transparent, and allows easily accessible participation for involved parties. It provides a structure for solving complex problems. Besides, it obtains reliable evaluation methods which make this process objective and consistent with criteria for making rational decisions and enhances the validity of the decision analysis. Moreover, this process is repeatable, reviewable, and revisable until everyone involved is satisfied that all important features required for solving the problem have been included and the preferred alternative has been selected.

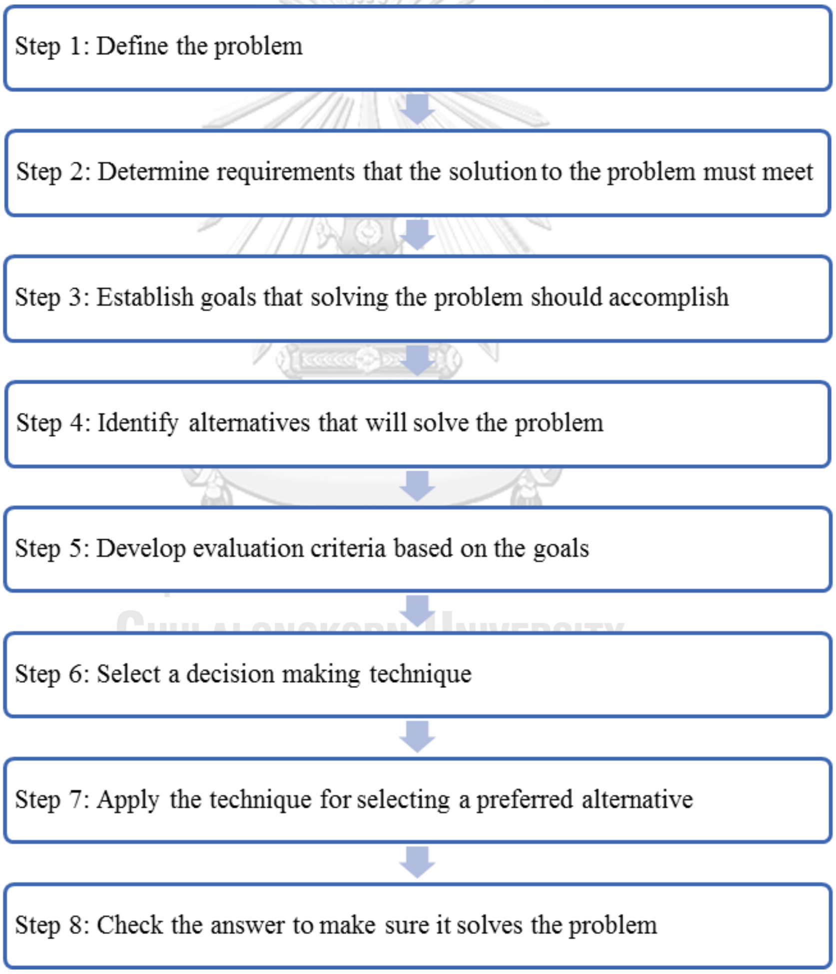

Figure 2.5 General decision-making process
Source: Baker et al. (2001)

Before starting a decision making process, it is necessary to identify the decision maker and stakeholders in the decision, in order to reduce disagreement in the process (Baker et al., 2001). Moreover, it is vital to accommodate an environment where the decision maker and stakeholders are able to be properly advised, discuss, and participate in the process actively in order to share their information, experience, and knowledge (Mendoza & Martins, 2006).

Moreover, it is strongly recommended to have experts from relevant fields as well as skilled and experienced analysts or facilitators as a decision support team. They need to be involved in all steps of the process in order to ensure that the process is valid, transparent, and well performed. The size of the team is also important since it requires broad based knowledge for analyzing, recommending, and supporting a decision (Baker et al., 2001). They are helpful to finding potential compromise among conflicting goals by contributing consistent information, individual opinions, knowledge, expertise, and experience with the decision maker and stakeholders in the focus group discussions (de Kok & Wind, 2003; Mendoza & Martins, 2006).

- **Step 1: Define the problem**

This first step is very important for making an efficient decision. It is about identifying root causes as well as limiting assumptions, systems, and organizational boundaries. It is advised to describe both initial and desired conditions in a clear problem statement which is agreed upon by everyone involved (Baker et al., 2001). Besides, it is needed to identify constraints hindering the effectiveness of alternatives and uncertain future conditions influencing the outcomes of alternatives (de Kok & Wind, 2003). The process of the first step is presented in Figure 2.6.

- **Step 2: Determine requirements**

Requirements are conditions that any selected alternatives must meet. Experts from relevant fields propose requirements, which are agreed upon by the decision maker, for discriminating between alternatives (Baker et al., 2001).

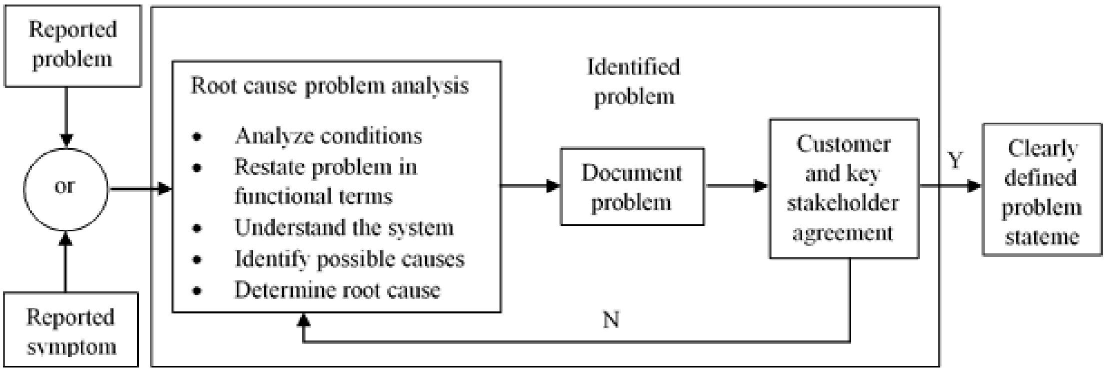

Figure 2.6 Problem definition process
Source: Baker et al. (2001)

- **Step 3: Establish goals**

Goals are broad statements of intent and desirable programmatic values which exceed a must level. They should be stated positively. Goals are used to identify superior alternatives. They may sometimes conflict. They may suggest new or revised requirements or requirements that should be converted to goals. However, both requirements and goals are vital for defining alternatives (Baker et al., 2001).

- **Step 4: Identify alternatives**

Alternatives are distinct potential solutions which propose diverse methods for changing the initial condition to the desired condition. They are suggested based on requirements and goals in order to meet requirements and fulfill as many goals as possible. Each alternative has different resources to achieve requirements and goals. Its description of how to solve the defined problem and its distinction from other alternatives must be clearly explained. Alternatives that do not meet requirements must be discarded; otherwise, requirements must be either adjusted, rejected, or restated as goals (Baker et al., 2001).

- **Step 5: Define criteria**

Criteria are rules of acceptability and standards of evaluating alternatives. Criteria are defined based on goals (Baker et al., 2001). Each goal must have at least one criterion; while, each criterion can be decomposed into sub-criteria.

However, they have to acquire a description and a unit of measurement or a definition for the estimation, in terms of an indicator. Each criterion comprises the information provided by indicators which are specific details reflecting a desired condition of a particular criterion (Mendoza et al., 1999; Prabhu, Colfer, & Dudley, 1999).

Criteria should be non-redundant and few in number. They are objective measures of effectiveness for each goal to discriminate among alternatives in a meaningful way. They enable the decision maker to understand the implication of the alternatives and suggest the one that most nearly satisfies goals. There are several useful methods for selecting criteria, including brainstorming, round robin, reverse direction method, and previously defined criteria (Baker et al., 2001).

- **Step 6: Select a decision-making technique**

No one decision making technique fits all decisions. Therefore, it is recommended to select a method based on the complexity of the problem and experience of the decision maker (Baker et al., 2001). Some of these techniques are too complicated and difficult to apply. Therefore, it is advised to select a user-friendly method; the simpler the method, the better. While, more complex methods can be added later if necessary (Harvey, 2007).

These techniques have rational and systematic procedures for scoring criteria and alternatives. They handle and communicate information as well as eliminate personal preferences and idiosyncratic behaviors from the decision making (Baker et al., 2001). They apply human critical thinking skills, which are developed from the process of gathering answers to questions about the problem through information, data, and experience, for balancing a decision when the selection among alternatives is unclear (Mysiak et al., 2005).

- **Step 7: Evaluate alternatives against criteria**

Alternatives are evaluated by quantitative, qualitative, or combined methods. They are also ranked by weighted criteria. The evaluation methods are selected by the complexity of the problem and experiences of assisting analysts or facilitators and the decision maker. It is also important to be concerned about time and budget constraints to limit the scope of the analysis (Baker et al., 2001).

- **Step 8: Validate solution against problem statement**

The chosen alternative should be checked in order to confirm that it can solve the identified problem. Comparing the original problem statement to requirements and goals, the selected solution should satisfy the desired condition, meet requirements, and best achieve goals. In case that the selected alternative cannot fulfill requirements and goals in practice, it is advised to recheck any probable causes, especially in the first step of defining the problem. If the problem is incorrectly defined, the selected alternative cannot produce the desired result (Baker et al., 2001).

2.4.3 Multiple Criteria Decision Making (MCDM)

In single criterion decision problems, the best alternative is the optimum one for which the criterion value is maximized or minimized when compared to other alternatives. However, in multi-criteria decision problems, the optimum of each criterion does not fit in the same alternative, which causes a conflict among criteria. Therefore, it sometimes needs to compromise and trade-off outcomes in order to select the preferred or most satisfactory one as the best alternative (Ravindran, 2009).

Multiple Criteria Decision Making or MCDM is a formal approach which takes explicit account of multiple and conflicting criteria in order to make a rational, justifiable, and explainable decision. It structures management problems in a systematic and traceable process (Belton & Stewart, 2002). MCDM techniques are applied as a decision-making tool for selecting the most preferred choice of complex problems. There are various methods of MCDM, such as Pros and Cons Analysis, Kepner-Tregoe Decision Analysis, Analytic Hierarchy Process, Multi-Attribute Utility Theory Analysis, Cost Benefit Analysis, Elimination and Choice Expressing Reality, Preference Ranking Organization Method for Enrichment Evaluation, Custom Tailored Tools, and the like (Baker et al., 2001; Belton & Stewart, 2002; Mendoza & Martins, 2006; Ravindran, 2009). They facilitate a discussion and encourage collaborative planning. They also offer a convenient environment for the involvement and participation of individuals or groups of individuals in the decision-making process. Besides, they can manage mixed sets of qualitative and quantitative data, including expert opinions and knowledge. The result derived from these MCDM methods is, therefore, objective, rational, participatory, and transparent with a traceable record from the democratic and structured decision-making process (Adham et al., 2016; Baker et al., 2001; Mendoza et al., 1999; Mendoza & Martins, 2006; Prabhu et al., 1999).

2.4.3.1 Criteria related to sustainable rain-fed agriculture referenced to the New Theory of His Majesty King Bhumibol Adulyadej The Great

In order to make a rational selection of the agricultural water management scheme of the on-farm pond, it has to be unavoidably involved with multiple and conflicting criteria. It is recommended that the total number of criteria should cover as many of the possible assessment issues, in as many different ways, possible. However, there are usually very real constraints on resources for the criteria evaluation (Mendoza et al., 1999). Therefore, it is recommended to start with a small set of criteria which are simple and easily measured (Stauffer, 2017).

There are some key attributes for the assessment and selection of the appropriate criteria, including the relevance and logical association between each decision element and each decision hierarchy; the simple and unambiguous definition of criteria; the straightforward interpretation of the fulfillment of a criterion; the reliability and replicability of criteria; the ease and cost-effectiveness of the data collection; the acquirement of meaningful, efficient, and integrated information related to a number of criteria; and the appeal of criteria in terms of important, logical, practical, and economical, to users (Mendoza et al., 1999; Prabhu et al., 1999). Nevertheless, the most preferred criteria are those which are simply and directly detected, recorded, measured, and interpreted without the experience and judgement required (Prabhu et al., 1999). Besides, they should be locally specific based on social, economic, and environmental contexts of each country (Hayati et al., 2010).

Table 2.3 presents criteria related to the concept of the sustainable agriculture and the New Theory. They are derived from international and national research papers and organizations. They can be applied for assessing the sustainability of agricultural water management schemes of the on-farm pond.

Table 2.3 Criteria related to sustainable rain-fed agriculture referenced to the New Theory of His Majesty King Bhumibol Adulyadej The Great

Criteria	**Criteria description**	**Unit of measure**
Land use efficiency [1-3]	Increasing the cultivated area in the dry season [3, 4]	m^2/season [4]
	Irrigable area per season [4]	
	Agricultural land use efficiency for the whole year [1, 5]	The extent, duration, and timing of vegetative cover on the land or land cover of the year [6]
Yield and risk of crop failure [7]	Size of cropping area determined by the level of rainfall probability [7]	Trees survival and growth rate [8]
Production cost [3, 4, 9-11]	Minimizing cash requirement per annum for supply of productive resource during the year [11] Note: Production cost includes seeds, machine, land preparation, fertilizer, pesticide, herbicide, wage, animal food [1]	\$/year [11]
Land productivity [3]	Maximizing profit [11]	\$/m^2 [4]
	Revenue per area [4, 7]	
	The annual value of production per area [12]	
On-farm water utilization [1]	Water utilization throughout the year [1]	The standard deviation of the rate of change of total water use benefit over all year [13]
	Water availability [5, 14]	Available amount of water during the season [11]
	Irrigation water constraint [11]	
Water productivity [4]	The ratio of agricultural output to the amount of water consumed [15]	kg/m^3 [4, 15]
	Total biomass or grain yield per unit of water or crop per drop [4, 13, 15, 16]	
	Revenue per unit of water [4, 7, 15]	\$/m^3 [4, 15]

Criteria	Criteria description	Unit of measure
	Value for agricultural products per unit of water or price per drop [13, 16]	
Water use efficiency [3-5]	Unit of water per area [4, 13]	m^3/m^2 [4]
	Increased crop and vegetation growth during dry spells and in the dry season [4]	m^2/season [4]
Production cost and benefit [10]	The result of cost-benefit ratio [7, 9, 12]	Cost-benefit analysis [7, 12, 17]
		The production input requirements and yields of land [17]
	Farm income [9]	Net production income = total revenues - total expenses [12, 17, 18]
		The value of output per unit of cost [12]
Farm productivity [2, 4, 7, 9, 14]	Maximizing yields or output per area [1, 4, 10-12]	kg/m^2 [4, 11, 12]
	Total crop yield per cultivated land during the season [11]	kg/m^2/season [11]
Product diversification [3, 10, 12]	Diversity of farm outputs [12, 19]	The number of separate final products and by-products flowing from each activity [12]
	Extensive use of all by-products [12]	The number of ways in which these products can be used or disposed of [12] Note: A maximum of four ways: consume/use, sell/barter, store, or process
Resource use efficiency [1, 9, 10, 14]	Continuity of reusable or recyclable agricultural residue as the farm input [3, 10, 12]	Proportion of farm resources generated on the farm and purchased inputs [12]
	Maximizing usage of farm yard manure or the amount of farm yard manure used during the year [9, 11, 12]	tons/year [11]
	Minimizing usage of N P K or the amount of nitrogen, phosphorus, and potash used during the year [11]	kg/year [11]

Criteria	Criteria description	Unit of measure
Diversity of agricultural activities [6, 10, 12, 19]	The extent of diversification of production systems over the landscape, including livestock and agroforestry systems [6]	The areas occupied by the various crops [12]
		The amounts or values of outputs from the various activities [12]
	The degree of flexibility and resilience of farming systems and their capacity to absorb shocks and respond to opportunities [6]	The relative time-dispersion (RTD) of production [12]
Food security [2, 4, 5, 9, 10, 13, 14, 16]	Nutrition contribution [1, 2, 4]	month with harvests/year [1, 4]
	Quantity of crop feeding amount of people or kilogram per drop [16]	kg/m^3 [16]
Food self-sufficiency [13]	Rice availability for the whole year [2, 3]	kg/person or family/year [17]
	Yields to cover the needs based on the consumptive capacities as a baseline consumption requirement [17]	
Household self-sufficiency [9, 17]	The amount of each product consumed by the household [12]	
Poverty [5]	The reduction of the cost of living [1, 3]	The amount of money saved as household consumption per year [2, 3, 10]
	The value of produce consumed by the household [12]	Food price for household consumption at the local market [17]
		Production net income/The cost of the annual household food consumption [17] Note: below 1 signifies insufficient food requirement for family self-sufficiency and above indicates a surplus
	Poverty in all dimensions according to national definitions [5]	National poverty line [5]
The diet with important nutrients and vitamins [4, 5, 15]	Variability of nutrition [1, 2, 10]	Number of nutrition [1, 2, 10]
	The nutritional values of different crops [15]	kcal [15]
	Food and energy equivalent per unit of	kcal/m^3 [15]

Criteria	Criteria description	Unit of measure
	water or nutrition per drop [15, 16]	
	Energy requirements of the family members using nutritional data [17]	kcal/person or family [17]
Job creation [4, 5, 14, 15]	Agricultural employment generation [4, 7, 9, 11, 14]	Month with household labor employment per year [1, 10]
	Jobs per drop [16]	
	Labor per farm unit [1, 3, 6]	The sum of full-time adult household labors used for all farm activities [1, 6, 18]
	Productive employment [5, 15]	Volume of production per labor unit [5]
	Labor productivity [3]	Number of working hours per day [3]
	Agricultural work intensity [3]	
	Labor opportunity cost [17]	The salaries paid to farm workers [9, 15]
		Monthly income comparing with minimum wage [1, 17]
Household income generation [1, 4, 5, 7, 9, 10, 14, 15]	Real income [1-3, 5-7, 10, 12, 17, 19]	Net income or net profit = net production income - the cost of the annual household food consumption [3, 4, 17, 19]
		Growth rates of household expenditure [5, 12]
	Saving [2, 12]	The amount of money saved per year [4]
	The time-pattern of income received [12]	The uniformity of within-year income flow [2, 3, 10, 12] Note: An income which is perfectly dispersed, received as 12 equal monthly amounts over the operating year
	Variability of income generation [3, 7, 10, 12]	Available profit from all the yielding crops in different season during the year [11]
		The dispersion of individual monthly values of income relative

Criteria	Criteria description	Unit of measure
		to their annual totals [12]
	Income stability [12]	The coefficient of variation (CV) of income [12]
Mixed farming [1, 3, 9, 14]	Crop diversity [7, 9, 10]	Diversity of farm activities [12, 19-21]
		Number of plant and animal genetic resources for food and agriculture secured [5]
		The number of tree/crop/animal species present [12]
		The number of individuals within each species [12]
		The areas occupied by the various crops [12]
		Local breeds [5]
Multiple cropping [3, 9, 14]	Multiple cropping over both space and time [12, 19]	The number of crops in the same area in sequenced seasons [12, 22, 23]
Irrigation water consumption [7]	Balancing farm water demands and supply [3]	Adequate water for the whole year [2]

Source: [1] Prime Minister's Office (1999); [2] Weerawut Songsai et al. (1999); [3] Wisarn Pupphavesa et al. (1999); [4] Woltersdorf (2010); [5] Division for Sustainable Development. Department of Economic and Social Affairs [UN-DESA] (2016); [6] Dumanski et al. (1998); [7] Dantsis et al. (2010); [8] Critchley and Siegert (1991); [9] Hayati et al. (2010); [10] Tangon Munjaiton et al. (1999); [11] Umanath and Rajsekar (2013); [12] McConnell and Dillon (1997); [13] Cai, McKinney, and Rosegrant (2003); [14] Wallop Promthong (2008); [15] Sharma et al. (2015); [16] Kijne (2003); [17] Fox et al. (2005); [18] Manos, Chatzinikolaou, and Kiomourtzi (2013); [19] Pradit Withisuphakorn et al. (1999); [20] AgriInfo.in (2015e); [21] AgriInfo.in (2015d); [22] AgriInfo.in (2015b); [23] AgriInfo.in (2015a)

It can be seen that these criteria are interdependent and interactive. Therefore, it is necessary to find a MCDM technique which is suitable for them.

2.4.3.2 Analytic Hierarchy Process (AHP)

Analytic Hierarchy Process or AHP is one MCDM techniques which is widely applied as a decision-making tool (Adham et al., 2016; Baker et al., 2001; Fülöp, 2005; Mendoza et al., 1999; Mendoza & Martins, 2006; Mendoza & Prabhu, 2000a, 2000b, 2003; Mysiak et al., 2005; Qureshi & Harrison, 2001). It is appropriate for the problem with a large number of alternatives and multiple criteria, both quantitative and qualitative (Baker et al., 2001). It is a structured technique for analyzing complex decisions based on mathematics and expert judgement (Adham et al., 2016). Input, therefore, can be obtained from both actual measurements and subjective opinions. This technique is not data-intensive and easy to apply. Its methodologies and calculations are understandable. It handles and communicates information as well as eliminates personal preferences and idiosyncratic behaviors from the decision making (Mysiak et al., 2005). Moreover, it accommodates participation among a wide range of involved parties (Mendoza & Prabhu, 2000b).

This method believes that a human is better at making relative judgements than absolute ones. Thus, it allows relative judgements as a replacement for absolute judgements (Saaty, 1988, 1990). AHP is a quantitative comparison method. It has rational and systematic procedures for scoring criteria and alternatives (Mysiak et al., 2005). This method is very accurate for reflecting the relative weights of each element. It applies the pairwise comparison method and mathematics for scoring alternatives based on their relative performance against the criteria and selecting a preferred alternative. AHP presents the element of a problem hierarchically as illustrated in Figure 2.7. It breaks down the problem into smaller and smaller components from goals at the top level to criteria and alternatives at the last level. It then guides the decision maker through a series of one-on-one judgement. This method uses a nine-point scale which can be translated to numbers as ratio scale estimates as follow, 1, equally important; 3, moderately more important; 5, strongly important; 7, very strongly important; 9, extremely most important. While, the even values 2, 4, 6, and 8 are intermediate values. The preferred alternative is prioritized among criteria and acquires the highest total score. It shows its relative strength or intensity of impact in the hierarchy and synthesizes judgements (Saaty & Kearns, 1985).

Moreover, this method has a mean for measuring the consistency of the judgements made by the decision maker, so-called Consistency Ratio (C.R.). It provides information on consistency in terms of which element between two elements compared is more important and how much more important. In general, C.R. of 0.10

or less is considered acceptable. Otherwise, it is necessary to recheck the pairwise comparison matrix in order to ensure a clear rational decision and the most preferred choice (Adham et al., 2016; Mendoza et al., 1999).

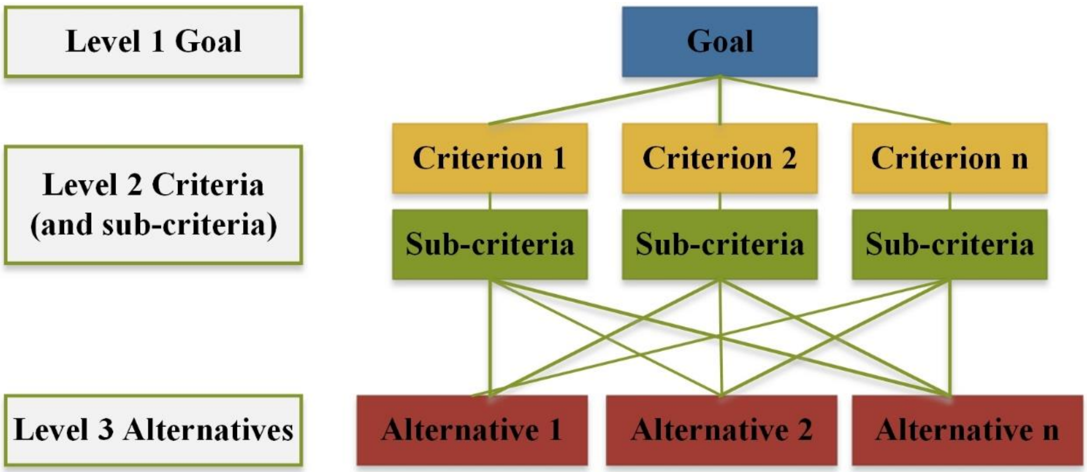

Figure 2.7 Analytic Hierarchy Process
Source: Yau (2009)

AHP is applied for a wide range of sustainable development purposes due to their multiple and conflicting objectives in nature. These subjects require considerations of social, economic, environmental, political, and technical issues in a structured framework for making a rational decision. These subjects include the assessment of criteria and indicators for sustainable forest management, an evaluation of riparian revegetation policy options, sustainable catchment use, water resource management, natural resources management planning, integrate biodiversity in strategic forest planning, environmental conflict analysis, land-use allocation, prioritize watersheds and reaches for protection and restoration, and wetland management (Adham et al., 2016; Baker et al., 2001; Fülöp, 2005; Mendoza et al., 1999; Mendoza & Martins, 2006; Mendoza & Prabhu, 2000a, 2000b, 2003; Mysiak et al., 2005; Qureshi & Harrison, 2001).

CHAPTER III
METHODOLOGY

3.1 Conceptual framework

This research aimed to select an appropriate decision support tool for sustainable rain-fed agriculture referenced to the New Theory of His Majesty King Bhumibol Adulyadej The Great. This tool enabled farmers in the rain-fed agricultural area to assess the sustainability of agricultural water management schemes of the on-farm pond and make a rational and appropriate selection based on the concept of the sustainable agriculture and the New Theory.

Literature about sustainable agriculture, the New Theory, agricultural water management of the on-farm pond, and decision making were reviewed. Moreover, available relevant secondary data from government agencies, which are required for the agricultural water management of the on-farm pond, was studied.

This research followed the eight step disciplined decision-making process of Baker et al. (2001). This process is simple, clearly defined, transparent, easily accessible and participatory for all involved parties. Besides, this research selected the Analytic Hierarchy Process or AHP technique as its decision-making technique. This method is one of the widely applied MCDM techniques. It is appropriate for the problem which has many alternatives and multiple criteria, both qualitative and quantitative. It enables the decision maker to make a rational decision by weighing all factors among multiple criteria and considering alternatives systematically (Hayati et al., 2010; Mendoza & Martins, 2006; Mendoza & Prabhu, 2000b; Mysiak et al., 2005). Therefore, this tool supported farmers to manage sustainably their limited agricultural water in the on-farm pond, which was their only water source during dry spells and in the dry season. Besides, it helped them realize self-reliance, self-sufficiency, and risk management as well as balance farm water productivities in all aspects, including economic, social, and environmental.

Figure 3.1 illustrates the conceptual framework of the study based on the eight step disciplined decision-making process of Baker et al. (2001).

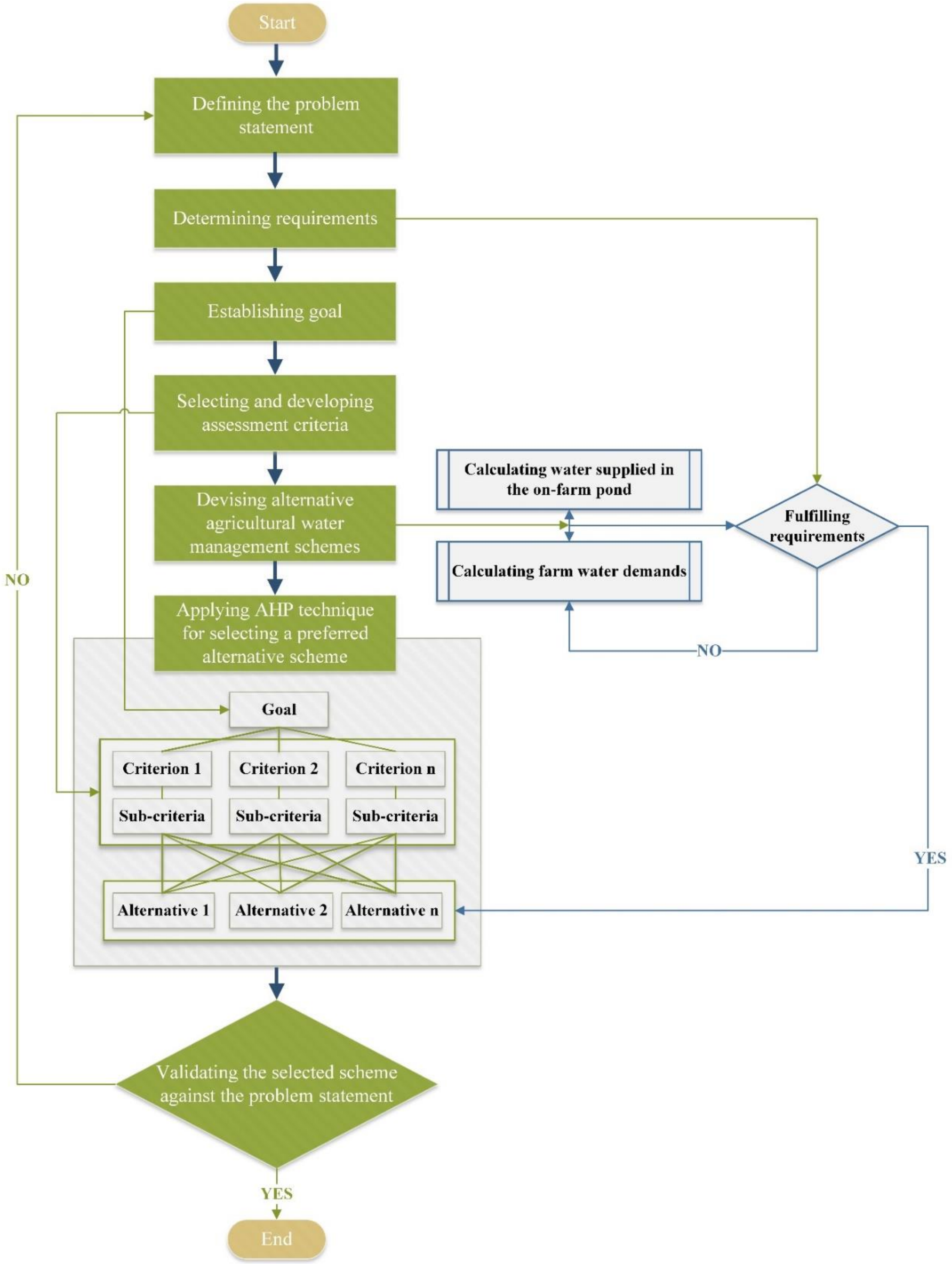

Figure 3.1 The conceptual framework of the study

3.2 Study area

The research was purposely conducted at the unirrigated area of Khao Wong district, Kalasin province. It is one of the most well-known rain-fed agricultural areas in Thailand. It is the place where His Majesty King Bhumibol Adulyadej The Great initiated and tested the concept of the New Theory in 1992. The New Theory Demonstration Project was established for experimenting and demonstrating the implementation of the New Theory of farming practice in the rain-fed agricultural area. Besides, the Lam Phra Young reservoir and the irrigation system was constructed at Song Plueai sub-district, which expanded the irrigated area of Khao Wong district to 4,600 rais (OPM, 2012). Moreover, the Lam Phra Young Bhumipat diversion tunnel was constructed at Khum Kao sub-district in 1995. It diverted water stored in the Huai Phai reservoir, Dong Luang district, Mukdahan province, which is located at another side of the Phu Phan ridge, to fill the Lam Phra Young reservoir. It expanded the irrigated area of Khao Wong district from 4,600 rais to 16,600 rais (MOAC, 2009). It demonstrated the full concept of water source management of the New Theory, which is a *large reservoir filling a small reservoir, small reservoir filling a pond*. This concept reduces risks from relying only on rainwater, which fills up the on-farm pond only once a year during the rainy season. It ensures that water stored in the on-farm pond is sufficient in the dry season and in years when the amount of rainfall is less than normal (OPM, 2012).

Moreover, Kalasin province has had the highest number of on-farm ponds with 1,260 m^3 storage capacity from the on-farm pond construction project in the unirrigated area of Land Development Department, Ministry of Agriculture and Cooperatives since 2005. There are more than 23,000 on-farm ponds of this project located in this province (MOAC, 2018a). Office of the Royal Development Projects Board evaluated the on-farm pond construction project based on the New Theory farming practice. This project was initiated by Her Royal Highness Princess Maha Chakri Sirindhorn in order to help farmers nearby the New Theory Demonstration Project at Khao Wong district, Kalasin province (OPM, 2009). The survey showed that 45% of the on-farm pond of the project could not provide enough water to be used for the whole year, mainly due to dry spells and various kinds of crop cultivation. There were also other factors affecting the sufficiency of the harvested rainwater, including crop types, size of farmland, field management practices of farmers, rainfall characteristic of the area, and storage capacity of the on-farm pond (OPM, 1999).

Nevertheless, according to the average annual rainfall and mean monthly rainfall of Khao Wong district, Kalasin province (MOAC, 2014), it is possible for farmers in this area to have their cultivated land irrigated and productive throughout the year. They have to make a rational and appropriate selection of the agricultural water management scheme of the on-farm pond, which applies the harvested rainwater efficiently and productively during dry spells and in the dry season. Besides, they need to manage their agricultural resources based on the concept of the New Theory, which will lead to sustainable rain-fed agriculture.

This research did a survey based on the list of agricultural holders who acquired an on-farm pond with 1,260 m^3 storage capacity from the on-farm pond construction project in the unirrigated area of Land Development Department from 2005-2016. They were in six sub-districts of Khao Wong district, Kalasin province, which were Khum Kao, Song Plueai, Kut Pla Khao, Kut Sim Khum Mai, Saphang Thong, and Nong Phue. The result of the survey shows that Song Plueai sub-district was the sub-district with the highest number of survey responses and qualified agricultural holders willing to participate in the beta testing of the selected appropriate decision support tool for sustainable rain-fed agriculture referenced to the New Theory of His Majesty King Bhumibol Adulyadej The Great. Therefore, this research purposely selected Song Plueai sub-district as the study area.

As demonstrated in Figure 3.2, Song Plueai sub-district, Khao Wong district is located at the northern part of Kalasin province. It is surrounded by the Phu Phan ridge, so it has a wide range of 160-262 meter height above the mean sea level. The land slope of this area is 0-5% which is suitable for rainwater harvesting since it distributes more regular runoff. This area is a plateau of quaternary river terraces of the Mekong River and its tributaries (Royal Institute of Thailand, 2002). According to the soil taxonomy of Land Development Department, soil in this area can be classified into the soil series No.35 Korat group. It is normally found in the dry highland of the northeastern region (MOAC, 2014). Its physical and chemical characteristics is deep to very deep fine loam soil group. It is arisen from distributaries sediment or coarse mass parent material. The soil reaction is a very strong acid, good to moderate drainage, and low fertility (MOAC, 2015).

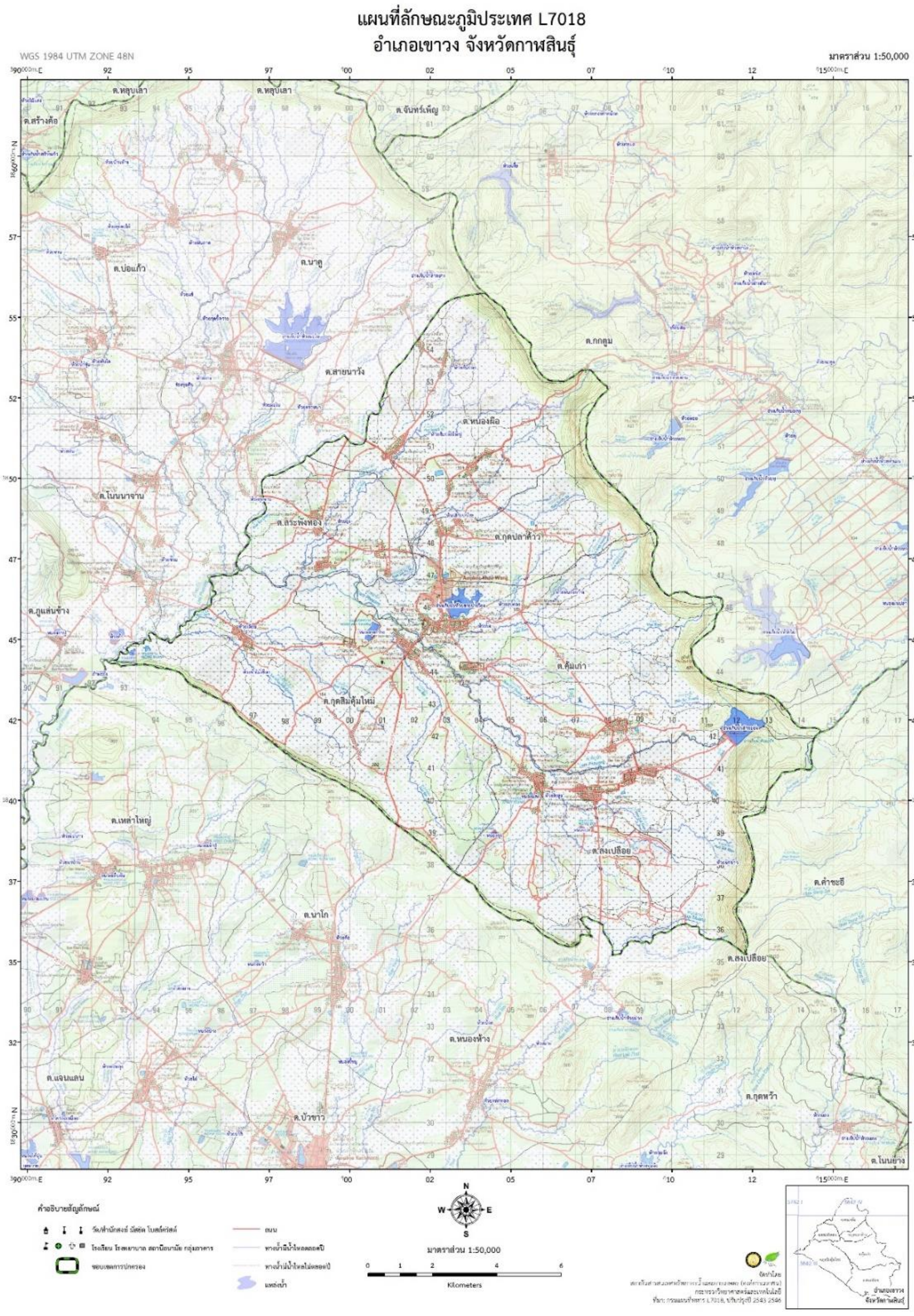

Figure 3.2 Topographical map of Khao Wong district
Source: Ministry of Science and Technology (2017)

Climate in this area belongs to the tropical savanna with low precipitation and noticeable dryness in the winter (Donner, 1978). As situated at the center of the Indo-Chinese peninsula, the weather pattern is, therefore, the result of the seasonal differences in temperatures between the Asian landmass and two great oceans. It is mainly influenced by two tropical monsoons, which are the southwest monsoon and the northeast monsoon. The southwest monsoon from the Indian Ocean in the south brings a wet season to the area. While, the northeast monsoon from the Asian continental in the north brings a dry season to the area (Gall, 2003). Typhoons from the South China Sea also cause heavy rainfall in the area between April and June. However, when they move northwards to southern China, the area faces the intra-seasonal dry spells. Until they move southerly to the area again, they cause the heaviest rainfall from August to September.

Consequently, the weather in this area can be divided into three seasons, according to the variability of monthly rainfall, temperature, evaporation, and humidity. Winter starts from November to January and the minimum temperature can drop to 9.9°C. Summer starts from February to April and the maximum temperature can reach 41.8°C. The rainy season starts from May to October and the heaviest rainfall is in August. The annual relative humidity is 63%, with the highest in August and the lowest in March (Kalasin Provincial Office, 2017; Watcharin Chetananon, 2009).

Figure 3.3-3.5 are total annual rainfall, monthly rainfall, and mean monthly rainfall, respectively, in 19-year period of Song Plueai sub-district, Khao Wong district, Kalasin province. They were recorded at Lam Phra Young reservoir station. With the average annual rainfall of 1,633 mm per year, it is obvious that Song Plueai sub-district is not short of water. However, the amount of rainfall between the rainy season and the dry season is apparently different. Therefore, it is possible and radical for farmers in this area to harvest rainwater in the rainy season in their on-farm pond for the supplemental irrigation of farm activities during dry spells and in the dry season. It enables them to use their cultivated land efficiently and productively throughout the year.

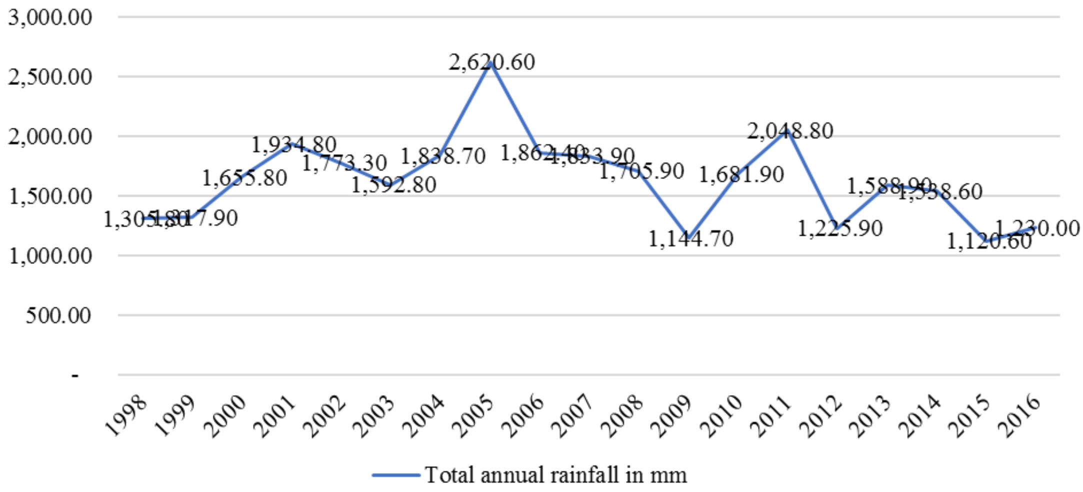

Figure 3.3 Total annual rainfall of Song Plueai sub-district, Khao Wong district in 19-year period: 1998-2016
Source: Ministry of Agricultural and Cooperatives (2017g)

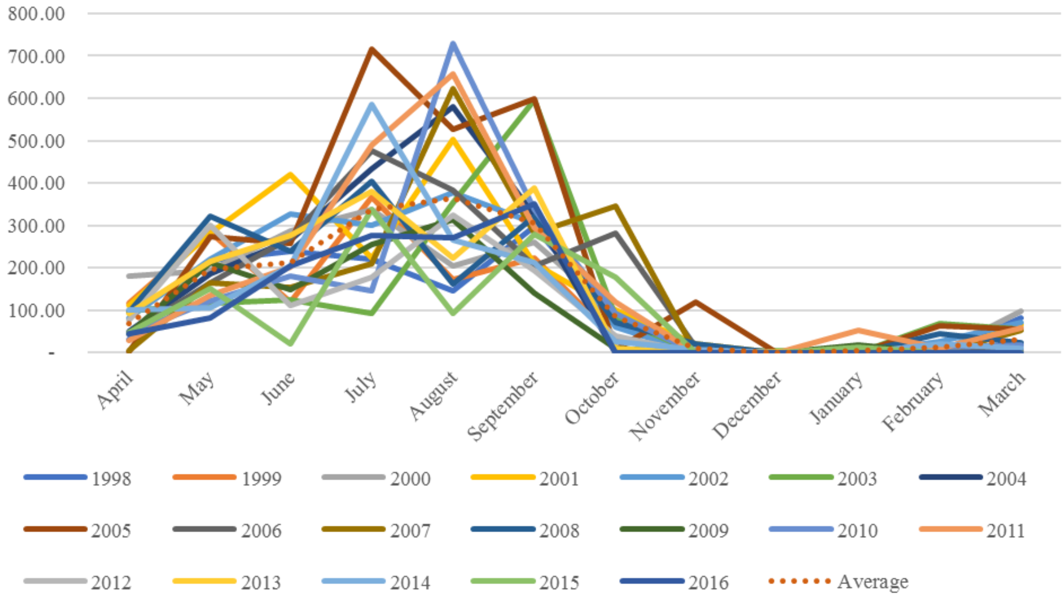

Figure 3.4 Monthly rainfall of Song Plueai sub-district, Khao Wong district in 19-year period: 1998-2016
Source: Ministry of Agricultural and Cooperatives (2017g)

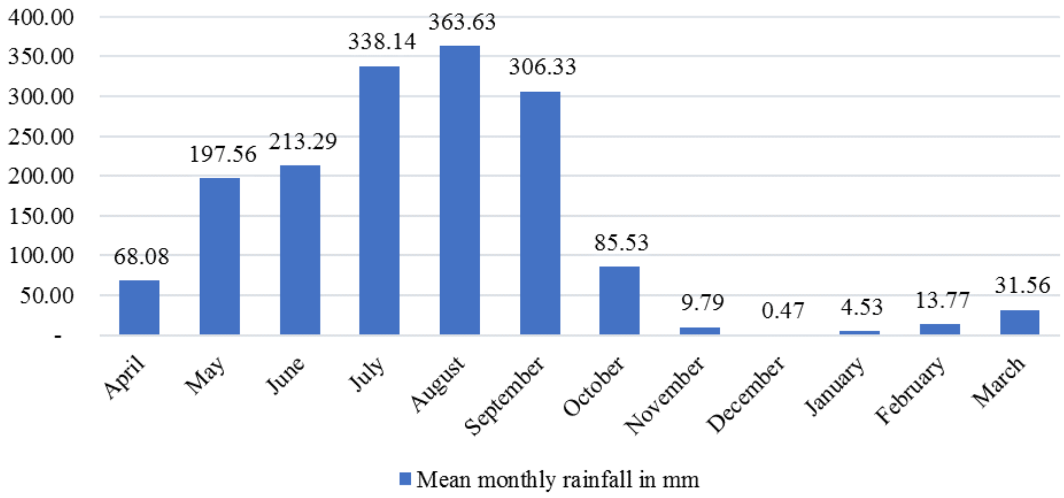

Figure 3.5 Mean monthly rainfall of Song Plueai sub-district, Khao Wong district in 19-year period: 1998-2016
Source: Ministry of Agricultural and Cooperatives (2017g)

With the total area of 207 square kilometers, Song Plueai sub-district can be divided into 16 villages. There are 2,204 households and 7,271 residents. The average number of household member per household is 3.30. Most people in this area are Phu Tai. Their ancestor emigrated from Lao People's Democratic Republic to settle down at Khao Wong district during the reign of His Majesty King Rama III. Phu Tai language is the dialect in this area (Kalasin Provincial Office, 2017). 52.87% of population in the area have an elementary education; while, 6.12% of those have a secondary education. Their major occupation is farmer; while, minor occupations are household handicraft and worker. The average number of agricultural labor per household is three. The average area of holding is 8.57 rais per holder (MOAC, 2014; MICT, 2014; Thaitambon.com, 2015).

The major economic agricultural crop in 2017 was rice with the total area of 19,428 rais. Whereas, the minor economic agricultural crops in 2017 were para rubber with the total area of 781 rais, sugarcane with the total area of 510 rais, and maize with the total area of 153 rais (MOAC, 2018b). Apart from economic agricultural crops, they also plant horticultural crops and perennial trees, such as fruits, vegetables, and herbs above the edge of the on-farm pond for the daily household consumption (MOAC, 2009). They also rear livestock naturally in the field, including buffalos for field works, cows for selling; while, ducks, chickens, and fish for daily household consumption (MOAC, 2014).

The Geographical Indication or GI product of this area is Khao Wong Kalasin sticky rice. It is Gaw Diaw, which is a local rice variety, and RD6 glutinous rice. It is cultivated in a particular topography of Khao Wong district, Kalasin province. The cultivated area is flatlands surrounded by mountains. Its soil is high in calcium and silicon. The climate is cool and arid. These conditions make this sticky rice very fragrant and soft when cooked. Besides, it is not mashed and sticky to the hands. Another GI product of the area is Praewa Kalasin Thai silk. It is created by the local technique and authentic pattern of Phu Tai people, which is inherited from generation to generation. It reflects the cultural heritage of Phu Tai people (Ministry of Commerce [MOC], 2016).

3.3 Stakeholders of the study

This research used purposive sampling, which is one of the nonprobability sampling techniques, to select stakeholders involved in the decision making process (Bernard, 2013). According to Baker et al. (2001), participants in the decision making process can be classified into two groups based on their role in the process, which are the decision maker and the decision supporters.

3.3.1 Decision maker

The decision maker of this research was an agricultural holder who used the selected decision support tool for making a rational and appropriate selection of the agricultural water management scheme of the on-farm pond either by him/herself or receiving the support from the decision supporters to interact with the tool.

They were farmers on the premise of the New Theory, which are small farmers who are poor and own a little land in the rain-fed area (Chaipattana Foundation, 2014). This type of agricultural production can be categorized as small semi-subsistence or part-commercial family farms. Their operating objective is to produce sufficient food for the daily household consumption and generate cash income for the purchase of non-farm produced food, farm inputs, and other essentials throughout the year (McConnell & Dillon, 1997). They were the sample group of the beta testing of this research.

The objective of the beta testing of this research was to understand the performance of the conceptual prototype of the selected decision support tool in the user's environment since it was entirely new. There were no historical data on which to judge user acceptance (Macefield, 2009). In the beta testing, the sample group had to assess the usability of the selected decision support tool and recommends further improvement (Ozer, 1999). Usability is the extent to which a product can be used by specified users to achieve goals with effectiveness, efficiency, and satisfaction in a specified context of use. Effectiveness is the ability of users to complete tasks through the application of the product and the quality of the output of those tasks. Efficiency is the level of resources consumed in performing tasks; while, satisfaction is the subjective reactions of users to the product (International Organization of Standardization [ISO], 1998). The field usability testing is necessary for designing a new product. It helps the developer identify required features for product modifications by considering reactions from consumers, better understanding them, and adding their opinion into the design of the new product (Ozer, 1999).

It is vital to note that the beta testing requires only a small sample group to be involved since it is just the conceptual prototype testing, not the marketing customer testing. Besides, it is found that findings from the study with a large sample size are not meaningful. Its performance increase is too small to be noticed (Macefield, 2009). Therefore, the group size of participants should not be large since meaningful findings from the user and field usability testing are the most important (Bhuiyan, 2011; Ozer, 1999).

Many researchers study the optimal numbers of a sample required for the user and field usability testing. Virzi (1990) finds that 4-5 participants can detect 80% of the usability problems. Additional participants are less and less likely to find new information. Whereas, Nielsen (2000) shows that three small groups of 3-5 participants can reveal 70-85% of the usability problems. It might take 15 participants to fully uncover all usability problems. Hwang and Salvendy (2010) report that around 10 participants can discover 80% of the usability problems. Meanwhile, Sauro and Lewis (2012) argue that 19 participants are required to detect 85-95% of the usability problems. Faulkner (2003) explains that it needs 20 participants to discover 95-98% of the usability problems.

Macefield (2009) suggests that 3-20 participants per group is valid, with 5-10 participants as a sensible baseline range. It enhances the problem discovery level and reliability of the study. Whereas, it reduces costs and duration in the early conceptual prototypes, whose scope is normally very limited. Besides, prototypes tend to contain more usability problems, which increases the likelihood of problem discovery by fewer participants. Moreover, a small group of participants enhances meaningful findings from the user and field usability testing. However, it also depends on the context and complexity of the study as well as the requirement of the study about probability of problem occurrence and likelihood of problem discovery.

Therefore, this research selected 25 agricultural holders as its samples for the beta testing. The sample group was filtered and selected from the list of 1,597 agricultural holders of Khao Wong district, Kalasin province, who acquired the on-farm pond with 1,260 m^3 storage capacity from the on-farm pond construction project in the unirrigated area of Land Development Department from 2005-2016. They were in six sub-districts of Khao Wong district, Kalasin province, which are Khum Kao, Song Plueai, Kut Pla Khao, Kut Sim Khum Mai, Saphang Thong, and Nong Phue. This research selected agricultural holders who acquired the on-farm pond with 1,260 m^3 storage capacity from the on-farm pond construction project in the unirrigated area of Land Development Department as its sample group because this project has been providing the on-farm pond with 1,260 m^3 storage capacity to more than 450,000 households in the unirrigated area throughout the country since 2005. It will be useful for these households to apply the selected decision support tool for making a rational and appropriate selection of the agricultural water management scheme of their on-farm pond.

This researcher did a survey, which is presented in Appendix A, to select agricultural holders with qualified characteristics, which were:

- Operating the rain-fed agriculture in their own land
- Rainwater is their only water source
- The engineering structure of the on-farm pond is able to collect surface runoff flowing into the pond
- The physical structure of the on-farm pond is suitable for storing the harvested rainwater for the whole year
- Willing to participate in the beta testing of the selected appropriate decision support tool for sustainable rain-fed agriculture referenced to the New Theory of His Majesty King Bhumibol Adulyadej The Great

Figure 3.6 shows the result of the selection process of qualified agricultural holders in Khao Wong district through the application of the survey. There were 294 agricultural holders who were qualified and willing to participate in the beta testing. The sub-district with the highest number of survey responses was Song Plueai as presented in Figure 3.7. Therefore, 25 agricultural holders with qualified characteristics from Song Plueai sub-strict were purposely selected as the sample group of this research based on their availability on the beta testing day.

3.3.2 Decision supporters

Decision supporters of this research were facilitators and multidisciplinary experts from relevant fields. It is suggested that the decision support team should consist of at least six experts or team members (Mendoza et al., 1999). They were selected from different fields of endeavor or perspectives, including academics, farmers, NGOs, and government officers. They were agricultural and water experts as well as project officers of the Chaipattana Foundation, water experts of the Royal Irrigation Department and Office of the National Water Resources, and officers as well as farmers from the farmer network of the Hydro-Informatics

Institute. They represented experience and expertise in sustainable agriculture, water resource management, the New Theory, and topographical and sociological conditions of Thailand.

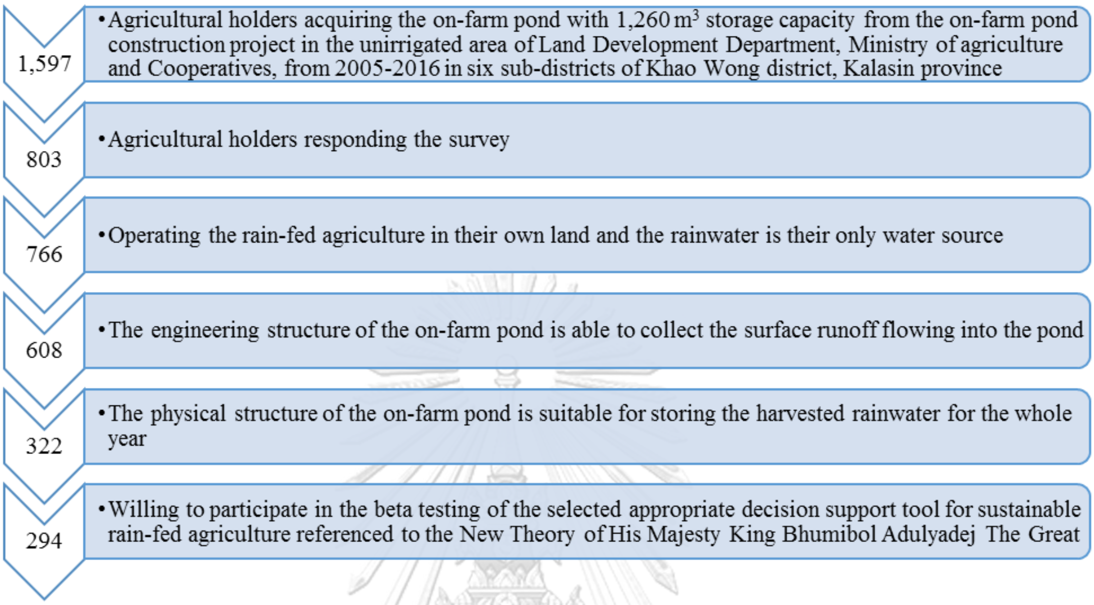

Figure 3.6 The result of the selection process of qualified agricultural holders in Khao Wong district through the application of the survey

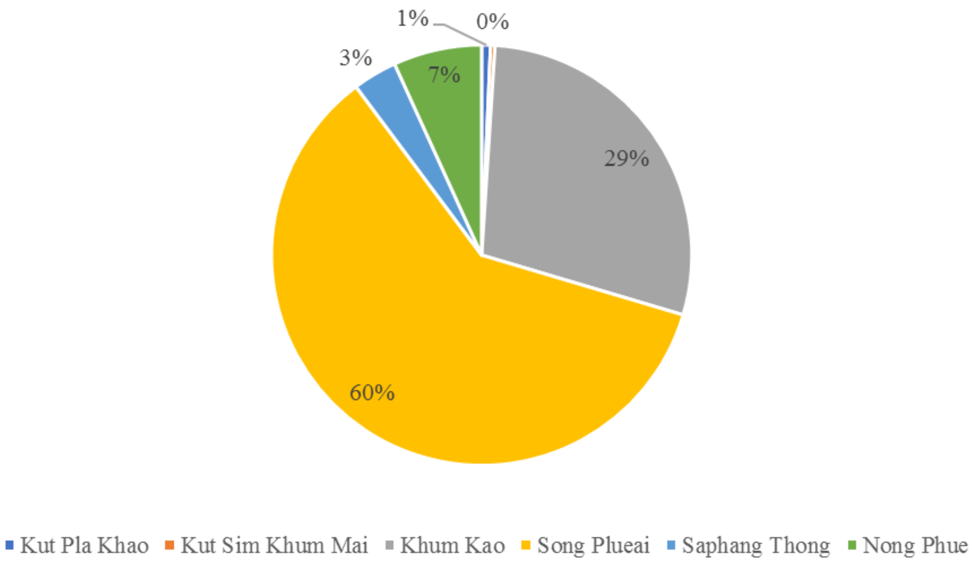

Figure 3.7 Number of agricultural holders from six sub-districts of Khao Wong district, Kalasin province, who were qualified and willing to participate in the beta testing of the selected appropriate decision support tool for sustainable rain-fed agriculture referenced to the New Theory of His Majesty King Bhumibol Adulyadej The Great

Decision supporters were engaged in workshops for the expert judgement, which were an open and in-depth discussions. They were encouraged to share their opinions towards the problem freely from the aspects they were familiar with, experienced, or specialized in. (Bernard, 2013). They helped the decision maker not only interact with the selected decision support tool; but also make a rational and appropriate selection of the agricultural water management scheme of their on-farm pond based on the concept of the New Theory.

3.4 Research design and methods

This research applies mixed methods, both qualitative and quantitative, including desk review, field visit, the workshop for the expert judgement, structured interview, and self-administrated questionnaire.

3.4.1 Desk review

This research reviewed literature about sustainable agriculture, the New Theory of His Majesty King Bhumibol Adulyadej The Great, and agricultural water management of the on-farm pond in order to find out factors affecting the agricultural water management of the on-farm pond. It also studied decision making, new product development, and usability in order to conduct the research through the eight step disciplined decision-making process of Baker et al. (2001) and the new product development process.

Besides, it reviewed available secondary data from government agencies related to topographical and sociological conditions of the study area and the agricultural water management of the on-farm pond, such as average annual rainfalls, average annual evaporation, average annual seepage, crop water requirements, and the like.

3.4.2 Field visit

The field visit was held in the unirrigated area of Khao Wong district, Kalasin province, which is the study area of this research. It helped better understand information and data obtained from the desk review. It also enhanced the understanding of specific topographical and sociological conditions of the study area and the context for which the selected decision support tool were applied (Rowley, 1994).

Moreover, the survey of the potential sample group for the beta testing of the research was sent to the list of 1,597 agricultural holders who acquired the on-farm pond with 1,260 m^3 storage capacity from the on-farm pond construction project in the unirrigated area of Land Development Department from 2005-2016. They were in six sub-districts of Khao Wong district, Kalasin province. The result of the survey shows that Song Plueai sub-district was the sub-district with the highest number of survey responses and qualified agricultural holders willing to participate in the beta testing. Therefore, 25 agricultural holders with qualified characteristics from Song Plueai sub-district, Khao Wong district, were purposely selected as the sample group of the research based on their availability on the beta testing day.

3.4.3 Workshops for the expert judgement

Several workshops for the expert judgement were convened. Before the workshops, the coordinator introduced the team members to each other and clarified the objectives and process of the workshops. Decision supporters were allowed to interact and express different perceptions and points of view freely with other team members in the sessions (Bernard, 2013).

3.4.3.1 The first workshop

The first workshop was convened in order to define the problem that the solution to the problem must solve, determine requirements that the solution to the problem must meet, and establish the goal that the solution to the problem should accomplish. This goal is the goal of selecting appropriate decision support tools for sustainable rain-fed agriculture referenced to the New Theory of His Majesty King Bhumibol Adulyadej The Great. 11 members of the decision support team shared their opinions from the aspects they were familiar with, experienced, or specialized in and developed a consensus about the problem statement, requirements, and goal of the selected appropriate decision support tool.

3.4.3.2 The second workshop

The second workshop was convened as the participatory assessment in order to develop and select criteria, sub-criteria, indicators, and the classification of the values for each indicator in terms of sustainability classes. In the brainstorming process, 11 members of the decision support team collaboratively reviewed, discussed, commented, selected, and modified the candidate set of criteria. As presented in Table 2.3, these criteria were derived from literature related to sustainable rain-fed agriculture referenced to the New Theory of His Majesty King Bhumibol Adulyadej The Great. The team reworded, rephrased, and replaced these criteria based on the goal of the selected appropriate decision support tool and the context of topographical and sociological conditions of Thailand. The results of expert comments were compiled and established as the initial site-specific set of criteria in the context of sustainable rain-fed agriculture referenced to the New Theory of His Majesty King Bhumibol Adulyadej The Great. It was the platform for the development of the final locality set of criteria.

After that, in the voting process, the team of experts independently gave individual judgements on the relative importance of each criterion and sub-criterion in the initial site-specific set with respect to sustainable rain-fed agriculture referenced to the New Theory of His Majesty King Bhumibol Adulyadej The Great. They applied three MCDM techniques called ranking, rating, and pairwise comparison. The ranking and rating method are a general filter for screening each selected decision element whether it should be either included or excluded. While, the pairwise comparison method is a finer filter for scoring and prioritizing decision elements which were applied for assessing the sustainability of the agricultural water management scheme of the on-farm pond.

These MCDM methods are objective, rational, participatory, and transparent with a traceable record from a democratic and structured decision-making process. Many researchers apply these MCDM techniques for assessing criteria. They make the selected criteria reliable and preferable for the adoption and the results of the criteria assessment gain the public acceptance (Mendoza et al., 1999; Mendoza & Martins, 2006; Mendoza & Prabhu, 2000a, 2000b, 2003).

- **Ranking**

This method assigns each decision element a rank based on its perceived degree of importance relative to the decision being made, following a nine-point scale where 1, weakly important; 3, less important; 5, moderately important; 7, more important; 9, extremely important. While, the even values 2, 4, 6, and 8 are intermediate values. The relative importance or weight can be calculated based on the ranks assigned to each element.

- **Rating**

This method assigns each decision element a score between 0 and 100, based on its perceived degree of importance relative to the decision being made. The scores for all elements being compared must add up to 100.

- **Pairwise comparisons**

This method is based on one of the MCDM techniques called AHP which is developed by Saaty (Saaty, 1988). It has rational and systematic procedures for scoring criteria and alternatives (Mysiak et al., 2005). It classifies decision elements into the decision hierarchy and divides these decision elements into a series of one-on-one judgement. The relative weight of decision elements is assigned by participants making a simple comparison between each pair of decision elements in the same decision hierarchy, following a nine-point scale where 1, equally important; 3, moderately more important; 5, strongly important; 7, very strongly important; 9, extremely most important. While, the even values 2, 4, 6, and 8 are intermediate values.

Moreover, this method has a mean for measuring the consistency of the judgements made by the decision maker, so-called Consistency Ratio (C.R.). It provides information on consistency in terms of which element between two elements compared is more important and how much more important. In general, C.R. of 0.10 or less is considered acceptable. Otherwise, it is necessary to recheck the pairwise comparison matrix in order to ensure a clear rational decision and the most preferred choice (Adham et al., 2016; Mendoza et al., 1999).

The result of the voting process was the final locality set of criteria with the relative weights assigned by the expert team. It was applied for measuring the degree to which alternative agricultural water management schemes possess or lack sustainability.

3.4.3.3 The third workshop

The third workshop was convened in order to find factors affecting the agricultural water management of the on-farm pond. These factors are important inputs for designing the structured interview questions and alternative agricultural water management schemes. 7 members of the decision support team, except farmers from the farmer network of the Hydro-Informatics Institute, were engaged in this workshop. In the brainstorming process, experts reviewed and discussed the candidate set of factors related to the agricultural water management of the on-farm pond. They were derived from the literature review in Chapter II.

After that, in the voting process, the expert team independently gave individual judgements on the relative importance of each factor with respect to the agricultural water management of the on-farm pond. They applied two MCDM techniques called ranking and rating. Generally, the acceptable cutoff value is a minimum of 80% (Turner & Carlson, 2003). Factors, that acquired the acceptable relative weights from all experts, were applied for designing an interview schedule for the structured interview of the sample group.

3.4.4 Structured interview

A structured interview was hold at Song Plueai sub-district, Khao Wong district, in order to collect the data required for devising alternative agricultural water management schemes of the on-farm pond of the sample group. This method helps interviewers with fewer interviewing skills collect reliable, consistent, and comparable data from the sample group by asking exactly the same set of questions in the same order in each interview (Kumar, 2014).

Before visiting the study area, questions for the structured interview were prepared in advanced as an interview schedule. It was used to obtain basic information of the sample group such as sex, age, education level, number of household members, and the like. It also collected specific information about their actual agricultural water management of the on-farm pond such as size of the farmland, crop cultivation plans, yearly agricultural activities, field management practices, and the like. This information was necessary for devising agricultural water management schemes.

Questions in the interview schedule were mostly closed-ended with some open-ended. They were evaluated for content validity and appropriateness through the Indexes of Item-Objective Congruence or IOC. It is a measure for assessing the compatibility between questions and objectives. Five independent experts rated each question by giving it a score where 1, the content is clearly measuring for the objective; -1, the content is clearly not measuring for the objective; 0, the content is unclearly measuring for the objective. Generally, the acceptable cutoff value is a minimum of 80% (Turner & Carlson, 2003). The interview schedule of the structured interview is presented in Appendix B.

The primary data, collected by the structured interview, were combined with available relevant secondary data from government agencies. This research applied these data with the application of the agricultural water management software, which was provided by the Hydro-Informatics Institute. This software calculated available water supply in the on-farm pond and farm water demands. It also proposed alternative agricultural water management schemes of the on-farm pond based on the concept of the New Theory for the sample group. Each scheme had different abilities to achieve requirements and goal; however, the scheme that could not fulfill requirements must be adjusted or eliminated.

After that, these alternative schemes were assessed for sustainability through the application of the AHP technique (Adham et al., 2016; Mendoza et al., 1999). This research selected AHP as the MCDM technique of the selected decision support tool because it is appropriate for the problem with many alternatives and multiple criteria, both quantitative and qualitative. Besides, it handles and communicates information as well as eliminates personal preferences and idiosyncratic behaviors from the decision making (Baker et al., 2001).

AHP is a quantitative comparison method which uses the pairwise comparison method and mathematics to score alternatives based on their relative performance against the criteria and select a preferred alternative (Saaty, 1988, 1990). The final locality set of criteria derived from the second workshop for the expert judgement was applied for evaluating alternative schemes in the hierarchical process. Figure 3.8 indicates the process which starts from indicators at the bottom level to criteria at the top level. It ranks alternative schemes and the final score of each alternative scheme reflects its sustainability. The scheme, that acquires the highest score, is the most sustainable and preferable.

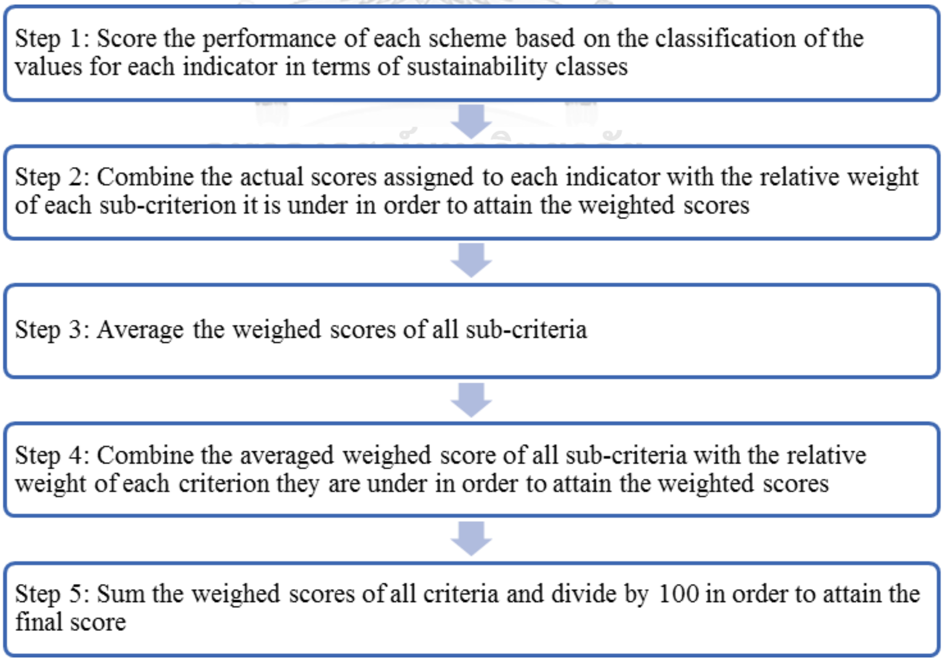

Figure 3.8 The hierarchical process of the sustainability assessment of the agricultural water management scheme
Source: Adham et al. (2016); Mendoza et al. (1999)

The most sustainable and preferable alternative agricultural water management scheme was, then, validated against the problem statement in order to confirm that it could solve the identified problem, fulfill the desired condition, meet requirements, and best achieve goals. However, in cases where it cannot fulfill the desired condition, requirements, and goals in practice, it is necessary to recheck for any probable causes, especially in the first step of defining the problem. As the problem is not correctly defined, the selected scheme cannot produce the desired result (Baker et al., 2001).

3.4.5 Self-administrated questionnaire

A self-administrated questionnaire was also held at Song Plueai sub-district, Khao Wong district, in order to collect data about the usability of the selected decision support tool in the beta testing and recommendations for further improvement. This method helps respondents, which is the sample group, express their preference and opinions about the selected decision support tool freely and confidentially (Kumar, 2014).

Before visiting the study area, questions in the self-administrated questionnaire were prepared in advanced. The Likert scale was used to measure the extent to which the selected decision support tool can be used by the sample group effectively, efficiently, and satisfactorily in the beta testing (ISO, 1998). Besides, one open-end question as provided for respondents to give a recommendation for the further improvement of the tool. These questions were evaluated for content validity and appropriateness through the Indexes of Item-Objective Congruence or IOC. It is a measure for assessing the compatibility between questions and objectives. Five independent experts rated each question by giving it a score where 1, the content is clearly measuring for the objective; -1, the content is clearly not measuring for the objective; 0, the content is unclearly measuring for the objective. Generally, the acceptable cutoff value is a minimum of 80% (Turner & Carlson, 2003). The self-administrated questionnaire is presented in Appendix C.

The beta testing is one of the most important steps of the new product development process. It is a field usability test which is conducted in the user's environment for a specific time period. It examines how the prototype of a new product fits into the user's environment and how the user's environment affects the prototype usage by determining product functionality and user acceptance (Ozer, 1999). Product functionality is tested in order to prove that claimed physical and perceptual features, functions, and benefits of the conceptual prototype exist and find the causes of missing attributes. Whereas, user acceptance is examined in order to measure users' level of interest, liking, and preferences towards the prototype (Bhuiyan, 2011). Data collected from potential users, both quantitative and qualitative, are useful for identifying and correcting potential problems of a new product as well as improving its features (Kantner, Sova, & Rosenbaum, 2003; Ozer, 1999; Rowley, 994).

Before the application of the self-administrated questionnaire, each agricultural holder, who was the decision maker of this selected decision support tool, was presented alternative agricultural water management schemes. These alternative schemes obtained the final score of sustainability, which was derived from the application of the AHP technique of the tool. They were compared among each other and with the actual one of each agricultural holder. Besides, decision supporters suggested each agricultural holder how to manage their agricultural resources sufficiently, productively, and sustainably based on the concept of the New Theory.

Data collected from the self-administrated questionnaire were both quantitative and qualitative. They were synthesized and analyzed by using the content analysis and descriptive statistical analysis (Bernard, 2013). Meanwhile, findings from the study are important for the new product development. They help developers better understand user and benefit future research. These include the tool performance in terms of effectiveness, efficiency, and satisfaction as well as recommendations from the sample group such as possible feature additions and product modifications (Ozer, 1999). Data sets, data collection methods, and data analysis methods of the research are summarized and presented in Table 3.1.

Table 3.1 Data sets, data collection methods, and data analysis methods

Data sets	Data collection methods	Data analysis methods
1. Grouped data related to the agricultural water management of the on-farm pond - Economic factors - Social factors - Natural resources and environmental factors - Management factors	- Desk review - Field visit - The workshop for the expert judgement (ranking and rating)	- Descriptive statistical analysis
2. Data for devising alternative agricultural water management schemes of the on-farm pond - Basic information of the sample group - Specific information about the actual agricultural water management of the on-farm pond of the sample group	- Desk review - Field visit - Structured interview	- Content analysis - Descriptive statistical analysis
3. Data from the decision-making process - Statement of problem - Requirements the solution to the problem must meet - The goal of the selected appropriate decision support tool for sustainable rain-fed agriculture referenced to the New Theory of His Majesty King Bhumibol Adulyadej The Great	- Desk review - The workshop for the expert judgement (consensus)	- Content analysis
- The final locality set of criteria for the sustainability assessment of alternative agricultural water management schemes of the on-farm pond	- Desk review - The workshop for the expert judgement (consensus, ranking, rating, and pairwise comparison)	- Content analysis - Descriptive statistical analysis
- Alternative agricultural water management schemes of the on-farm pond	- Desk review - Field visit - Structured interview	- AHP technique
4. Data about the usability of the selected decision support tool - Effectiveness - Efficiency - Satisfaction - Recommendations for further improvement	- Desk review - Field visit - Self-administrated questionnaire	- Descriptive statistical analysis - Content analysis

CHAPTER IV
RESEARCH RESULTS AND DISCUSSION

This chapter will be divided into four interrelated parts, starting from grouped data related the agricultural water management of the on-farm pond, site characteristics, selected decision support tool, to the usability of the selected decision support tool. They are results of this research, which will be presented and discussed as follows.

4.1 Grouped data related to the agricultural water management of the on-farm pond

This research classified factors related to the agricultural water management of the on-farm pond into two groups, which were grouped data related to farm water demands and grouped data related to farm water supply. Factors in each grouped data helped design an interview schedule for the structured interview of the sample group as presented in Appendix B. They also helped devise alternative agricultural water management schemes of the on-farm pond for the decision maker. These alternative schemes were, then, assessed and proposed the preferred one by the selected decision support tool.

This research reviewed literature about factors related to agricultural water management of the on-farm pond. It gathered a list of relevant factors which were, then, analyzed and weighted by the expert team in the third workshop for the expert judgement. The results of the expert judgement showed that there were 48 factors needed to be considered when devising the agricultural water management scheme. These factors were also classified into two group, which were grouped data related to farm water demands and grouped data related to farm water supply. Besides, these factors were analyzed and weighted the extent to which they were relevant to economic, social, natural resource and environmental, and management aspects to better understand their interrelation among aspects based on the concept of sustainable agriculture. It helped manage limited resources for agriculture to fulfill social and economic needs of human; while, conserve these resources and maintain or enhance the quality of the environment for future generations.

4.1.1 Grouped data related to farm water demands

Based on the expert judgement, there were 22 factors related to farm water demands as presented in Figure 4.1. Most factors were mainly related to the management aspect and partly related to natural resources and environmental, economic, and social aspect, respectively. However, there were several factors predominantly related to the natural resources and environmental aspect, which were “Crop varieties”, “Evapotranspiration”, and “Animal species”. These factors directly affect farm water demands and management since they were major water consumers of the rainwater harvested in the on-farm pond. Evapotranspiration affects supplemental water requirements for the crop production. It is different among crop varieties and varies over the growing season (Critchley & Siegert, 1991; Oweis et al., 2012). The daily water requirement of animal species also varies significantly (Watcharin Chetananon, 2009).

Meanwhile, “Market price” was the factor mainly related to the economic aspect. It guides the selection of crop types and animal species in the farm production, which affects farm water demands and management. In general, high-value crops and livestock are produced specifically for generating cash incomes (Ali, 2010; AFED, 2011; IWMI, 2014; McConnell & Dillon, 1997).

Whereas, “Household food self-sufficiency” was the factor that was almost equally related to both economic and social aspects. It is the most expected outcome of the New Theory which prioritizes staple crops and livestock for the household consumption. These crops and livestock are selected to provide enough food for the daily household consumption. The sale of food surpluses to the household consumption also generates cash incomes for the purchase of non-farm produced food, farm inputs, and other essentials throughout the year (Chaipattana Foundation, 2014).

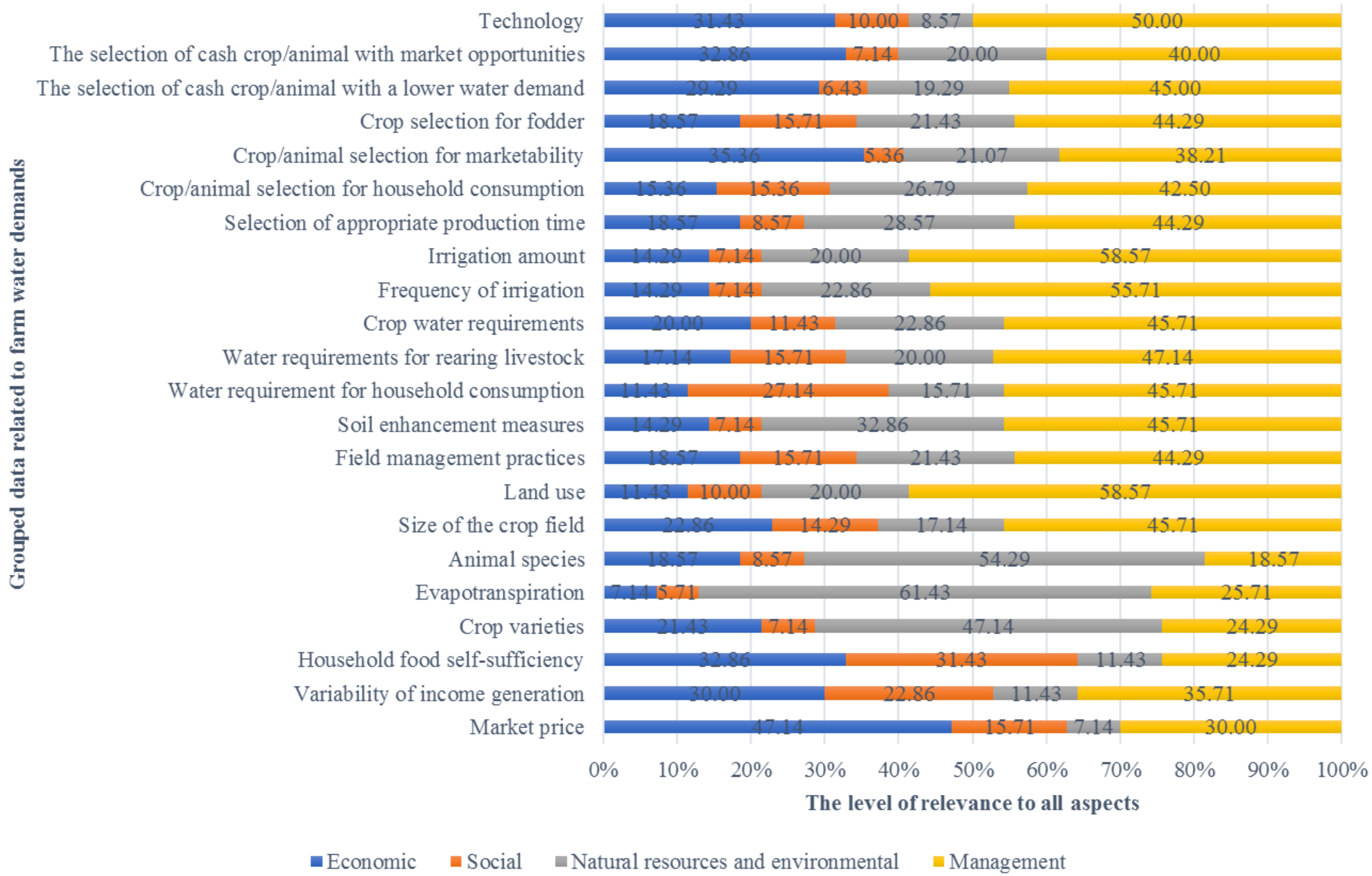

Figure 4.1 Grouped data related to farm water demands and their relevance to all aspects

4.1.2 Grouped data related to farm water supply

Based on the expert judgement, there were 29 factors related to farm water supply as presented in Figure 4.2. Among these, there were three factors related to both farm water demands and supply, which were "Soil enhancement measures", "The selection of economic crop/animal with a lower water demand", and "Technology".

They are related to both farm water demands and supply since they increase water use efficiency and reduce constraints on farm water supply. Soil enhancement measures improve soil fertility, which enhances both soil water availability for crops and the plant water uptake. Whereas, the selection of economic crop/animal with a lower water demand also increases the amount of available water for the farm water supply. Meanwhile, various technology in the field promotes water use efficiency differently. Normally, there are three main irrigation techniques, which are the surface or gravity irrigation, the sprinkler irrigation and the drip irrigation. The surface irrigation is widely applied because it is the easiest and cheapest. However, it is the least efficient method since less than 10% of water is used by the plant. Therefore, this technique needs more water to fulfill crop water requirements. Whereas, the sprinkler irrigation is costlier due to pressurized water requirement. Nevertheless, with low energy precision application, this method is efficient at 95% and saves around 20-50% of energy costs, compared to the conventional one. While, the drip irrigation is highly efficient since it drops water to the crop root zone. This technique has different levels of sophistication and cost. Nevertheless, it increases yields up to 100% with water saving up to 40-80% (Ali, 2010; AFED, 2011; IWMI, 2014).

Most factors in this group were also mainly related to the management aspect and partly related to natural resources and environmental, economic, and social aspect, respectively. However, there were some factors essentially related to the natural resources and environmental aspect, which were "Soil fertility", "Suitable area for rainwater harvesting", "A catchment area", "On-farm surface water sources", and "Amount of rainfall". The amount of rainfall radically impacts the farm water supply and management in the rain-fed agricultural area where rainfall is the only water source (Ali, 2010). Sustainable rain-fed agriculture cannot be achieved if the rainfall is not intense enough to produce surface runoff for harvesting in the on-farm pond.

Besides, the suitable area for the rainwater harvesting is fundamental for the farm water supply and management in the rain-fed agricultural area. It is also related to the catchment area and on-farm surface water sources, which are two of three main components of the rainwater harvesting system. The catchment area, which is suitable for the rainwater harvesting, distributes more regular runoff. Whereas, the on-farm surface water source, which is located in the suitable slope area, can use the gravity to flow and induce more regular runoff from the catchment area (Critchley & Siegert, 1991; Oweis et al., 1999; Oweis et al., 2012).

Meanwhile, soil fertility influences the farm water supply and management since it reduces infiltration rate and increases surface runoff. It also associates with the target area which is one remaining of three main components of the rainwater harvesting system. The target area is another factor equally related to both management and natural resources and environmental aspect. It is the place where the rainwater harvested in the on-farm pond is applied, mainly as the supplemental irrigation, for the crop production during dry spells in the rainy season and the dry season. The fertility of the soil in the target area enhances soil capacity to store water and allows the adequate moisture to the crop root zone. Therefore, it reduces stress on the farm water supply (Critchley & Siegert, 1991; Oweis et al., 1999; Oweis et al., 2012).

Moreover, there were several factors mainly related to the economic aspect, which were “Capital” and “Household self-sufficiency”. These factors directly affect the farm water supply and management. The capital specifies the size of the on-farm pond. Normally, the expenses for the effective construction of a functional on-farm pond are too expensive for farmers to afford it. Therefore, His Majesty the late King advised that both public and private sectors should assist farmers for these difficulties. The continuous maintenance after the construction of a functional on-farm pond also requires a certain amount of money; however, farmers should manage it by themselves (Chaipattana Foundation, 2014). The household self-sufficiency also determines the size of the on-farm pond. The on-farm pond has to be large enough to supply water to farm activities which are the sources of income for the household self-sufficiency (Chaipattana Foundation, 2014; Oweis et al., 2001, 2012).

In addition, there were some factors mainly related to the social aspect, which were “Labors” and “Agricultural extension services”. Labors are related to the farm water supply and management since an increase in labors enables more agricultural productions, which increases the requirement for the farm water supply. While, agricultural extension services can enhance the efficiency of the farm water supply and management. Government officers should advise and disseminate agricultural knowledge to farmers, including soil enhancement measures, the selection of economic crop/animal with a lower water demand, and technology in the field. This knowledge promotes water use efficiency and increase the amount of available water for the farm water supply.

4.2 Site characteristics

The sample group of the study comprised 25 agricultural holders with qualified characteristics from Song Plueai sub-district, Khao Wong district, Kalasin province. They operated the rain-fed agriculture in their own land where the rainwater was their only water source. Besides, the engineering structure of their on-farm pond could collect the surface runoff which flew into the pond. While, the physical structure of their on-farm pond was suitable for storing the harvested rainwater for the whole year. Moreover, they were willing to participate in the beta testing of the selected appropriate decision support tool for sustainable rain-fed agriculture referenced to the New Theory of His Majesty King Bhumibol Adulyadej The Great.

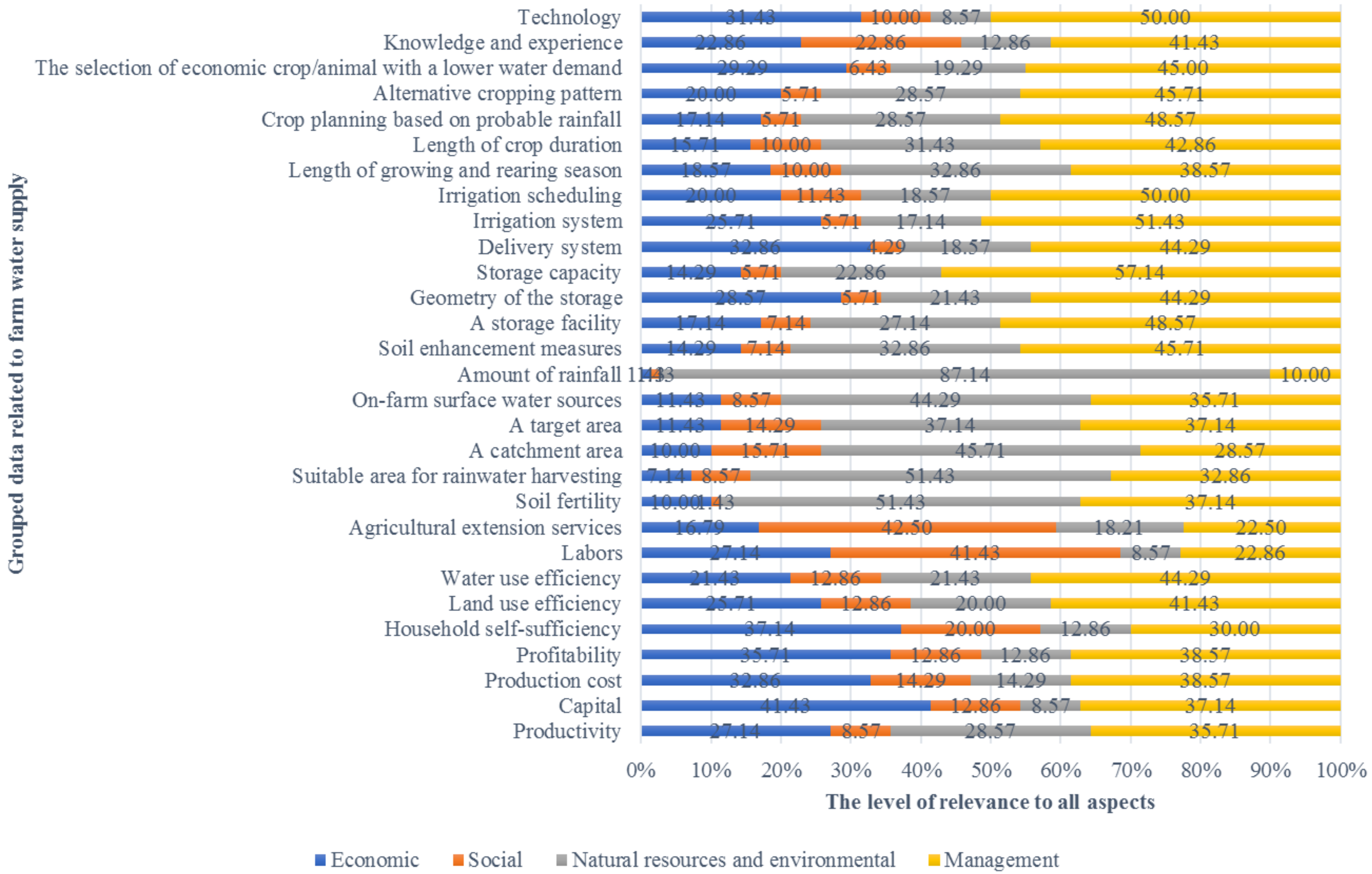

Figure 4.2 Grouped data related to farm water supply and their relevance to all aspects

4.2.1 Demographic characteristics of the sample group

These respondents represented their household. Table 4.1 summarizes demographic characteristics of the respondents. Of these respondents, more than half or 64% were male. When categorized by age, 48% of the respondents were 51-60 years old, 28% were 41-50 years old, and 16% were 61-70 years old. Whereas, the proportion of respondents whose age were under 41 years old and over 70 years were equally 4%. The average age of the respondents was 54.20 years old. When categorized by education, more than half of the respondents or 68% graduated the elementary education. While, the proportion of respondents with the secondary education and the high school education/vocational education were equally 12%. There were only 8% of the respondents who graduated the high vocational education/diploma, the bachelor's degree, and higher.

All respondents did an agriculture as their major occupation. For their minor occupation, 56% of them did a household handicraft and 8% were a worker. Whereas, 36% still did the agriculture as their minor occupation. When categorized by the household expenditure per month, half of the respondents or 52% spent 5,000-10,000 baht per month. While, 24% spent less than 5,000 baht per month and 20% spent 10,001-15,000 baht per month. There were only 4% spending more than 15,000 baht per month.

Table 4.1 Demographic characteristics of the respondents

Categories	Number (N=25)	Percentage
1. Sex		
Male	16	64
Female	9	36
2. Age		
Under 41 years	1	4
41-50 years	7	28
51-60 years	12	48
61-70 years	4	16
over 70 years	1	4

Categories	Number (N=25)	Percentage
μ=54.20 years, Max=74 years, Min=40 years, σ=0.49		
3. Education		
Elementary education	17	68
Secondary education	3	12
High school education/Vocational education	3	12
High vocational education/Diploma	1	4
Bachelor’s degree and higher	1	4
4. Major occupation		
Farmer	25	100
5. Minor occupation		
Farmer	9	36
Worker	2	8
Household handicraft	14	56
6. Household expenditure per month		
Under 5,000 baht	6	24
5,000-10,000 baht	13	52
10,001-15,000 baht	5	20
15,001-20,000 baht	1	4

4.2.2 Household member and the employment of agricultural workers of the sample group

Table 4.2 presents information about the household member and the employment of agricultural workers of the respondents. 60% of the respondents had 3-4 household members. While, 28% had 5-7 household members, 8% had 1-2 household members, and 4% had more than seven household members. The average number of household members of the respondents were 4.04 persons. Furthermore, it found that 64% of the respondents also had 3-4 household members in the work-force age, which is over 13 years old. Whereas, 32% had 1-2 household members in the work-force age and 4% had more than four household members in the work-force age. The average number of household members in the work-force age of the respondents were 3.12 persons. However, based on the interview, it found that some household members in the work-force age were either studying or working in the non-agriculture sectors and the urban area.

Therefore, most of respondents or 80% had 1-2 household members engaged in the agricultural work. Whereas, 16% had 3-4 household members engaged in the agricultural work and only 4% had more than four household members engaged in the agricultural work. The average number of household members engaged in the agricultural work of the respondents were 2.08 persons. It is also the reason why almost all of the respondents or 92% had to employ agricultural workers. However, most of them or 84% employed agricultural workers occasionally for some activities such as ploughing, transplanting, reaping, and threshing. The remaining or 8% hired agricultural workers seasonally. Of these respondents, 88% paid the employment of agricultural workers by cash. There were only 4% paid the employment by cash and yield. Besides, these respondents did not use a joint labor for cultivation.

Table 4.2 Household member and the employment of agricultural workers of the respondents

Categories	**Number (N=25)**	**Percentage**
1. Household member		
1-2 persons	2	8
3-4 persons	15	60
5-7 persons	7	28
8 persons and over	1	4
μ=4.04 persons, Max=8 persons, Min=1 person, σ=1.49		
2. Household members in the work-force age (over 13 years old)		
1-2 persons	8	32
3-4 persons	16	64
5 persons and over	1	4
μ=3.12 persons, Max=5 persons, Min=1 person, σ=1.01		
3. Household members engaged in agricultural work per household		
1-2 persons	20	80
3-4 persons	4	16
5 persons and over	1	4
μ=2.08 persons, Max=5 persons, Min=1 person, σ=1.04		
4. The employment of agricultural workers		
Employ	23	92

Categories	Number (N=25)	Percentage
Not employ	2	8
5. Types of employment		
Seasonal employment	2	8
Occasional employment	21	84
Not employ	2	8
6. Payment		
Cash	22	88
Cash and yield	1	4
Not employ	2	8
7. Joint labor for cultivation		
No joint labor for cultivation	25	100

4.2.3 Sources of capital for agriculture and the sale of agricultural products of the sample group

Table 4.3 shows information about sources of the capital for agriculture and the sale of agricultural products of the respondents. 64% of the respondents took on a loan only from the Bank for Agriculture and Agricultural Cooperatives. 4% took on a loan only from the village and city fund. Whereas, the proportion of respondents who used only their own capital and those who took on a loan from both the Bank for Agriculture and Agricultural Cooperatives and the village and city fund were equally 16%. When categorized by the sale of agricultural products, 68% of the respondents sold agricultural products by themselves, 24% sold agricultural products through a middleman, and 8% sold agricultural products through the farmer's group. It found that more than half of the respondents or 68% had adequate incomes from the sale.

Table 4.3 Sources of capital for agriculture and the sale of agricultural products of the respondents

Categories	Number (N=25)	Percentage
1. Source of capital		
Personal capital	4	16
Bank for Agriculture and Agricultural Cooperatives	16	64

Categories	Number (N=25)	Percentage
Village and city fund	1	4
Bank for Agriculture and Agricultural Cooperatives and village and city fund	4	16
2. Sale of agricultural products		
By themselves	17	68
By the middleman	6	24
By the farmer's group	2	8
3. Income sufficiency from selling agricultural products		
Sufficiency	17	68
Insufficiency	8	32

4.2.4 Agricultural land and water management of the sample group

Table 4.4 presents information about the area of holding of the respondents. All respondents had a title deed. The proportion of respondents who possessed 5-10 rais and those who possessed 11-15 rais were equally 36%. Whereas, 16% of the respondents possessed 16-20 rais. 8% possessed less than five rais and 4% possessed more than 20 rais. The average size of area of holding of the respondents were 11.24 rais.

Table 4.4 Area of holding of the respondents

Categories	Number (N=25)	Percentage
1. Land tenure		
Title deed	25	100
2. Area of holding		
under 5 rais	2	8
5-10 rais	9	36
11-15 rais	9	36
16-20 rais	4	16
21 rais and over	1	4
μ=11.24 rais, Max=23 rais, Min=4 rais, σ=4.93		

Whereas, Table 4.5 describes the agricultural land division for farm activities in the area of holding of all respondents. These area of holding were categorized into the area for the accommodation and other purposes, the area for the upland perennial cash crops, the area for the on-farm pond, the area for the mixed farming above the edge of the on-farm pond and surrounding, the area for the upland annual cash crops, the area for the upland cash crops in the rainy season, the area for the lowland major rice, and the area for lowland alternative crops after the major rice cultivation. The size of each farm activity of each respondent is presented in the metric unit and measurement. Maps of the area of holding of all respondents are presented in Appendix D. They help examine the actual agricultural water management scheme of the on-farm pond of respondents, which are also presented in Appendix E, more precisely.

All respondents acquired a standard on-farm pond from the Land Development Department. The dimension of the standard on-farm pond in the study area was 32 m long, 18 m wide, and 2.8 m deep with 1:1 side slope. The wetted surface area of the on-farm pond was 576 m^2. The volume of the evaporation loss from the on-farm pond in the dry season was 217 m^3. While, the volume of the seepage loss from the on-farm pond in the dry season was 98 m^3. The highest storage capacity of the on-farm pond was 1,248 m^3. It was calculated from the average annual rainfall in 19-year period of Song Plueai sub-district from 1998 to 2016, which was 1,630 mm per year, with 80% of the annual rainfall in the rainy season. The size of the catchment area was 32,000 m^2 and the runoff coefficient was 0.3. Whereas, the water harvesting efficiency of the on-farm pond was 0.6.

The rainwater harvested in the on-farm pond was applied only for crop cultivations, including the lowland major rice cultivation, the mixed farming above the edge of the on-farm pond and surrounding throughout the year, the lowland alternative crop cultivation after the major rice cultivation, the upland annual cash crop cultivation, and the upland cash crop cultivation in the rainy season. It was not applied for rearing livestock because they were reared naturally in the field. Besides, it was not applied for the household consumption because respondents did not live in their farmland. They lived in the village and went to their farmland only in the daytime.

Table 4.5 Agricultural land management of the respondents

NO.	Respondents	Agricultural land management (m^2)								
		Area of holding	**Accommodation and other purposes**	**Upland perennial cash crops**	**On-farm pond**	**Mixed farming above the edge of the on-farm pond and surrounding**	**Upland annual cash crops**	**Upland cash crops in the rainy season**	**Lowland major rice**	**Lowland alternative crops after the major rice cultivation**
1	AH01	25,600	3,536	12,800	576	480	208	-	8,000	-
2	AH02	16,000	544	800	576	480	-	-	13,600	800
3	AH03	17,600	824	1,800	576	1,600	-	-	12,800	-
4	AH04	24,000	64	-	576	960	-	-	22,400	-
5	AH05	14,400	544	-	576	480	-	-	12,800	-
6	AH06	20,800	896	-	576	1,328	400	-	17,600	480
7	AH07	9,600	-	1,024	576	1,600	-	-	6,400	-
8	AH08	19,200	64	-	576	2,560	-	-	16,000	-
9	AH09	17,600	244	-	576	780	-	-	16,000	1,440
10	AH10	22,400	2,350	2,225	576	1,249	-	-	16,000	1,600
11	AH11	36,800	1,800	3,074	576	2,550	-	-	28,800	832
12	AH12	12,800	650	-	576	1,974	-	-	9,600	1,008
13	AH13	9,600	784	1,000	576	840	-	-	6,400	208
14	AH14	6,400	966	1,600	576	1,658	-	-	1,600	96
15	AH15	17,600	1,317	-	576	1,307	-	-	14,400	800
16	AH16	14,400	-	-	576	1,024	-	-	12,800	-
17	AH17	22,400	5,000	1,600	576	1,624	-	-	13,600	400
18	AH18	25,600	2,172	1,052	576	1,170	1,190	1,840	17,600	920
19	AH19	30,400	3,884	2,400	576	1,140	-	-	22,400	1,098
20	AH20	22,400	1,454	-	576	1,170	-	-	19,200	562
21	AH21	6,400	-	-	576	1,024	-	-	4,800	-
22	AH22	8,000	-	-	576	1,024	-	-	6,400	-
23	AH23	27,200	1,246	7,671	576	1,707	-	-	16,000	-
24	AH24	14,400	1,800	-	576	824	-	-	11,200	-
25	AH25	8,000	315	400	576	309	-	-	6,400	-
Number (N=25)		25	21	13	25	25	3	1	25	13
Percentage		100	84	52	100	100	12	4	100	52
μ		17,984.00	1,450.19	2,880.46	576.00	1,234.48	599.33	1,840.00	13,312.00	788.00
Max		36,800	5,000	12,800	576	2,560	1,190	1,840	28,800	1,600
Min		6,400	64	400	576	309	208	1,840	1,600	96
σ		7,882.88	1,318.27	3,503.54	-	584.19	520.46	-	6,307.16	443.50

All respondents grew a major rice in the rainy season. The size of the cultivated area varied from 1,600 m^2 to 28,800 m^2. The average size was 13,312 m^2. As they were in the rain-fed agricultural area, water for the major rice cultivation was mainly from the rainfall. Normally, they started transplanting rice around June and July. The rainwater harvested in the on-farm pond was normally applied for the seedling in May, in case of the late rainy season or the insufficient rainfall for the seedling. It was also applied during dry spells in the rainy season, especially in the critical growth stages of rice, which were tillering, panicle initiation, and heading. Table 4.6 presents information about the lowland major rice cultivation and the mixed farming above the edge of the on-farm pond and surrounding of the respondents. Most of them or 92% grew RD6 glutinous rice. This glutinous rice variety is improved and recommended by the Rice Department to be cultivated in the Northern and Northeastern region of Thailand. It is drought-tolerant and fragrant. It also provides high yields. Besides, it has good milling and cooking quality. This rice variety is normally harvested around the mid-November (MOAC, 2017c).

The proportion of respondents who grew Gaw Diaw and those who grew RD15 non-glutinous rice were equally 12%. Gaw Diaw is a local glutinous rice. It is normally harvested around early October (Agricultural Research Development Agency (Public Organization) [ARDA], 2017). While, RD15 non-glutinous rice is generally harvested around early November (MOAC, 2017d). There were only 4% of the respondents who grew RD20 glutinous rice. This variety is normally harvested around the end of October (MOAC, 2017e). All respondents had enough rice for the household to consume throughout the year. Whereas, most of them or 88% had the surplus for selling to generate the household income. They preferred the glutinous rice to the non-glutinous rice because it is their staple food. Besides, Gaw Diaw and RD6 glutinous rice can produce the GI product of this area, which is Khao Wong Kalasin sticky rice (MOAC, 2016b; MOC, 2016). However, there is a difference between Gaw Diaw and RD6 glutinous rice in terms of the length of the crop duration. Gaw Diaw has a shorter crop duration than RD6 glutinous rice (ARDA, 2017). Therefore, it consumes less water than RD6 glutinous rice. Nevertheless, it yields less than RD6 glutinous rice. Gaw Diaw yields around 500 per rai (ARDA, 2017). While, RD6 glutinous rice yields around 666 kilograms per rai (MOAC, 2017c).

All respondents also did a mixed farming above the edge of the on-farm pond and surrounding. The size of the area for this activity varied from 309 m^2 to 2,560 m^2. The average size was 1,234.48 m^2. They mainly grew vegetables and some perennial plants for the daily household consumption; while, the surplus was given to the neighbors and sold in the local market, respectively. In the rainy season, water for the mixed farming was mainly from the rainfall. Whereas, the harvested rainwater was applied during dry spells and in the dry season.

Table 4.6 Lowland major rice cultivation and mixed farming above the edge of the on-farm pond and surrounding of the respondents

Categories	**Number (N=25)**	**Percentage**
1. Lowland major rice cultivation		
Yes	25	100
2. Rice varieties		
RD6 glutinous rice	23	92
Gaw Diaw (local glutinous rice)	3	12
RD20 glutinous rice	1	4
RD15 non-glutinous rice	3	12
*Answer more than one answer		
3. The sufficiency of the rice yield		
Sufficiency for the household consumption throughout the year	3	12
Sufficiency for the household consumption throughout the year with the surplus for selling	22	88
4. Mixed farming above the edge of the on-farm pond and surrounding		
Yes	25	100

Moreover, most of the respondents or 84% provided some parts of their farmland for accommodation and other purposes. The size of the area for the accommodation and other purposes varied from 64 m^2 to 5,000 m^2. The average size was 1,450.19 m^2. They built just a small hut with the multipurpose space for resting during the daytime as they lived in the village. Therefore, the rainwater harvested in the on-farm pond was not applied for the household consumption.

The proportion of respondents who grew upland perennial cash crops and those who grew lowland alternative crops after the major rice cultivation as the multiple cropping were equally 52%. The size of the area for growing upland perennial cash crops varied from 400 m^2 to 12,800 m^2. The average size was 2,880.46 m^2. Most respondents grew fruit trees mainly for the household consumption; while, the surplus was given to the neighbors and sold in the local market, respectively. While, some of them also grew rubber trees, which are an economic crop, for the household income generation. However, these respondents did not use the rainwater harvested in the on-farm pond for this activity.

Table 4.7 shows information about the lowland alternative crop cultivation after the major rice cultivation, the upland annual cash crop cultivation, and the upland cash crop cultivation in the rainy season of the respondents. The size of the area for the lowland alternative crop cultivation after the major rice cultivation varied from 96 m^2 to 1,600 m^2. The average size was 788 m^2. The proportion of respondents who grew luffa gourds and sweet corns were equally 20%. 16% grew peanuts and 12% grew chillis. The proportion of respondents who grew sweet potatoes, tomatoes, bottle gourds, and eggplants were equally 8%. Whereas, the proportion of respondents who grew garlics, corianders, waxy corns, pumpkins, cucumbers, scallions, and choy sum were equally 4%. These crops were grown as a cash crop for the household income generation. The harvested rainwater in the on-farm pond was applied for this activity.

12% of the respondents grew upland annual cash crops in succession over the same piece of land in one calendar year as a multiple cropping. The size of the area for this activity varied from 208 m^2 to 1,190 m^2. The average size was 599.33 m^2. The proportion of respondents who grew morning glories, cucumbers, and yard long beans were equally 8%. The proportion of respondents who grew corianders, scallions, chillis, luffa gourds, and eggplants were equally 4%. These crops were grown for the household income generation. In the rainy season, water applied for these cash crops was mainly from the rainfall. Whereas, the harvested rainwater was applied during dry spells and in the dry season.

There were only 4% of the respondents who did the upland cash crop cultivation in the rainy season. The size of the area for this activity was 1,840 m^2. They grew yard long beans and luffa gourds. These crops were also grown for the household income generation. Water applied for this activity was mainly from the rainfall. While, the harvested rainwater was only applied during dry spells.

Table 4.7 Lowland alternative crop cultivation after the major rice cultivation, upland annual cash crop cultivation, and upland cash crop cultivation in the rainy season of the respondents

Categories	**Number (N=25)**	**Percentage**
1. Lowland alternative crop cultivation after the major rice cultivation		
Yes	13	52
No	12	48
2. Crop types		
Luffa gourd	5	20
Garlic	1	4
Sweet potato	2	8
Tomato	2	8
Peanut	4	16
Sweet corn	5	20
Chilli	3	12
Coriander	1	4
Waxy corn	1	4
Pumpkin	1	4
Cucumber	1	4
Bottle gourd	2	8
Eggplant	2	8
Scallion	1	4
Choy sum	1	4
*Answer more than one answer		
3. Upland annual cash crop cultivation		
Yes	3	12
No	22	88

Categories	Number (N=25)	Percentage
4. Crop types		
Morning glory	2	8
Coriander	1	4
Scallion	1	4
Cucumber	2	8
Yard long bean	2	8
Chilli	1	4
Luffa gourd	1	4
Eggplant	1	4
*Answer more than one answer		
5. Upland cash crop cultivation in the rainy season		
Yes	1	4
No	24	96
6. Crop types		
Yard long bean	1	4
Luffa gourd	1	4
*Answer more than one answer		

Table 4.8 presents information about the knowledge about the New Theory and the water use sufficiency of the respondents. 76% of the respondents received advices about the New Theory. However, based on the interview, none of respondents devised their agricultural land and water management scheme based on the concept of New Theory.

56% of the respondents applied the harvested rainwater for the lowland major rice cultivation in the rainy season and the mixed farming above the edge of the on-farm pond and surrounding throughout the year. They also applied it for the lowland alternative crop cultivation after the major rice cultivation, the upland annual cash crop cultivation, and the upland cash crop cultivation in the rainy season. Meanwhile, the remaining 44% applied the harvested rainwater only for the lowland major rice cultivation in the rainy season and the mixed farming above the edge of the on-farm pond and surrounding throughout the year. Based on the interview, 36% of the respondents used to experience the water scarcity during the crop production in the dry season. Of these respondents, 24% faced the water scarcity in March and April; while, 12% faced the water scarcity only in April. Whereas, other respondents were not sure whether the rainwater harvested in the on-farm pond was enough for the crop cultivation in the dry season. Furthermore, there was a problem about a lack of household members engaged in the agricultural work. Besides, household members who were available to engage in the agricultural work were quite old. Therefore, they grow neither lowland alternative crops after the major rice cultivation nor upland annual cash crops. They either did a household handicraft or became worker in the dry season as their minor occupation.

Table 4.8 Knowledge about the New Theory and water use sufficiency of the respondents

Categories	**Number (N=25)**	**Percentage**
1. Advices about the New Theory		
Received	19	76
Not received	6	24
2. Water use sufficiency		
Sufficiency	16	64
Insufficiency	9	36
3. Water scarcity period		
March and April	6	24
April	3	12
No scarcity	16	64

Based on the actual agricultural water management scheme of the on-farm pond of these respondents, it found that the size of the lowland major rice cultivation in most schemes was too large for the rainwater harvested in the on-farm pond with 1,260 m^3 storage capacity to manage risks from the water scarcity which possibly occurred during dry spells in the rainy season. The size of the lowland major rice cultivation varied from 1,600 m^2 to 28,800 m^2. The average size was 13,312 m^2. However, according to the calculation program of Hydro-Informatics Institute, it was estimated that the rainwater harvested in the on-farm pond with 1,260 m^3 storage capacity was able to manage risks from the water scarcity for 8,000 m^2 or five rais of the rice cultivation during dry spells in the rainy season.

Moreover, based on the field visit and interview, it found that most of the respondents did not use their agricultural resources efficiently. They still used ineffective irrigation methods which were the flood and furrow irrigation. They used cheap and local available water application equipment, including rubber tubes, watering pots, and watering cans. These methods are the surface irrigation which uses the gravity to flow and flood water to the surface of the field. The surface irrigation is the easiest and cheapest method. However, it is also the least efficient method since less than 10% of water is used by plants. The remaining water infiltrates into the soil (AFED, 2011). There was only one respondent who applied the mini sprinkler irrigation and the drip irrigation. The mini sprinkler irrigation is costlier due to pressurized water requirement. Nevertheless, it is more efficient than the flood and furrow irrigation (AFED, 2011). For the drip irrigation, this respondent applied plastic bottles, which were cheap and local available, as water application equipment. This method increases yields up to 100% with water saving up to 40-80% (AFED, 2011). Besides, it shows that these respondents did an agriculture based on their experiences and indigenous knowledge. They still lacked academic knowledge about field management practices for the agricultural water use efficiency, including crop water requirements, the irrigation scheduling, and effective irrigation methods. This academic knowledge helps them manage their limited agricultural resources efficiently.

The result of the field visit and interview found that there were factors affecting the agricultural water management of the on-farm pond of respondents who are the sample group of the study. These included a lack of appropriate technology and household members engaged in the agricultural work as well as aging household members engaged in the agricultural work. Besides, these respondents had limited academic knowledge in agriculture, including field management practices, the land use efficiency, crop water requirements, the agricultural water management, and the water use efficiency in terms of the irrigation system, the irrigation amount, and the irrigation scheduling. Although, agricultural extensionists explained them about the New Theory and provided them an on-farm pond. There was still a problem about the application of the concept of the New Theory for managing their agricultural land and rainwater harvested in the on-farm pond efficiently and practically.

Therefore, it is necessary to help these respondents make a rational selection of the agricultural water management scheme of the on-farm pond which uses the harvested rainwater efficiently and productively. The selected decision support tool helps respondents realize how to manage their limited agricultural resources sustainably based on the concept of the New Theory. It applies human critical thinking skills, which are developed from the process of gathering answers to questions about the problem through information, data, and experience, for balancing a decision when the selection among alternatives is unclear (Mysiak et al., 2005). The tool enables respondents to understand academic knowledge in agriculture more easily, including crop water requirements, the irrigation amount, and the irrigation scheduling. Besides, it helps them not only select crops which are suitable for the limited amount of the rainwater harvested in the on-farm pond, but also determine the appropriate size of the farmland for cultivating each crop. However, at the same time, it is important to advise these respondents about the application of the new technology and innovation, including effective irrigation methods and their application for each crop type in practice. It helps increase their farm productivity and reduce their production cost (MOAC, 2017b).

4.3 Selected decision support tool

This research followed the eight step disciplined decision-making process of Baker et al. (2001). This process is simple, clearly defined, transparent, and easily accessible participatory for all involved parties. Results derived from each step are presented as below.

4.3.1 Statement of problem

11 members of the decision support team collaboratively defined and had a consensus about the problem statement of the selected decision support tool in the first workshop for the expert judgement. It is the problem that the solution must solve (Baker et al., 2001). It was defined as below.

"Small semi-subsistence or part-commercial family farms in the rain-fed area use the rainwater as their main water source for agriculture. These farmers face the problem about the imbalance of agricultural water demands and supply. However, this problem can be solved by making a rational and appropriate selection of the agricultural water management scheme which is devised based on the limited amount of the rainwater harvested in their on-farm pond. It enables them to use their limited harvested rainwater efficiently and productively to fulfill their social and economic needs, which will lead to the sustainable rain-fed agriculture in Thailand."

The problem statement clarified the target group of the selected decision support tool, which was small poor farmers living in the rain-fed area. It also identified the initial condition of these farmers. They confronted with the problem about managing their limited agricultural resources efficiently. Besides, it proposed the solution to the problem which was to make a rational and appropriate selection of the agricultural water management scheme of the on-farm pond. The schemes were assessed their sustainability based on the concept of the sustainable agriculture and the New Theory. The sustainability assessment helped farmers make a rational and appropriate selection. The scheme which used their limited agricultural resources most efficiently to fulfill their social and economic needs, was preferred and recommended for the selection.

4.3.2 Requirements

11 members of the decision support team also collaboratively determined and had a consensus about requirements of the selected decision support tool in the first workshop for the expert judgement. They are requirements that the solution must meet (Baker et al., 2001). There were three requirements as below.

- **Risk management**: Alternatives must be planned based on the available rainwater harvested in the on-farm pond
- **Reasonableness**: Agricultural activities in the schemes must be selected reasonably based on topographical and sociological conditions of the area

- **Moderation**: Alternatives must not cause any negative outcome in any sustainability pillars

These requirements were derived from the concept of the Sufficiency Economy Philosophy which is the fundamental concept of the New Theory (Chaipattana Foundation, 2014). All alternative agricultural water management schemes of the on-farm pond had to meet these requirements. The risk management was to ensure that all alternative schemes were designed based on the limited amount of the rainwater harvested in the on-farm pond. Schemes that consumed water more than the available amount could not manage risks form the water scarcity during dry spells and in the dry season. The reasonableness was directly relevant to the selection of crop types for the cultivation. Based on the New Theory, it is recommended to grow what you eat and to eat what you grow. It also prioritizes local species. It not only ensures the household food self-sufficiency, but also meets the needs and preferences of local markets (Ampol Senanarong, 2014). Besides, local species perform well under local topographical conditions, which reduces risks from the crop failure (AFED, 2011). While, the moderation was to ensure that all alternative schemes were devised based on available natural resources to fulfill social and economic needs. They should be devised at the moderate level, neither too little nor too much, which was the most efficient.

4.3.3 Goal

11 members of the decision support team also collaboratively established and had a consensus about the goal of the selected decision support tool in the first workshop for the expert judgement. It was set as below.

"To help the decision maker make a rational and appropriate selection of the agricultural water management scheme of the on-farm pond which will lead to the sustainable rain-fed agriculture referenced to the New Theory of His Majesty King Bhumibol Adulyadej The Great."

This goal was defined to ensure that the selected alternative scheme was the most sustainable, referenced to the New Theory, for the decision maker to apply for managing the limited rainwater harvested in the on-farm pond.

4.3.4 Criteria

11 members of the decision support team also collaboratively developed and selected the assessment criteria of the selected decision support tool in the second workshop for the expert judgement. These criteria helped small semi-subsistence or part-commercial family farms in the rain-fed agricultural area, who were the decision maker of the tool, assess the sustainability of agricultural water management schemes of the on-farm pond and make an appropriate and rational selection.

These assessment criteria were developed and selected based on existing ones related to the concept of the sustainable agriculture and the New Theory. They were derived from both international and national sources, so they conformed and represented the global state of the art as well as international and national sources to which they belonged. In addition, these assessment criteria were adapted to the context of topographical and sociological conditions of the rain-fed agricultural area of Thailand and established based on three goals of the New Theory. The first goal is to enable farmers to achieve a self-reliant agriculture by maximizing benefits from their limited agricultural resources. The second goal is to enable farmers to produce agricultural products sufficiently for the daily household consumption and income generation to purchase non-farm produced food essentials and other necessities. The third goal is to enable farmers to maintain a rain-fed agriculture sustainably. These criteria also reflected the desired conditions of the New Theory, which were self-reliance, self-sufficiency, and risk management (Ampol Senanarong, 2014; Chaipattana Foundation, 2014; OPM, 2004b).

The result of the brainstorming process was the initial site-specific set of criteria. It comprised three criteria and 15 sub-criteria. Each sub-criterion had its own unit of measure in terms of an indicator. Each indicator also had its own classification of values in terms of sustainability classes due to the variety of measurements and scales of different indicators (Adham et al., 2016). A comparable scale between indicators was identified and applied in the selected MCDM technique of the study, which was AHP. All indicators were reclassified into five sustainability classes with values and the score for each value, which were derived from the expert judgement based on their knowledge and experience as well as information found in the literature review. The sustainability classes make the assessment criteria more objective and reliable for applying in the selected decision support tool (Adham et al., 2016).

In the part of the voting process, the initial site-specific set of criteria was, firstly, assessed and screened through the application of the ranking and rating methods. The results showed that all criteria and sub-criteria in the initial site-specific set were important. There was no decision element weighted significantly low enough to be eliminated. After that, they were prioritized through the application of the pairwise comparison method. The result was consistent with those derived from the ranking and rating methods. However, it is noticeable that the range of the relative weights of each decision element derived from the pairwise comparison method was likely to be much wider than those derived from the ranking and rating methods. The pairwise comparison method is able to differentiate the relative importance of decision elements more accurately than the ranking and rating methods (Mendoza & Prabhu, 2000b). The result from the pairwise comparison method was also used in the AHP technique.

The result of the second workshop for the expert judgement was the final locality set of the assessment criteria, which comprised three criteria and 15 sub-criteria. Table 4.9 demonstrates the final locality set of the assessment criteria with their relative weights assigned by the expert team according to the ranking method, the rating method, the combined weights of the ranking and rating methods in terms of the average relative weights, and the pairwise comparison method, respectively. While, Table 4.10 presents the classification of values for each indicator in terms of sustainability classes.

Table 4.9 The final locality set of the assessment criteria with relative weights for multiple criteria decision-making techniques assigned by the expert judgement

Criteria	Unit of measure (Indicators)	Relative weight for multiple criteria decision-making techniques			
		Ranking	Rating	Combine weight	Pairwise comparison
C1 The pursuit of self-reliant agriculture based on limited agricultural land and water resources		**34.94**	**40.00**	**37.47**	**48.60**
S1.1 Land use efficiency	The ratio of the total cultivated area in both rainy and dry season to the maximum cultivated area based on the water use efficiency of the on-farm pond	15.83	17.82	16.82	17.61
S1.2 Production cost	The percentage of the operation cost reduced per square meter per year	13.04	11.91	12.48	13.82
S1.3 Farm productivity	The percentage of the production income increased per area per year	13.57	11.82	12.69	12.00
S1.4 Water productivity	The percentage of the production income increased per unit of water per year	13.91	13.27	13.59	13.18
S1.5 Water use efficiency	The ratio of the cultivated area in the dry season to the amount of rainwater harvested in the on-farm pond	14.78	15.09	14.94	16.58
S1.6 Production cost and benefit	Benefit Cost Ratio: BCR	14.61	15.09	14.85	13.38
S1.7 The diversification of farm production system	The number of agricultural activities in the farm	14.26	15.00	14.63	13.42
C2 The self-sufficiency of daily household consumption and income generation		**33.09**	**32.27**	**32.68**	**25.59**
S2.1 Food self-sufficiency	The sufficiency of rice products for the annual household consumption	21.90	26.09	23.99	30.90
S2.2 The reduction of the cost of living	The percentage of the annual household consumption expenditure for food and beverages reduced by the rice production for the annual household consumption	20.19	20.64	20.42	16.80
S2.3 Household self-sufficiency	The ratio of the net profit to the annual household consumption expenditure	22.38	22.91	22.65	21.17
S2.4 Job creation	The number of months with household members engaged in agricultural work per year	17.52	13.36	15.44	13.70
S2.5 Variability of income generation in terms of time-dispersion	The number of months with income generation per year	18.00	17.00	17.50	17.44
C3 The pursuit of sustainable rain-fed agriculture		**31.97**	**27.73**	**29.85**	**25.82**
S3.1 Mixed farming	The diversity of plant types and animal species in the farm	37.11	40.91	39.01	51.12
S3.2 Multiple cropping	The number of crops in the same area in sequenced seasons	33.59	35.45	34.52	26.33
S3.3 Environmental benefits and services of perennial plants	The ratio of the area with perennial plants to the maximum cultivated area based on the water use efficiency of the on-farm pond	29.30	23.64	26.47	22.55

Note: C = Criterion
S = Sub-criterion

Table 4.10 The classification of values for each indicator in terms of sustainability classes

Criteria	Unit of measure (Indicators)	Sustainability classes	Values	Scores
C1 The pursuit of self-reliant agriculture based on limited agricultural land and water resources				
S1.1 Land use efficiency	The ratio of the total cultivated area in both rainy and dry season to the maximum cultivated area based on the water use efficiency of the on-farm pond	Very high sustainability	2	5
		High sustainability	1.5-1.9	4
		Medium sustainability	1.1-1.4	3
		Low sustainability	1	2
		Very low sustainability	<1.0	1
S1.2 Production cost	The percentage of the operation cost reduced per square meter per year	Very high sustainability	≥21%	5
		High sustainability	16-20%	4
		Medium sustainability	11-15%	3
		Low sustainability	6-10%	2
		Very low sustainability	≤5%	1
S1.3 Farm productivity	The percentage of the production income increased per area per year	Very high sustainability	≥21%	5
		High sustainability	16-20%	4
		Medium sustainability	11-15%	3
		Low sustainability	6-10%	2
		Very low sustainability	≤5%	1
S1.4 Water productivity	The percentage of the production income increased per unit of water per year	Very high sustainability	≥21%	5
		High sustainability	16-20%	4
		Medium sustainability	11-15%	3
		Low sustainability	6-10%	2
		Very low sustainability	≤5%	1
S1.5 Water use efficiency	The ratio of the cultivated area in the dry season to the amount of rainwater harvested in the on-farm pond	Very high sustainability	>3.0	5
		High sustainability	2.6-3.0	4
		Medium sustainability	2.0-2.5	3
		Low sustainability	1.5-1.9	2
		Very low sustainability	<1.5	1

Criteria	Unit of measure (Indicators)	Sustainability classes	Values	Scores
S1.6 Production cost and benefit	Benefit Cost Ratio: BCR	Very high sustainability	>2.0	5
		High sustainability	1.6-2.0	4
		Medium sustainability	1.1-1.5	3
		Low sustainability	1.0	2
		Very low sustainability	<1.0	1
S1.7 The diversification of farm production system	The number of agricultural activities in the farm	Very high sustainability	≥5	5
		High sustainability	4	4
		Medium sustainability	3	3
		Low sustainability	2	2
		Very low sustainability	1	1
C2 The self-sufficiency of daily household consumption and income generation				
S2.1 Food self-sufficiency	The sufficiency of rice products for the annual household consumption	Very high sustainability	Rice products are sufficient for the annual household consumption with the surplus for the sale in order to purchase the non-farm produced food, farm inputs, and other essentials and generate the household cash income	5
		High sustainability	Rice products are sufficient for the annual household consumption with the surplus for the sale in order to purchase the non-farm produced food, farm inputs, and other essentials	4
		Medium sustainability	Rice products are sufficient only for the annual household consumption but not for the sale	3
		Low sustainability	Rice products are sufficient for the household consumption for more than six months but not for the whole year	2
		Very low sustainability	Rice products are sufficient for the household consumption for six months and under	1

Criteria	Unit of measure (Indicators)	Sustainability classes	Values	Scores
S2.2 The reduction of the cost of living	The percentage of the annual household consumption expenditure for food and beverages reduced by the rice production for the annual household consumption	Very high sustainability	≥61%	5
		High sustainability	51-60%	4
		Medium sustainability	41-50%	3
		Low sustainability	31-40%	2
		Very low sustainability	≤30%	1
S2.3 Household self-sufficiency	The ratio of the net profit to the annual household consumption expenditure	Very high sustainability	>2.0	5
		High sustainability	1.6-2.0	4
		Medium sustainability	1.1-1.5	3
		Low sustainability	1.0	2
		Very low sustainability	<1.0	1
S2.4 Job creation	The number of months with household members engaged in agricultural work per year	Very high sustainability	11-12	5
		High sustainability	9-10	4
		Medium sustainability	7-8	3
		Low sustainability	5-6	2
		Very low sustainability	≤4	1
S2.5 Variability of income generation in terms of time-dispersion	The number of months with income generation per year	Very high sustainability	12	5
		High sustainability	9-11	4
		Medium sustainability	5-8	3
		Low sustainability	2-4	2
		Very low sustainability	1	1
C3 The pursuit of sustainable rain-fed agriculture				
S3.1 Mixed farming	The diversity of plant types and animal species in the farm	Very high sustainability	≥21	5
		High sustainability	16-20	4
		Medium sustainability	11-15	3
		Low sustainability	6-10	2
		Very low sustainability	≤5	1

Criteria	Unit of measure (Indicators)	Sustainability classes	Values	Scores
S3.2 Multiple cropping	The number of crops in the same area in sequenced seasons	Very high sustainability	≥5	5
		High sustainability	4	4
		Medium sustainability	3	3
		Low sustainability	2	2
		Very low sustainability	1	1
S3.3 Environmental benefits and services of perennial plants	The ratio of the area with perennial plants to the maximum cultivated area based on the water use efficiency of the on-farm pond	Very high sustainability	≥10%	5
		High sustainability	9%	4
		Medium sustainability	8%	3
		Low sustainability	7%	2
		Very low sustainability	≤6%	1

4.3.4.1 Criteria level

It is obvious that criterion 1 "The pursuit of self-reliant agriculture based on limited agricultural land and water resources" was given the most importance from all MCDM techniques. Whereas, criterion 2 "The self-sufficiency of daily household consumption and income generation" and criterion 3 "The pursuit of sustainable rain-fed agriculture" were nearly important according to the ranking and rating methods and almost the same importance according to the pairwise comparison method.

The result was consistent with the objective of the New Theory, which is to enable farmers to manage and maximize benefits from their limited agricultural resources by themselves (Chaipattana Foundation, 2014). Criterion 1 is the solid foundation for farmers to fulfill the two remaining criteria. The self-reliant agriculture based on limited agricultural land and water resources can be achieved through the resource use efficiency. It brings about the farm productivity which provides adequate foods for the daily household consumption. It also generates cash income from the sale of both food surpluses to the household consumption and cash crops raised specifically for this purpose. Moreover, it reduces internal and external risks and uncertainties through the mixed farming and the multiple cropping, which diversify agricultural activities and disperse the production system throughout the year, leading to sustainable rain-fed agriculture.

4.3.4.2 Sub-criteria level

- **Sub-criteria under criterion 1 " The pursuit of self-reliant agriculture based on limited agricultural land and water resources"**

Sub-criterion 1.1 "Land use efficiency" and sub-criterion 1.5 "Water use efficiency" were prioritized as the two highest sub-criteria from all MCDM techniques. In order to pursue the self-reliant agriculture based on limited agricultural land and water resources, it is necessary to initially use limited resources efficiently to fulfill social and economic needs of the household. While, the remaining sub-criteria are needed to be concerned consecutively, after deciding on the most efficient use of agricultural resources.

The land use efficiency of each alternative scheme was measured in terms of the ratio of the total cultivated area in both rainy and dry season to the maximum cultivated area based on the water use efficiency of the on-farm pond. Its values of sustainability classes were categorized based on the findings of Eakawit Jornpradit (2007). Besides, according to the calculation program of Hydro-Informatics Institute, it was estimated that the rainwater harvested in the on-farm pond with 1,260 m^3 storage capacity was able to manage risks from the water scarcity for 8,000 m^2 or five rais of the rice cultivation during dry spells in the rainy season. It was also able to manage risks from the water scarcity for around 3,200 m^2 or two rais of the crop cultivation in the dry season based on the evapotranspiration of each crop variety. Moreover, based on the New Theory, it is estimated that Thai people consume around 200 kilograms of rice per person per year. While, a family with 5-6 members consumes around 1,200 kilograms of rice per year. Thus, each family has to grow rice around five rais of land, with at least 240 kilograms of yields per rai, in order to have enough rice for the annual household consumption (Chaipattana Foundation, 2014). Meanwhile, the water use efficiency of each alternative scheme was measured in terms of the ratio of the cultivated area in the dry season to the amount of the rainwater harvested in the on-farm pond. Its values of sustainability classes were categorized based on the calculation program of Hydro-Informatics Institute. It was estimated that the rainwater harvested in the on-farm pond with 1,260 m^3 storage capacity was able to manage risks from the water scarcity for around 3,200 m^2 or two rais of the crop cultivation in the dry season based on the evapotranspiration of each crop variety.

The remaining sub-criteria were dispersed in a narrow range of weights. The sub-criteria, which were given a subsequent importance under this criterion, were sub-criterion 1.2 “Production cost” and sub-criterion 1.6 “Production cost and benefit”. They related to the production cost and benefit of the agricultural water management scheme of the on-farm pond. The production cost of each alternative scheme was measured in terms of the percentage of the operation cost reduced per square meter per year. Its values of sustainability classes were categorized based on the A4 policy of the Ministry of Agriculture and Cooperatives. This policy targets to reduce 20% of the actual production cost in order to raise the quality of life of Thai farmers and increase incomes. It also proposes that the target will succeed through the application of the New Theory with new technology and innovation (MOAC, 2017b). While, the production cost and benefit of each alternative scheme was measured in terms of the Benefit Cost Ratio or BCR. It is a basic and universal method for assessing the economic sustainability of the scheme or project (Dantsis et al., 2010; Fox et al., 2005; Hayati et al., 2010; McConnell & Dillon, 1997; P. K. Pandey et al., 2006; Panigrahi et al., 2005; Panigrahi et al., 2007; Panigrahi et al., 2001).

Along with sub-criterion 1.7 "The diversification of farm production system", it considered the number of agricultural activities in the farm of each alternative scheme. Based on topographical and sociological conditions of the rain-fed agricultural area of Thailand, agricultural activities in the farm can generally be classified into eight types, which are rice, field crops, vegetables/flower and ornamental plants/herbs, perennial plants, aquatic plants, poultry, and livestock (Ampol Senanarong, 2014). Following by sub-criterion 1.3 "Farm productivity" and sub-criterion 1.4 "Water productivity", they were related to the productivity and reflected the performance of alternative schemes based on limited agricultural resources. They measured the productivity of each alternative scheme in terms of the percentage of the production income increased per area and per unit of water per year, respectively. Their values of sustainability classes were also categorized based on the A4 policy of the Ministry of Agriculture and Cooperatives. This policy targets to increase 20% of the actual farm productivity in order to raise the quality of life of Thai farmers and increase incomes (MOAC, 2017b).

- **Sub-criteria under criterion 2 " The self-sufficiency of daily household consumption and income generation"**

From all MCDM techniques, the sub-criterion with the highest weight was sub-criterion 2.1 "Food self-sufficiency", following by sub-criterion 2.3

"Household self-sufficiency". They were directly relevant to the criterion they were under. Besides, the most expected outcome of the New Theory is that farmers can, firstly, live their life at the economical level through the production of adequate food stuffs to live and eat throughout the year. It will lay a firm foundation for them to gradually raise their standard of living and finally to live well and eat well, which will lead to sustainable rain-fed agriculture (Ampol Senanarong, 2014).

The food self-sufficiency was measured in terms of the sufficiency of rice products received from alternative schemes for the household consumption throughout the year. Its values of sustainability classes were categorized based on the New Theory, which estimates that Thai people consume around 200 kilograms of rice per person per year (Chaipattana Foundation, 2014). One of the significant principles of the New Theory is that every household must produce enough rice, which is the staple food of Thai people, to consume for the whole year. It enables them to be self-reliant without buying their staple at an expensive price (OPM, 2004b). Besides, it resulted in sub-criterion 2.2 "The reduction of the cost of living". This sub-criterion determined the percentage of the annual household consumption expenditures for food and beverages, excluding alcoholic, reduced by the rice production for the annual household consumption of alternative schemes. Its values of sustainability classes were categorized based on the average monthly expenditure per household by expenditure group and household size of each province. These secondary data are derived from the annual household socio-economic survey of each province which is conducted by the National Statistical Office (Ministry of Information and Communication Technology [MICT], 2018).

While, the household self-sufficiency was indicated as the ratio of the net profit received from alternative schemes to the annual household consumption expenditures. Its values of sustainability classes were also categorized based on the average monthly expenditure per household by expenditure group and household size of each province (MICT, 2018). Every household needs to generate enough cash income from the sale of both surplus to the household consumption and cash crops raised specifically for this purpose in order to purchase the non-farm produced food, farm inputs, and other essentials. In addition, for more sustainability, the household should have savings from the final surplus after these expenses (McConnell & Dillon, 1997). However, to acquire the household self-sufficiency, it is necessary to take sub-criterion 2.5 "Variability of income generation in terms of time-dispersion" into account. It stabilizes the household income generation and reduces internal and external risks and uncertainties (OPM, 2004b). This sub-criterion was measured in terms of the number of months with the income generation per year. Its values of sustainability classes were categorized based on the assumption of the expert team that each household has the monthly household expenditure inevitably. Therefore, the more the number of months that each household generates incomes, the more the sustainable rain-fed agriculture (McConnell & Dillon, 1997).

Besides, it was also related to sub-criterion 2.4 "Job creation" which considered alternative schemes in terms of the number of months with household members engaged in the agricultural work per year. Its values of sustainability classes were categorized based on the assumption of the expert team that household members should engage in agricultural works as much as possible. It increases the labor productivity and sources of the household income generation. It also reduces the seasonal unemployment and the rural to urban seasonal migration, which enhances the sustainable rural livelihoods. Therefore, the more the number of months that household members engage in agricultural works, the more the labor productivity and sustainable rain-fed agriculture. (OPM, 1999; Tangon Munjaiton et al., 1999; Wallop Promthong, 2008; Wisarn Pupphavesa et al., 1999; Woltersdorf, 2010).

- **Sub-criteria under criterion 3 "The pursuit of sustainable rain-fed agriculture"**

From all MCDM techniques, the sub-criterion with the highest weight was sub-criterion 3.1 "Mixed farming", following by sub-criterion 3.2 "Multiple cropping" and sub-criterion 3.3 "Environmental benefits and services for perennial plants", respectively.

The mixed farming is a system of farming on a particular farm, including crop cultivation, livestock production, poultry, fish farming, bee keeping and the like, to sustain and satisfy as many of the needs of the farmer as possible (AgriInfo.in, 2015e). It is directly relevant to the concept of the land division and the farm activity diversification of the New Theory (OPM, 2004b). It was measured in terms of the diversity of plant types and animal species in the farm (McConnell & Dillon, 1997). The more the number of plant types and animal species in the farm, the more the sustainable rain-fed agriculture. The application of the mixed farming sustains and satisfies as many of the needs of the household as possible. It reduces internal and external risks which affect the household from solely depending on the mono-cropping. Besides, it makes them self-supporting by ensuring the household food security, the agricultural work, and the income generation through various times and activities received food stuffs and cash incomes throughout the year (McConnell & Dillon, 1997; OPM, 2004b). Furthermore, the mixed farming enables the pursuit of sustainable rain-fed agriculture by maintaining the ecological balance and the soil fertility, which is the production base, for much longer periods (AgriInfo.in, 2015d).

The multiple cropping is the practice of growing different crops in succession over the same piece of land in one calendar year. It was measured in terms of the number of crops in the same area in sequenced seasons (AgriInfo.in, 2015a, 2015b). The more the number of crops, the more the sustainable rain-fed agriculture. The multiple cropping improves the land use efficiency in terms of the intensive cropping (AgriInfo.in, 2015a). It also enhances the water use efficiency through the whole year farm production, which is the major purpose of the on-farm pond construction of the New Theory (Chaipattana Foundation, 2014). Besides, it provides food stuffs, works, and cash incomes for the household throughout the year, which reduces internal and external risks affecting the household. Moreover, the multiple cropping accommodates the pursuit of sustainable rain-fed agriculture. It maintains the long-term productivity of the land by preventing the soil erosion, shifting the composition of the soil, as well as enhancing the soil nutrient recycling and soil organic matter for better plant growing and higher yielding. Besides, it reduces crop specific pests and diseases which are often observed in the mono-cropping (FAO, 2015). Therefore, alternative schemes should encourage the multiple cropping.

Environmental benefits and services for perennial plants were measured in terms of the ratio of the area with perennial plants to the maximum cultivated area based on the water use efficiency of the on-farm pond. Its values of sustainability classes were also categorized based on the New Theory, which indicates that one part of the farmland should grow perennial trees whose products can be food stuffs and wood can be used for general purposes, firewood, and the construction for the household consumption and utilization (Ampol Senanarong, 2014). Perennial plants also accommodate the pursuit of sustainable rain-fed agriculture. They improve the soil structure, the soil nutrient, and the soil moisture through their root systems. They also protect the soil erosion by winds and rainfalls, preserve the valuable topsoil through their shading and cover, and provide animal habitats. Therefore, the more the ratio of the area with perennial plants to the cultivated area, the more the sustainable rain-fed agriculture.

4.3.5 Alternative agricultural water management schemes of the on-farm pond

Alternative agricultural water management schemes of the on-farm pond were distinct potential solutions to the problem about the imbalance of agricultural water demands and supply. They were devised based on three requirements which were consensually proposed by the decision support team as below.

- Alternatives must be planned based on the available rainwater harvested in the on-farm pond.
- Agricultural activities in the schemes must be selected reasonably based on topographical and sociological conditions of the area.
- Alternatives must not cause any negative outcome in any sustainability pillars.

Besides, they needed to fulfill as many criteria as possible. However, each alternative scheme had different abilities to fulfill criteria. Therefore, the scheme that used limited agricultural resources most efficiently to fulfill social and economic needs of the household, was preferred and recommended for the selection.

4.3.5.1 The selection of agricultural activities

Alternative schemes, which were proposed to respondents, were devised based on the amount of the rainfall in the area and the available rainwater harvested in the on-farm pond with 1,260 m^3 storage capacity. Based on the calculation program of Hydro-Informatics Institute, it was estimated that the rainwater harvested in the on-farm pond with 1,260 m^3 storage capacity was able to manage risks from the water scarcity for 8,000 m^2 or five rais of the rice cultivation during dry spells in the rainy season. Moreover, based on the New Theory, it is estimated that Thai people consume around 200 kilograms of rice per person per year. While, a family with 5-6 members consumes around 1,200 kilograms of rice per year. Thus, each family has to grow rice around five rais of land, with at least 240 kilograms of yields per rai, in order to have enough rice for the annual household consumption and ensure the household food self-sufficiency (Chaipattana Foundation, 2014).

Moreover, the mixed farming above the edge of the on-farm pond, which was the all year-round activity, was also applied the harvested rainwater during dry spells in the rainy season and throughout the dry season. Vegetables and perennial plants grown in this activity were mainly for the daily household consumption. The surplus was, then, given to the neighbors and sold in the local market, respectively. Consequently, there was not enough water for other crop cultivations in the rainy season.

Whereas, it was estimated that the rainwater harvested in the on-farm pond with 1,260 m^3 storage capacity was able to manage risks from the water scarcity for around 3,200 m^2 or two rais of the crop cultivation in the dry season. It also depends on the evapotranspiration of crops cultivated in the dry season of each scheme. These crops were mainly grown as a cash crop for the household income generation. Therefore, the harvested rainwater was applied only for the crop cultivation, including the lowland major rice cultivation, the lowland alternative crop cultivation after the major rice cultivation, and the mixed farming above the edge of the on-farm pond throughout the year.

4.3.5.2 The selection of crop types

Crop types, which were proposed in each scheme, were selected reasonably based on topographical and sociological conditions of the area. They were selected based on the household preference for the daily consumption. Local crops were preferred as they are grown up well in the local environment, which reduces the crop failure. Respondents also acquired knowledge and experience about how to cultivate them, which made the cultivation more productive. Besides, people in the area were familiar with these crops in their daily consumption, which enhanced local market opportunities. Cash crops with a lower water demand and a good market price were also prioritized. However, it is also necessary to take the length of crop duration into account. It is related to the crop water requirement throughout the growing season, which affects the water use efficiency of alternative schemes (AFED, 2011; Critchley & Siegert, 1991). Therefore, alternative schemes did not propose any new crop type. They selected local and short duration crops which respondents had knowledges and experience in the cultivation as informed in the interview.

For the lowland major rice cultivation, RD6 glutinous rice and Gaw Diaw were selected. Both are a glutinous rice which is the staple food of people in the study area. Besides, they can be produced as the GI product of this area, which is Khao Wong Kalasin sticky rice (MOAC, 2016b; MOC, 2016). Respondents can sell the surplus from the daily household consumption throughout the year to generate the household income.

For the lowland alternative crop cultivation after the major rice cultivation, cash crops for the food processing industry, including sweet corns, peanuts, and tomatoes, were selected. These cash crops have a local market opportunity in terms of a contract farming with the local middleman. In general, the local middleman agrees to buy these farm products based on the quality standards at a good price guaranteed before the production. Disqualified products can also be sold at local markets. Cash crops for the local market, including, morning glories, chillis, eggplants, pumpkins, luffa gourds, cucumbers, and yard long beans, were also selected for the alternative crop cultivation after the major rice cultivation. They were selected based on the result of the field visit and interview. It found that most of respondents grew these vegetables for the daily household consumption and for sale at local markets. The lowland alternative crop cultivation after the major rice cultivation increases the variability of the household income generation in terms of the time-dispersion. It also enhances the land use efficiency in terms of the multiple cropping.

For the mixed farming above the edge of the on-farm pond, it is recommended to grow perennial trees and vegetables, which are preferred by the household and do not require much water, for the daily household consumption throughout the year. These crops prevent the bank erosion, conserve the humidity in the ground, and preserve organic substances in the soil (OPM, 2008).

Figure 4.3 presents the production cost, the gross profit, the net profit, and the market price of crop types which were proposed in alternative schemes. Data were collected from the field visit and the structured interview and rechecked with the literature review and the expert team. It found that morning glories had the highest production cost, which was 11,300 baht per rai, following by pumpkins, sweet corns, and tomatoes, which were 8,100 baht, 7,800 baht, and 7,500 baht per rai, respectively. However, when considering the net profit, it also found that tomatoes had the highest net profit, which 103,500 baht per rai, following by morning glories, chillis, and pumpkins, which were 88,700 baht, 73,500 baht, and 51,900 baht per rai, respectively, because of their high market price and yields.

Meanwhile, RD6 glutinous rice and Gaw Diaw had the lowest production cost, which was 4,000 baht per rai. They also had the lowest net profit, which were 2,660 baht and 1,000 baht per rai, respectively, since their yields are not high when comparing to other crops. Besides, respondents normally sold them as the paddy whose market price is only 10 baht per kilogram. However, the glutinous rice is their staple food. They should grow it in order to ensure the household food self-sufficiency and reduce the living cost of the household (Chaipattana Foundation, 2014).

Otherwise, they need to buy it as the milled rice at the market price, which is 35 baht per kilogram. Nevertheless, if respondents sell the product as the milled rice at local markets, the sale price will increase to 35 baht per kilogram. Moreover, if respondents sell the product as the GI product, which is Khao Wong Kalasin sticky rice, the sale price will increase to 70 baht per kilogram (MOAC, 2016b; MOC, 2016).

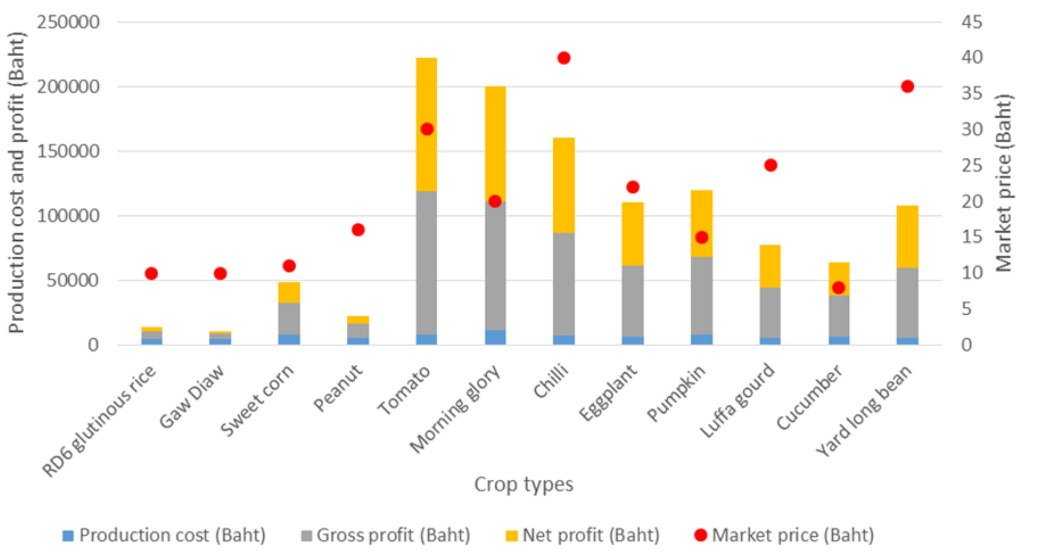

Figure 4.3 Production cost, gross profit, net profit, and market price of crop types proposed in the alternative agricultural water management schemes of the on-farm pond

Whereas, the size of the cultivated area of each crop, which was proposed in each scheme, was determined based on the crop water requirement throughout the growing season and the length of the crop duration. They affect the water use efficiency of alternative schemes (AFED, 2011; Critchley & Siegert, 1991). Figure 4.4 presents the crop duration and the crop water requirement of crop types which were proposed in alternative schemes. Data were derived from the literature review. It found that RD6 glutinous rice consumes water the most throughout the growing season, which is 1,250 m^3, following by Gaw Diaw, tomatoes, and chillis, which are 1,000 m^3, 850 m^3, and 750 m^3, respectively. However, when considering the crop duration, it found that chillis has the longest crop duration, which is 150 days, following by RD6 glutinous rice and pumpkins, which are 130 day and 120 days, respectively. Meanwhile, morning glories consumes water the least throughout the growing season, which is 200 m^3. It also has the shortest crop duration, which is 25 days.

It is obvious that Gaw Diaw consumes less water and has a shorter crop duration than RD6 glutinous rice. Gaw Diaw is normally harvested in early October (ARDA, 2017); while, RD 6 glutinous rice is generally harvested in mid-November (MOAC, 2017c). Thanks to this coincidence between the rainfall period of the area and its water use period, Gaw Diaw uses the rainfall in the rainy season more beneficially and optimizes the rainwater harvested in the on-farm pond more efficiently than RD 6 glutinous rice. Furthermore, Gaw Diaw makes the lowland alternative crop cultivation after the major rice cultivation possible since November. It makes use of the available soil water content in the active root zone of the crop beneficially and saves the rainwater harvested in the on-farm pond. On the contrary, RD 6 glutinous rice delayed the lowland alternative crop cultivation after the major rice cultivation to be in December when the available soil water content in the active root zone of the crop starts depleting. Thus, it has to uses the supplemental irrigation from the on-farm pond instead. However, most respondents still preferred RD6 glutinous rice to Gaw Diaw. Gaw Diaw is a local glutinous rice; while, RD6 glutinous rice is improved to be drought-tolerant and fragrant, provide high yields, and have a good milling and cooking quality (MOAC, 2017c).

Tomatoes and chillis require a large amount of water throughout the growing season. While, pumpkins and chillis have a long crop duration. However, their net profit per crop is high, so it is necessary to take both the water use efficiency and the net profit into consideration. Meanwhile, morning glories consumes a small amount of water throughout the growing season and has a short crop duration. It increases the variability of the household income generation in terms of the time-dispersion. Besides, it enhances the land use efficiency in terms of the multiple cropping. Moreover, its net profit per crop is high. Therefore, it is recommended as the lowland alternative crop after the major rice cultivation.

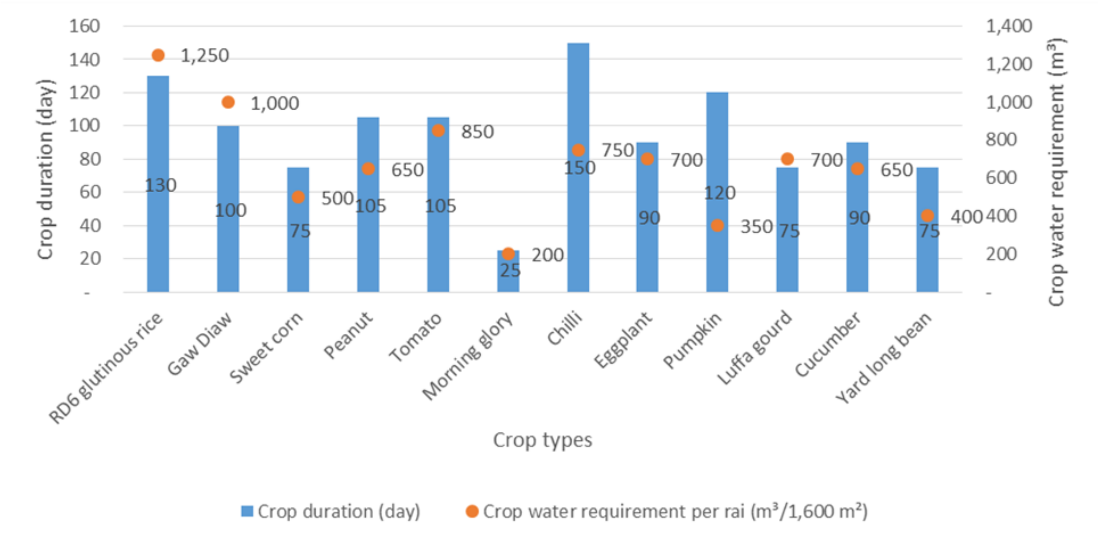

Figure 4.4 Crop duration and crop water requirement of crop types proposed in the alternative agricultural water management schemes of the on-farm pond
Source: Ministry of Agriculture and Cooperatives (2011); Ministry of Science and Technology (2016)

4.3.5.3 The devising of alternative agricultural water management schemes of the on-farm pond

Table 4.11 illustrates 12 alternative agricultural water management schemes of the on-farm pond devised for respondents. While, alternative schemes with details about the cultivated area, crop water requirements, the crop duration, and the yielding period are presented in Appendix F.

Alternative schemes could be grouped into three groups based on the rice variety proposed in the scheme. The first group was schemes which cultivated RD 6 glutinous rice, consisting of ALT01, ALT02, ALT03, and ALT04. The second group was schemes which cultivated Gaw Diaw, consisting of ALT05, ALT06, ALT07, and ALT08. The last group was schemes which cultivated both RD 6 glutinous rice and Gaw Diaw, consisting of ALT09, ALT10, ALT11, and ALT12.

For the lowland alternative crop cultivation after the major rice cultivation, each scheme proposed different crop types. ALT01, ALT05, and ALT09 proposed only three cash crops for the food processing industry, which were sweet corns, peanuts, and tomatoes. There were no cash crops for the local market. While, ALT02, ALT06, and ALT10 proposed only one cash crop for the food processing industry, which was sweet corns. There were also seven cash crops for the local market, which were morning glories, chillis, eggplants, pumpkins, luffa gourds, cucumbers, and yard long beans. ALT03, ALT07, and ALT11 proposed only one cash crop for the food processing industry, which was peanuts. There were also seven cash crops for the local market, which were morning glories, chillis, eggplants, pumpkins, luffa gourds, cucumbers, and yard long beans. Whereas, ALT04, ALT08, and ALT12 proposed only one cash crop for the food processing industry, which was tomatoes. There were also seven cash crops for the local market, which were morning glories, chillis, eggplants, pumpkins, luffa gourds, cucumbers, and yard long beans.

The size of the cultivated area of each alternative scheme was adjusted by the calculation program of Hydro-Informatics Institute which balanced the amount of the rainfall in the area and the available rainwater harvested in the on-farm pond with crop water requirements in each scheme. They selected an appropriate production time for each crop in order to use the rainfall and the harvested rainwater most efficiently, which enhances the land and water use efficiency of the schemes (Ali, 2010; AFED, 2011). Therefore, these alternative schemes did not cause any negative outcome in any sustainability pillars.

The size of the cultivated area of all alternative schemes varied from 3,600 m^2 to 8,400 m^2. The maximum cultivated area based on the water use efficiency of the on-farm pond with 1,260 m^3 storage capacity was 8,400 m^2. It was compatible with the average number of household members engaged in the agricultural work of the respondents which were 2.08 persons. They could manage the crop cultivation by themselves without employing agricultural workers or with employing occasionally for some activities. The cultivated area of ALT01, ALT02, ALT03, and ALT04 was 3,600 m^2. While, the cultivated area of the remaining alternative schemes was 8,400 m^2. It is obvious that schemes which cultivated only RD 6 glutinous rice used agricultural resources less efficiently than those which cultivated only Gaw Diaw and those which cultivated both RD 6 glutinous rice and Gaw Diaw. RD6 glutinous rice is a rice variety which requires a large amount of water throughout its long crop duration. Besides, its water use period does not fully coincide with the rainfall period of the area. Therefore, it is necessary to supply a large amount of the rainwater harvested in the on-farm pond to manage any possible risks throughout the growing season.

Table 4.11 12 alternative agricultural water management schemes of the on-farm pond devised for the respondents

Scheme NO.	**ALT 01**	**ALT 02**	**ALT 03**	**ALT 04**	**ALT 05**	**ALT 06**	**ALT 07**	**ALT 08**	**ALT 09**	**ALT 10**	**ALT 11**	**ALT 12**
Lowland major rice cultivation												
RD6 glutinous rice	✓	✓	✓	✓					✓	✓	✓	✓
Gaw Diaw					✓	✓	✓	✓	✓	✓	✓	✓
Lowland alternative crop cultivation after the major rice cultivation (cash crops for the food processing industry)												
Sweet corn	✓	✓			✓	✓			✓	✓		
Peanut	✓		✓		✓		✓		✓		✓	
Tomato	✓			✓	✓			✓	✓			✓
Lowland alternative crop cultivation after the major rice cultivation (cash crops for the local market)												
Morning glory		✓	✓	✓		✓	✓	✓		✓	✓	✓
Chilli		✓	✓	✓		✓	✓	✓		✓	✓	✓
Eggplant		✓	✓	✓		✓	✓	✓		✓	✓	✓
Pumpkin		✓	✓	✓		✓	✓	✓		✓	✓	✓
Luffa gourd		✓	✓	✓		✓	✓	✓		✓	✓	✓
Cucumber		✓	✓	✓		✓	✓	✓		✓	✓	✓
Yard long bean		✓	✓	✓		✓	✓	✓		✓	✓	✓
Mixed farming above the edge of the on-farm pond	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Figure 4.5 compares the size of the cultivated area in the rainy season and the size of the cultivated area in the dry season of alternative schemes. In the rainy season, the cultivated area was used for the lowland major rice cultivation and the mixed farming above the edge of the on-farm pond. The cultivated area in the rainy season of all alternative schemes was optimized. Whereas, in the dry season, the cultivated area was used for the lowland alternative crop cultivation after the major rice cultivation and the mixed farming above the edge of the on-farm pond. The size of cultivated area in the dry season of all alternative schemes varied from 1,700 m^2 to 3,100 m^2. The average size was 2,145.83 m^2.

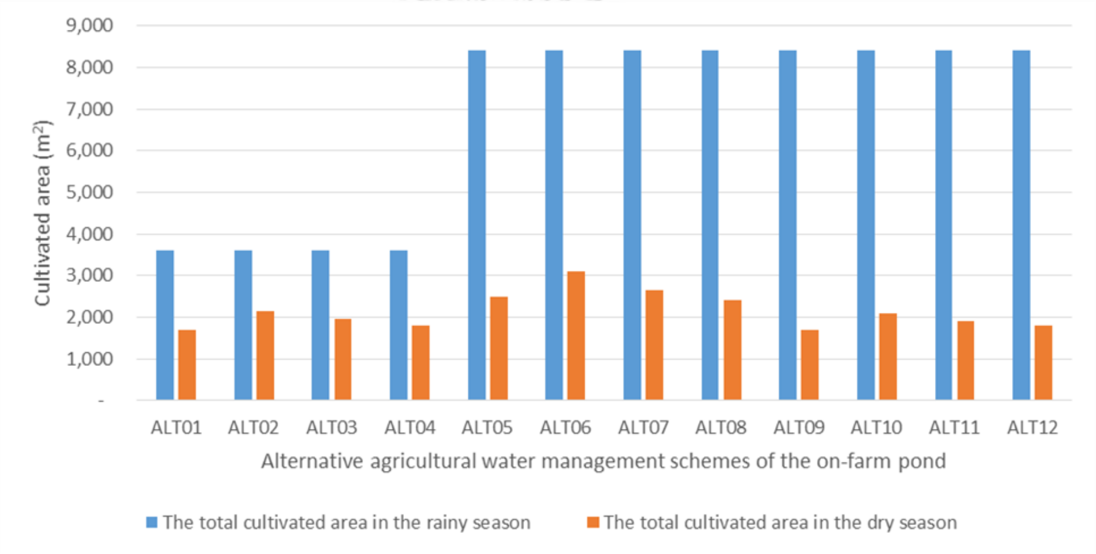

Figure 4.5 The comparison between the size of cultivated area in the rainy season and the size of cultivated area in the dry season of alternative agricultural water management schemes of the on-farm pond

The result shows that ALT05, ALT06, ALT07, and ALT08, which cultivated only Gaw Diaw as the lowland major rice in the rainy season, used agricultural resources most efficiently in the dry season. Gaw Diaw is a rice variety whose crop duration is not too long. Besides, its water use period fully coincides with the rainfall period of the area. Therefore, it is not necessary to supply a large amount of the rainwater harvested in the on-farm pond to manage any possible risks throughout the growing season. There is still a certain amount of the rainwater harvested in the on-farm pond available for the lowland alternative crop cultivation after the major rice cultivation. Besides, its appropriate crop duration helps the lowland alternative crop cultivation after the major rice cultivation makes beneficial use of available soil water content in the active root zone of the crop, which also saves the rainwater harvested in the on-farm pond.

Figure 4.6 presents the number of the multiple cropping, the number of months with the household labor employment, and the number of months with the income generation per year of alternative schemes. It found that the number of the multiple cropping per year varied from two to five times. The average number of the cropping were four times per year. When considering the number of months with the household labor employment per year, it varied from 8.31 to 10.60 months. The average number of months were 9.88 months per year. While, the number of months with the income generation per year varied from 3 to 7 months. The average number of months were 5.50 months per year. The result of the study found that the number of the multiple cropping, the number of months with the household labor employment, and the number of months with the income generation were correlated. The increasing number of the multiple cropping tended to enhance the number of months with the household labor employment and the income generation per year.

ALT01, ALT05, and ALT09 were able to cultivate only two crops per year since they proposed only three cash crops for the food processing industry as the lowland alternative crops after the major rice cultivation. They did not propose any cash crops for the local market. Therefore, the number of months with the household labor employment per year of these alternative schemes were very low, compared to other alternative schemes. There were 9.23 months, 8.31 months, and 9.00 months per year, respectively. Following the same trend, the number of months with the income generation per year of these alternative schemes were also very low, compared to other alternative schemes. There were three months, four months, and five months per year, respectively.

On the contrary, schemes, which proposed only one cash crop for the food processing industry and seven cash crops for the local market as the lowland alternative crops after the major rice cultivation, were able to cultivate from four to five crops per year. Among these alternative schemes, ALT10, ALT11, and ALT12, which cultivated both RD6 glutinous rice and Gaw Diaw as the lowland major rice and followed this pattern for the lowland alternative crop cultivation after the major rice cultivation, had a very high performance. They were able to cultivate five crops per year. Besides, the number of months with the household labor employment per year of these alternative schemes were the highest, which were 10.62 months per year. The number of months with the income generation per year were also the highest, which were five months.

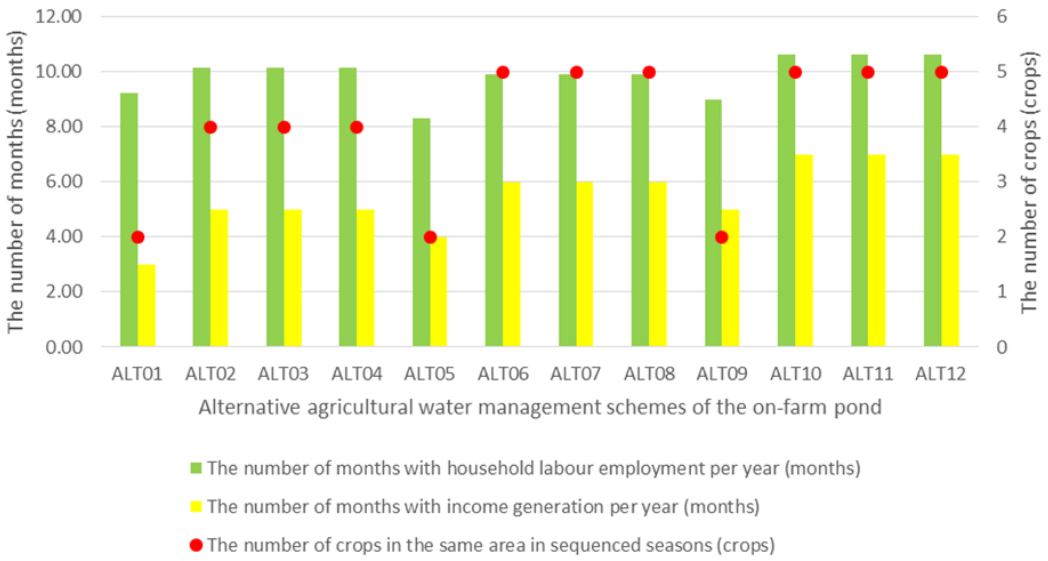

Figure 4.6 The number of multiple cropping, the number of months with household labor employment, and the number of months with income generation per year of alternative agricultural water management schemes of the on-farm pond

ALT06, ALT07, and ALT08, which cultivated only Gaw Diaw rice as the lowland major rice and followed this pattern for the lowland alternative crop cultivation after the major rice cultivation, were also able to cultivate five crops per year. However, the number of months with the household labor employment per year of these alternative schemes were 9.92 months per year. While, the number of months with the income generation per year were six months. Whereas, ALT02, ALT03, and ALT04, which cultivated only RD6 glutinous rice as the lowland major rice and followed this pattern for the lowland alternative crop cultivation after the major rice cultivation, were able to cultivate four crops per year. The number of months with the household labor employment per year of these alternative schemes were 10.15 months per year. While, the number of months with the income generation per year were five months.

Figure 4.7 shows the production cost, the gross profit, the net profit, and the size of the cultivated area throughout the year of alternative schemes. It found that ALT06 maximized the cultivated area, which was 11,300 m² per year, followed by ALT07, ALT08, and ALT10, which were 10,850 m², 10,600 m², and 10,150 m² per year, respectively. Following the same trend, ALT06 also had the highest production cost, which was 37,338 baht per year, followed by ALT07, ALT08, and ALT10, which were 32,910 baht, 31,513 baht, and 31,381 baht per year, respectively. However, when considering the net profit, it found that ALT08 had the highest net profit, which 129,878 baht per year, followed by ALT06, ALT12, and ALT04, which were 86,003 baht, 84,163 baht, and 82,015 baht per year, respectively. The result shows that schemes, which proposed tomatoes as only one cash crop for the food processing industry and seven cash crops for the local market, tended to make a higher profit. Tomatoes are a cash crop for the food processing industry which has the highest market price, compared to peanuts and sweet corn.

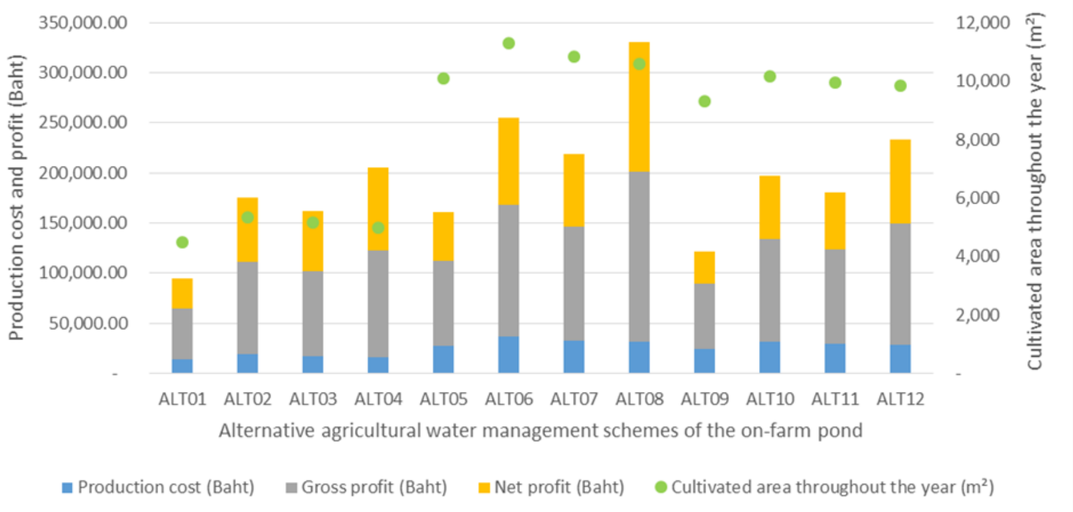

Figure 4.7 Production cost, gross profit, net profit, and the size of cultivated area throughout the year of alternative agricultural water management schemes of the on-farm pond

Figure 4.8 presents the amount of rice yields per crop of alternative schemes. The amount of rice yields per crop ranged from 1,332 to 2,666 kilograms. The average yield per crop was 2,166 kilograms. ALT09, ALT10, ALT11, and ALT12, which cultivated 1,600 m² of RD6 glutinous rice and 6,400 m² of Gaw Diaw as the lowland major rice, yielded the most. There were 2,666 kilograms per crop. Followed by, ALT05, ALT06, ALT07, and ALT08, which cultivated 8,000 m² of Gaw Diaw as the lowland major rice, yielded 2,500 kilograms per crop. While, ALT01, ALT02, ALT03, and ALT04, which cultivated 3,200 m² of RD6 glutinous rice as the lowland major rice, yielded the least. There were 1,332 kilograms per crop. This amount of rice yield was still able to fulfill the annual household consumption of a family with 5-6 members, which consumes around 1,200 kilograms of rice per year. It is estimated from the assumption of the New Theory that Thai people consume around 200 kilograms of rice per person per year (Chaipattana Foundation, 2014). However, it could not fulfill the annual household consumption of the respondent who had eight family members. Therefore, other alternative schemes were preferred since they ensured the household food self-sufficiency with a wide range of the surplus for sale to generate the household income.

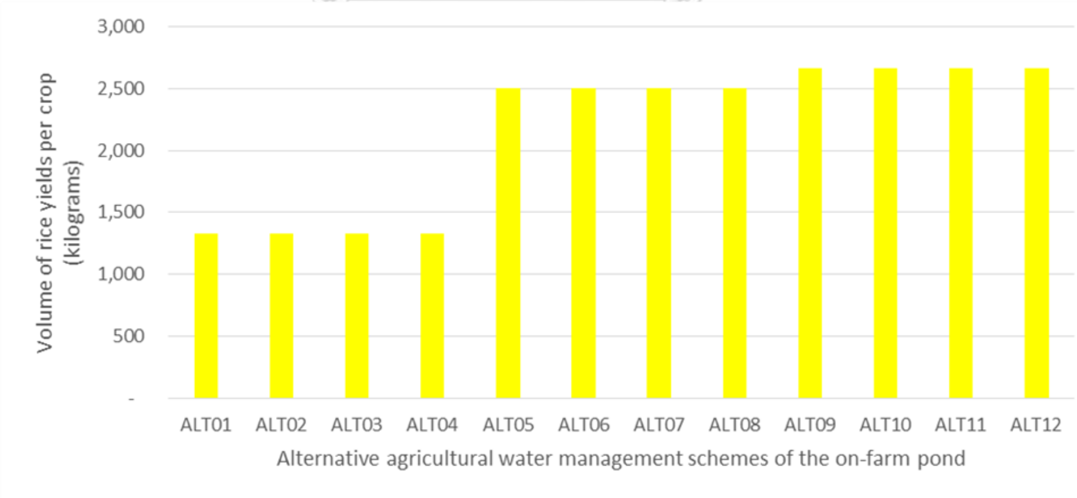

Figure 4.8 The amount of rice yields of alternative agricultural water management schemes of the on-farm pond

4.3.6 AHP technique and its application in the selected decision support tool

AHP technique was selected as the MCDM technique of the selected decision support tool. It is appropriate for the problem with a large number of alternatives and multiple criteria in both quantitative and qualitative (Baker et al., 2001). It is a structured technique for analyzing complex decisions based on mathematics and expert judgement (Adham et al., 2016). Input, therefore, can be obtained from both actual measurements and subjective opinions. Besides, AHP has rational and systematic procedures for scoring criteria and alternatives. It presents decision elements hierarchically by breaking down decision elements into smaller and smaller components from the goal at the top level to criteria and alternatives at the last level (Mysiak et al., 2005).

All alternative agricultural water management schemes of the on-farm pond were assessed and selected by the AHP technique. Basic information of each respondent, which was collected by the field visit and the structured interview, was also applied in the sustainability assessment of alternative schemes. Each alternative scheme had different abilities to fulfill the assessment criteria. The score of each alternative scheme was calculated firstly by combining the relative weight of each sub-criterion, which was derived from the pairwise comparison method, with the score of sustainability classes of each alternative scheme assigned to each sub-criterion. The sum of the weighted scores of the sub-criteria level was then combined with the relative weight of each criterion. The final score of each alternative scheme was calculated by dividing the sum of the weighted scores of the criteria level by 100 (Mendoza et al., 1999). It reflected the sustainability of each alternative scheme. The preferred alternative scheme was prioritized among criteria and acquired the highest total score.

The study did not group respondents based on the size of the area of holding since most of respondents or 92% possessed 5 rais and over. While, the maximum cultivated area based on the water use efficiency of the on-farm pond with 1,260 m^3 storage capacity was 8,400 m^2 or only 5.25 rais. Therefore, these alternative schemes were not applicable and could not manage risks of the remaining cultivated area of these respondents.

Respondents were classified into seven groups based on the number of the household members instead. It is related to sub-criterion 2.1 "Food self-sufficiency", which measured the sufficiency of rice products for the annual household consumption of alternative schemes. It is estimated from the assumption of the New Theory that Thai people consume around 200 kilograms of rice per person per year (Chaipattana Foundation, 2014). Therefore, the more the number of the household members, the more the amount of rice required for the annual household consumption.

It also links to sub-criterion 2.2 "The reduction of the cost of living". This sub-criterion determined the percentage of the annual household consumption expenditure for food and beverages, excluding alcoholic, reduced by the rice production for the annual household consumption of alternative schemes. These secondary data were derived from the average monthly expenditure per household by expenditure group and household size of Kalasin province. Kalasin Provincial Statistical Office categorized the average monthly consumption expenditures for food and beverages, excluding alcoholic, by household sizes into four groups. Firstly, the household with one to two household members spent 3,509 baht per month. Secondly, the household with three to four household members spent 5,612 baht per month. Thirdly, the household with five to seven household members spent 7,701 baht per month. Lastly, the household with eight household members and over spent 10,786 baht per month (MICT, 2017). Thus, the greater the number of the household members, the more the monthly consumption expenditure for food and beverages, excluding alcoholic.

Besides, it is related to sub-criterion 2.3 "Household self-sufficiency". This sub-criterion was indicated as the ratio of the net profit received from alternative schemes to the annual household consumption expenditures. These secondary data were also derived from the average monthly expenditure per household by expenditure group and household size of Kalasin province. It was correlated with the household expenditure per month of the respondents, which was collected from the field visits and structured interviews. Kalasin Provincial Statistical Office categorized the average monthly consumption expenditures by household sizes into four groups. Firstly, the household with one to two household members spent 7,765 baht per month. Secondly, the household with three to four household members spent 11,365 baht per month. Thirdly, the household with five to seven household members spent 15,300 baht per month. Lastly, the household with eight household members and over spent 21,088 baht per month (MICT, 2017). Hence, the greater the number of the household member, the greater the monthly consumption expenditures.

Figure 4.9-4.15 show the performance of each alternative scheme to fulfill the assessment criteria and the final score of each alternative scheme of each household size. It found that all alternative schemes of each household size did not have a much different ability to fulfill criterion 1 and 3. While, their ability to fulfill criterion 2 was quite different. Criterion 1 and 3 assessed the performance of each alternative scheme, mainly in terms of its resource use efficiency and productivity. Meanwhile, criterion 2 assessed the performance of each alternative scheme, mainly in terms of its ability to fulfill the household consumption and income generation, which was also related to household sizes and the amount of the household consumption expenditure.

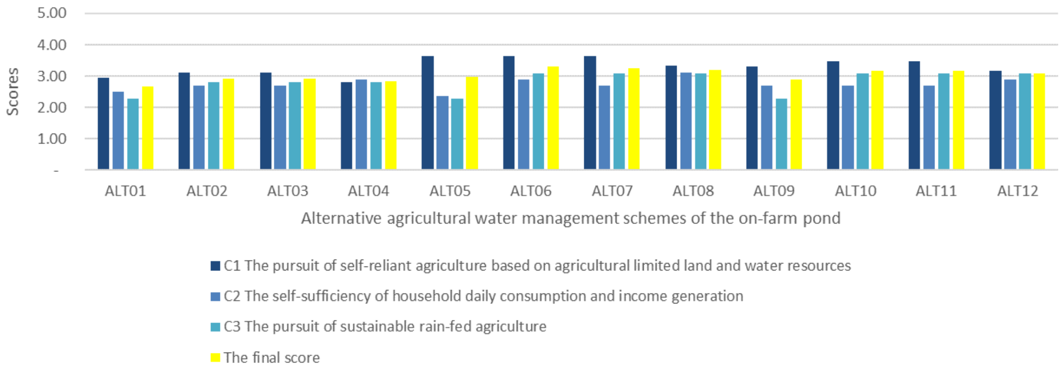

Figure 4.9 The score of each alternative scheme to fulfill established criteria and the final score of each alternative scheme for the household with one household member

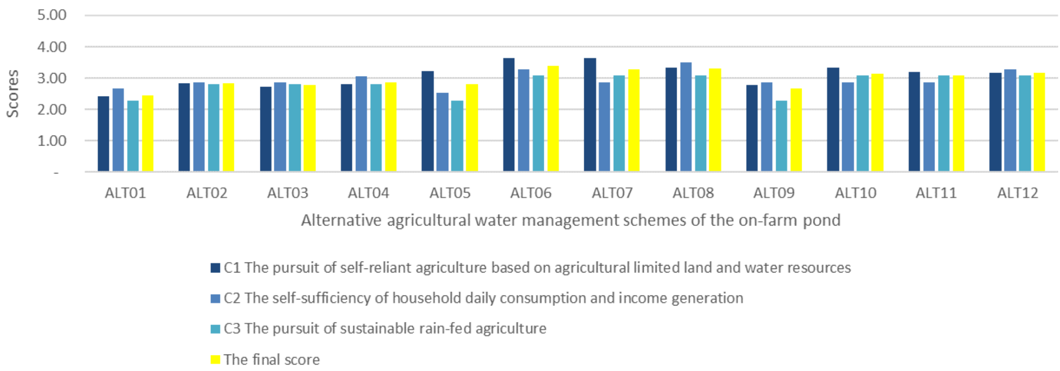

Figure 4.10 The score of each alternative scheme to fulfill established criteria and the final score of each alternative scheme for the household with two household members

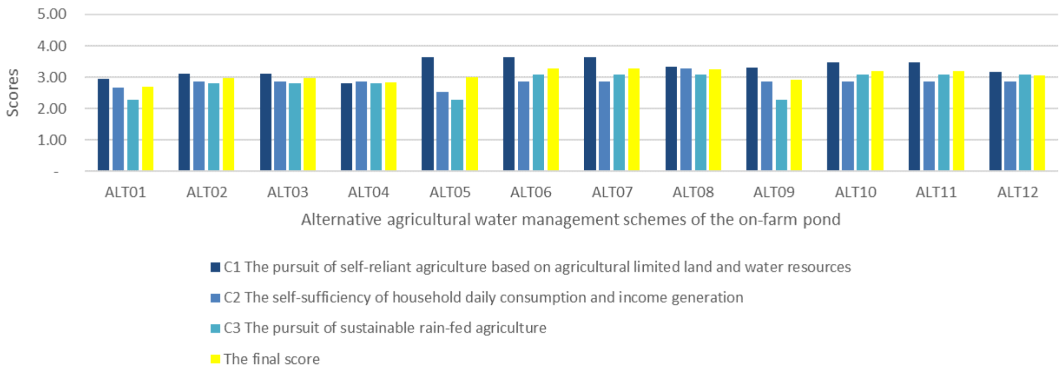

Figure 4.11 The score of each alternative scheme to fulfill established criteria and the final score of each alternative scheme for the household with three household members

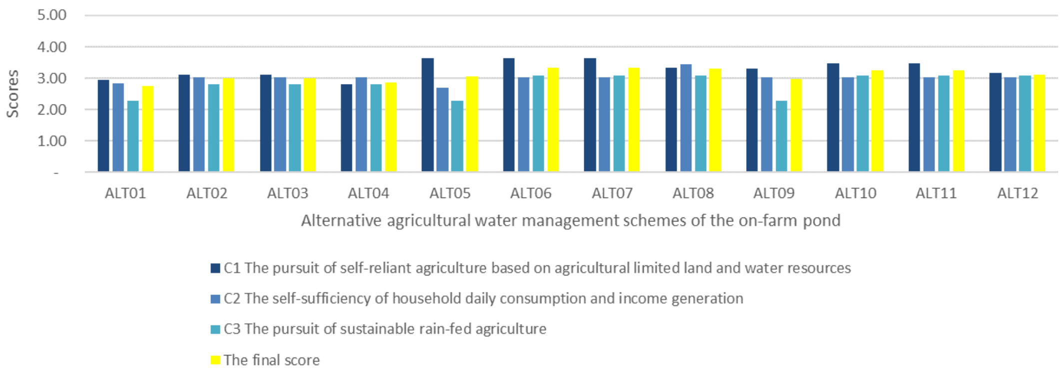

Figure 4.12 The score of each alternative scheme to fulfill established criteria and the final score of each alternative scheme for the household with four household members

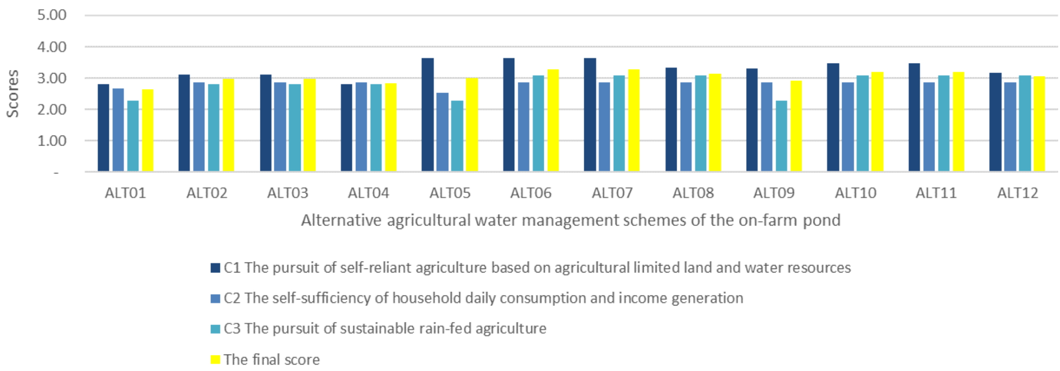

Figure 4.13 The score of each alternative scheme to fulfill established criteria and the final score of each alternative scheme for the household with five household members

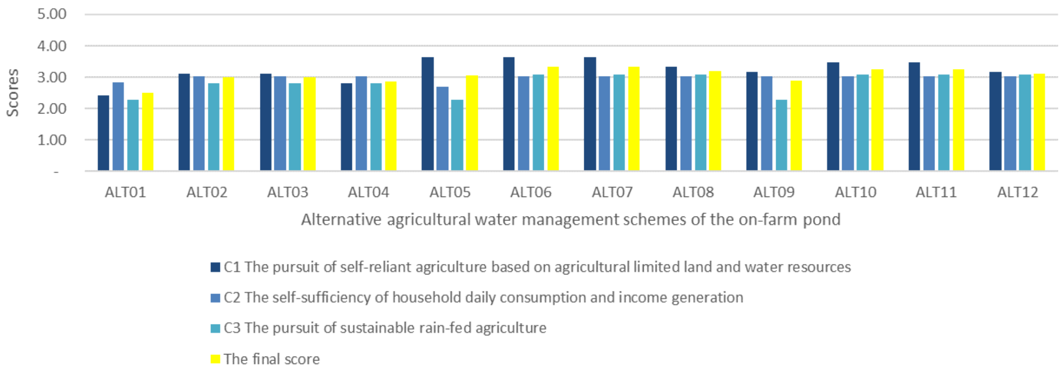

Figure 4.14 The score of each alternative scheme to fulfill established criteria and the final score of each alternative scheme for the household with six household members

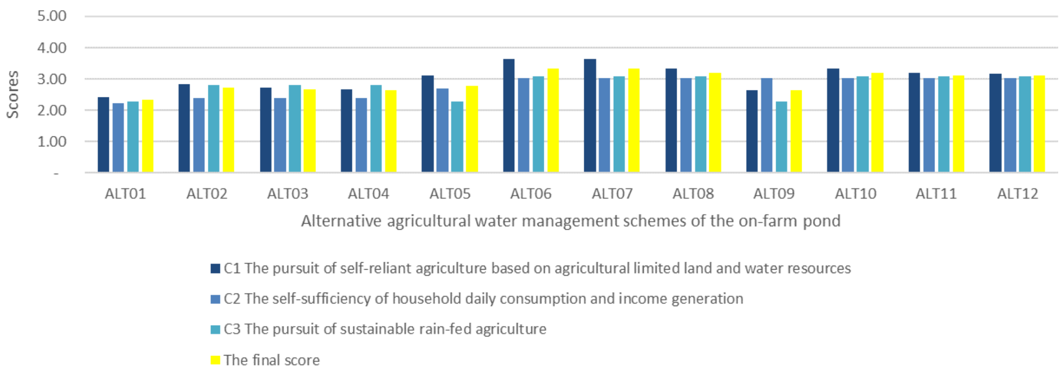

Figure 4.15 The score of each alternative scheme to fulfill established criteria and the final score of each alternative scheme for the household with eight household members

In criterion 1, these alternative schemes did not perform well in sub-criterion 1.2 “Production cost”, since they proposed the whole-year crop production. Besides, their production cost was calculated based on the academic advice in order to optimize crop yields. Therefore, their production cost was unavoidably higher than those of the actual agricultural water management scheme of the on-farm pond of respondents. However, they performed well in sub-criterion 1.3 “Farm productivity”. They proposed the production income which was higher than the actual scheme of respondents. They also performed well in sub-criterion 1.6 “Production cost and benefit”. It shows that although their production cost was high, they were still able to provide a higher production income, which resulted in more production benefits.

Meanwhile, in sub-criterion 1.1 “Land use efficiency”, ALT01, ALT02, ALT03, and ALT04 of each household size maximized the cultivated area less efficiently than the remaining alternative schemes. For sub-criterion 1.5 “Water use efficiency”, it found that ALT05, ALT06, and ALT07 of each household size used the rainwater harvested in the on-farm pond in the dry season more efficiently than the remaining alternative schemes. Whereas, in sub-criterion 1.7 “The diversification of farm production system”, ALT04, ALT08, and ALT12 of each household size were less diverse than the remaining alternative schemes.

For sub-criterion 1.4 “Water productivity”, each alternative scheme of each household size performed differently. It is related to the actual scheme of respondents which was different. Therefore, the production income of each alternative scheme, which increased from the actual scheme of respondents, was inevitably different. This sub-criterion, thus, differentiated the ability of the alternative schemes of respondents.

In criterion 2, all alternative schemes of each household size performed well in sub-criterion 2.1 “Food self-sufficiency”, except ALT01, ALT02, ALT03 and ALT04 of the household with eight household members. These alternative schemes proposed 1,332 kilograms of rice yields per crop. This amount of rice was sufficient for the annual household consumption of the household with a maximum of six household members with some surplus for sale. Therefore, these alternative schemes could not fulfill the annual household consumption of the household with eight household members. For sub-criterion 2.2 “The reduction of the cost of living”, it found that all alternative schemes performed better when the number of household members increased. The more the number of household members, the more the amount of rice consumed as the annual household consumption. Simultaneously, the more the amount of rice consumed as the annual household consumption, the more the amount of the annual household consumption expenditures for food and beverages, excluding alcoholic, was reduced.

Whereas, in sub-criterion 2.3 “Household self-sufficiency”, it found that ALT04, ALT06, and ALT12 were able to make ends meet for the household with a maximum of two household members. While, ALT08 was able to make ends meet for the household with a maximum of four household members. It shows that these alternative schemes could not produce sufficient net profit for the household with five household members and over to spend on their annual household consumption expenditures. The on-farm pond with 1,260 m^3 storage capacity might not support the livelihoods of large households. For sub-criterion 2.4 “Job creation”, ALT05 of each household size proposed the number of months with the household labor employment as less than the remaining alternative schemes. While, in sub-criterion 2.5 “Variability of income generation in terms of time-dispersion”, ALT01 and ALT05 of each household size proposed the number of months with the income generation as less than the remaining alternative schemes. These alternative schemes proposed only two crop productions per year, while the remaining alternative schemes proposed four to five crop productions per year. Therefore, the number of months with the household labor employment and the income generation of these alternative schemes were less than the remaining alternative schemes.

In criterion 3, all alternative schemes of each household size did well in sub-criterion 3.1 “Mixed farming”. They proposed a variety of plant types, including perennial trees and vegetables, in order to fulfill the daily household consumption needs throughout the year. However, these alternative schemes did not perform well in sub-criterion 3.3 “Environmental benefits and services for perennial plants”. Because of the limited amount of the rainwater harvested in the on-farm pond with 1,260 m^3 storage capacity, they proposed only 400 m^2 for perennial plants as a mixed farming above the edge of the on-farm pond. The harvested rainwater was supplied for the lowland major rice cultivation during dry spells and the lowland alternative crop cultivation in the dry season after the major rice cultivation. Meanwhile, in sub-criterion 3.2 “Multiple cropping”, ALT01, ALT05, and ALT09 of each household size performed worse than the remaining alternative schemes, since they proposed only two crop productions per year, which were less than the remaining alternative schemes.

To summarize, for the household with one and two household members, ALT06 had the highest final score. Its range was from 3.30 to 3.40, which was in the medium sustainability class. It was prioritized among the assessment criteria. Therefore, it was the preferred and recommended alternative scheme, compared to other alternative schemes. On the contrary, ALT01 had the lowest final score, compared to other alternative schemes of these household sizes. Its range was from 2.45 to 2.66, which was in the low sustainability class. For the household with three to eight household members, ALT06 and ALT07 had the highest final score. Their range was from 3.29 to 3.33, which was in the medium sustainability class. They were prioritized among the assessment criteria. Hence, they were the preferred and recommended alternative schemes, compared to other alternative schemes. Nevertheless, ALT01 still had the lowest final score, compared to other alternative schemes of these household sizes. Its range was from 2.34 to 2.75, which was in the low sustainability class.

4.3.7 The validation of the preferred alternative agricultural water management schemes of the on-farm pond

The preferred and recommended alternative agricultural water management schemes of the on-farm pond have to be validated as to whether they meet requirements, best achieve the goal, and satisfy the desired condition (Baker et al., 2001). Figure 4.16-4.22 presents the performance of preferred alternative schemes of each household size in detail. ALT06 was the preferred and recommended alternative scheme for the household with one and two household members. While, ALT06 and ALT07 were the preferred and recommended alternative schemes for the household with three to eight household members.

Preferred and recommended alternative schemes were able to meet three requirements of the selected decision support tool. They were planned based on the available rainwater harvested in the on-farm pond with 1,260 m^3 storage capacity. They proposed 8,400 m^2 of the cultivated area for the lowland major rice cultivation in the rainy season and the mixed farming above the edge of the on-farm pond, which was the maximum cultivated area based on the water use efficiency of the on-farm pond. While, in the dry season, they proposed 3,100 m^2 and 2,650 m^2 of the cultivated area, respectively, for the lowland alternative crop cultivation after the major rice cultivation and the mixed farming above the edge of the on-farm pond. They were the two largest cultivated areas in the dry season based on the water use efficiency of the on-farm pond.

Besides, their agricultural activities were selected reasonably based on topographical and sociological conditions of the area. Both ALT06 and ALT07 proposed Gaw Diaw for the lowland major rice cultivation. It is a glutinous rice which is the staple food of respondents. Besides, it can produce the GI product of this area, which is Khao Wong Kalasin sticky rice (MOAC, 2016b; MOC, 2016). Therefore, respondents can sell the surplus from the daily household consumption throughout the year to generate the household income. For the lowland alternative crop cultivation after the major rice cultivation, these alternative schemes proposed sweet corn and peanuts, respectively, as a cash crops for the food processing industry. These cash crops have a local market opportunity in terms of a contract farming with the local middleman. In general, the local middleman agrees to buy these farm products based on the quality standards at a good price guaranteed before the production. Disqualified products can also be sold at local markets. These alternative schemes also proposed seven cash crops for the local market, which were morning glories, chillis, eggplants, pumpkins, luffa gourds, cucumbers, and yard long beans. These cash crops were selected based on the result of the field visits and interviews. It found that most of the respondents grew these vegetables for daily household consumption and for sale at local markets.

Moreover, these alternative schemes did not cause any negative outcome in any sustainability pillars. They proposed an appropriate production time for each crop in order to use the rainfall in the area and the available rainwater harvested in the on-farm pond most efficiently. They also proposed the whole-year crop production, which not only enhanced the land use efficiency in terms of the multiple cropping; but also increased the variability of the household income generation in terms of the time-dispersion. Besides, it provided the household labor employment. In addition, these alternative schemes proposed the amount of rice which was sufficient for the annual household consumption of all household sizes. It reduced the cost of living in terms of the annual household consumption expenditures for food and beverages, excluding alcoholic. However, the net profit, which was proposed by these alternative schemes, was not enough for the large households to spend on their annual household consumption expenditures. Therefore, the on-farm pond with 1,260 m^3 storage capacity might not support the livelihoods of the large households.

These preferred and recommended alternative schemes were also able to achieve the goal of the selected decision support tool. They were selected rationally and systematically through the AHP technique, which is appropriate for the problem with a large number of alternatives and multiple criteria in both quantitative and qualitative (Baker et al., 2001). It is a structured technique for analyzing complex decisions based on mathematics and expert judgement (Adham et al., 2016). Therefore, it is ensured that preferred and recommended alternative schemes were the most sustainable, referenced to the New Theory of His Majesty King Bhumibol Adulyadej The Great. Respondents, who were small semi-subsistence or part-commercial family farms in the rain-fed area, could apply these alternative schemes for managing their limited rainwater harvested in the on-farm pond sufficiently and productively. Consequently, they were able to fulfill their social and economic needs, which will lead to sustainable rain-fed agriculture in Thailand. Thus, the desired condition of the decision support tool was satisfied.

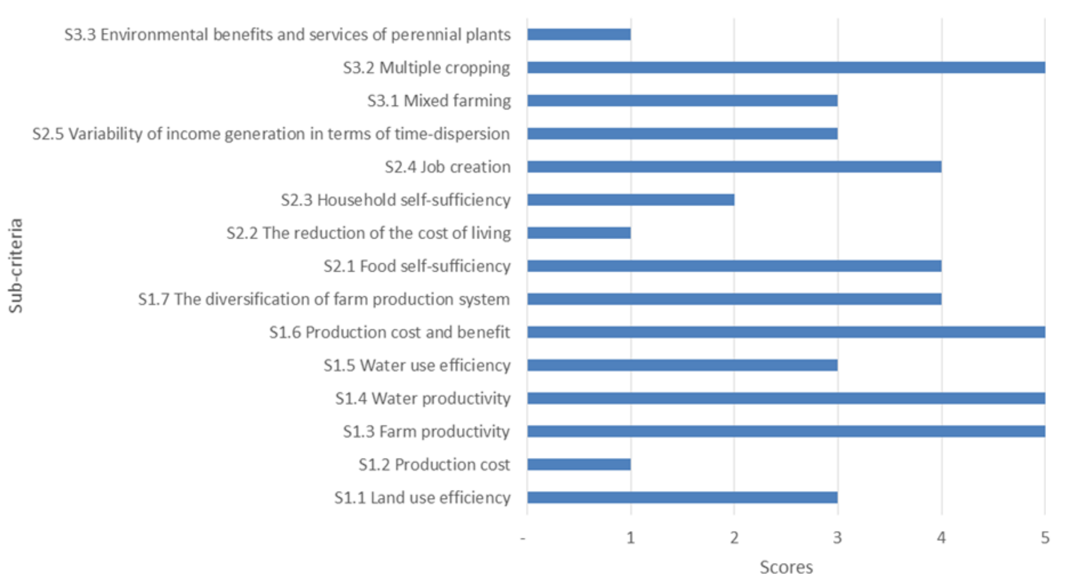

Figure 4.16 The preferred alternative scheme of the household with one household member: ALT06

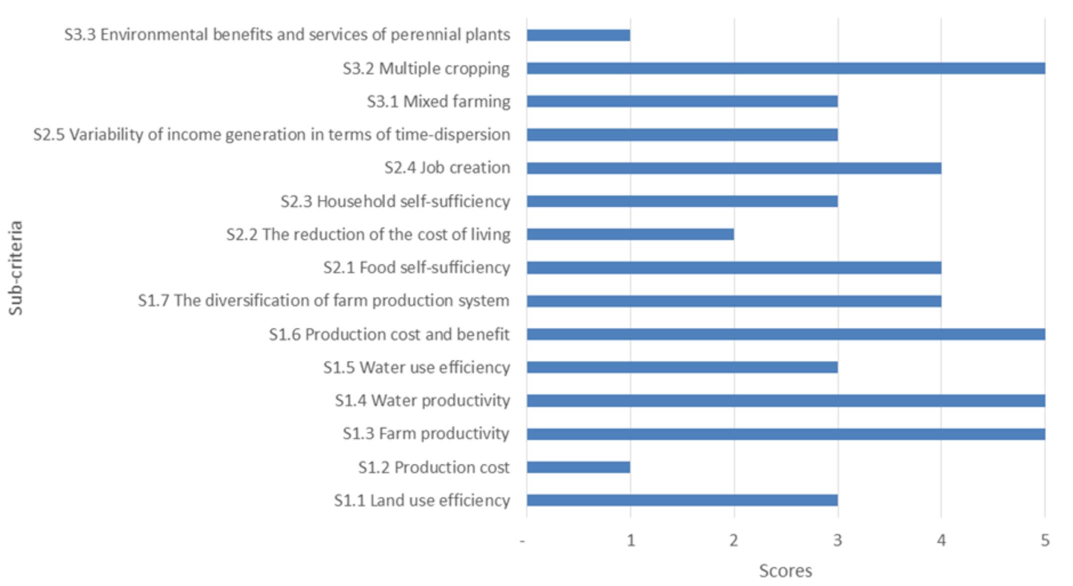

Figure 4.17 The preferred alternative scheme of the household with two household members: ALT06

Figure 4.18 The preferred alternative schemes of the household with three household members: ALT06 and ALT07

Figure 4.19 The preferred alternative schemes of the household with four household members: ALT06 and ALT07

Figure 4.20 The preferred alternative schemes of the household with five household members: ALT06 and ALT07

Figure 4.21 The preferred alternative schemes of the household with six household members: ALT06 and ALT07

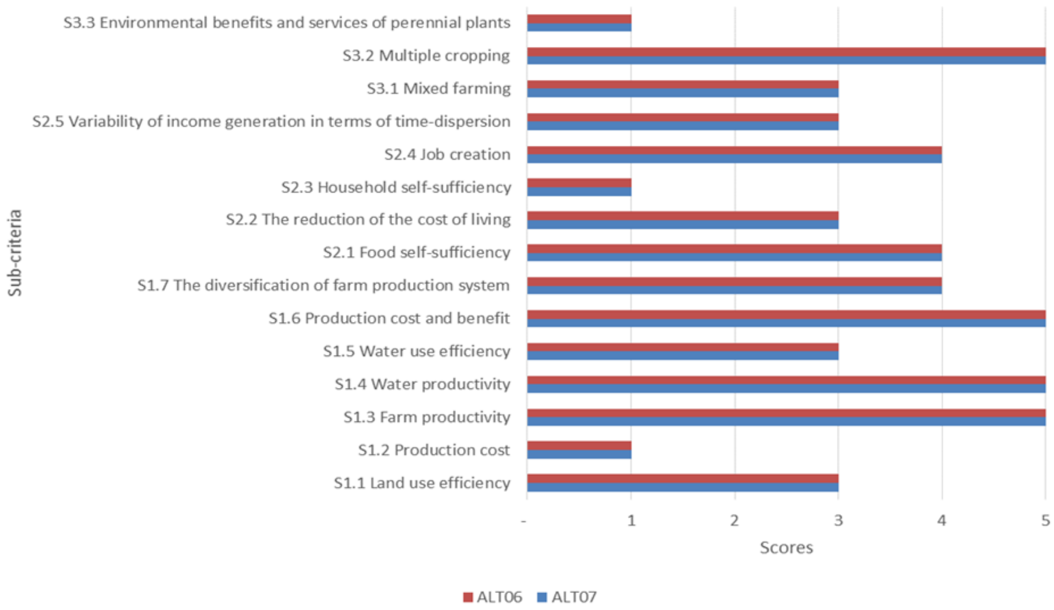

Figure 4.22 The preferred alternative schemes of the household with eight household members: ALT06 and ALT07

4.4 The usability of the selected decision support tool

The selected decision support tool was tested for its usability, in terms of effectiveness, efficiency, and satisfaction, at the study area. The field usability testing examined how the conceptual prototype of the tool fitted into the user's environment for a specific time period and how the user's environment affected the conceptual prototype usage by determining the product functionality and user acceptance. The self-administrated questionnaire was applied in the beta testing in order to collect data about the usability of the tool and recommendations for the further improvement. This method helps respondents, which is the sample group, express their preference and opinions about the tool freely and confidentially (Kumar, 2014).

Table 4.12 presents the usability of the conceptual prototype of the selected decision support tool based on the preference and opinions of respondents, who were the user of the tool, in the beta testing. The results show that the overall usability of the tool was good. The total score from all attributes of the tool was 4.26 out of 5 points.

Table 4.12 The usability of the selected decision support tool

Usability	$\bar{X}$	SD	% of total score
Effectiveness			
1. The tool is able to present the results of the alternative agricultural water management schemes of the on-farm pond accurately	3.76	0.78	75.20
2. The tool is able to present the results of the alternative agricultural water management schemes of the on-farm pond reliably	4.24	0.78	84.80
3. The tool is able to present the results of the alternative agricultural water management schemes of the on-farm pond completely	4.24	0.88	84.80
Efficiency			
4. The tool is able to present the results of the alternative agricultural water management schemes of the on-farm pond sufficiently for making a rational decision	4.08	1.04	81.60
5. The tool is able to present the results of the alternative agricultural water management schemes of the on-farm pond diversely and inclusively in all aspects, including social, economic, and environmental	4.28	0.74	85.60
Satisfaction			
6. The tool is able to present the interesting results of the alternative agricultural water management schemes of the on-farm pond	4.40	0.76	88.00
7. The tool is able to present the results of the alternative agricultural water management schemes of the on-farm pond easily understood	4.04	0.79	80.80
8. The tool is able to present the useful results of the alternative agricultural water management schemes of the on-farm pond for making a rational decision	4.36	0.76	87.20
9. The tool is able to present the alternative agricultural water management schemes of the on-farm pond which are suitable for your interest	4.32	0.69	86.40
10. The tool is able to present the applicable alternative agricultural water management schemes of the on-farm pond	4.40	0.76	88.00
11. The tool is able to support a decision making of agricultural water management of the on-farm pond	4.44	0.82	88.80
12. The tool is able to present the concept of sustainable rain-fed agriculture referenced to the New Theory of His Majesty King Bhumibol Adulyadej The Great	4.40	0.87	88.00
13. Overall, I am satisfied with the selected decision support tool for	4.36	0.76	87.20

Usability	$\bar{X}$	SD	% of total score
sustainable rain-fed agriculture referenced to the New Theory of His Majesty King Bhumibol Adulyadej The Great			
14. I expect to use this tool again in the future for supporting my decision making of selecting alternative agricultural water management schemes of the on-farm pond	4.36	0.81	87.20
Total	**4.26**	**0.80**	**85.26**

4.4.1 Effectiveness

The effectiveness of the selected decision support tool was evaluated in terms of the accuracy, the reliability, and the completeness. The results show that the accuracy of the tool was fair. Its score was 3.76 out of 5 points, which was the lowest score comparing to other attributes of the tool. There were several causes which reduced the accuracy of the tool. Firstly, the primary data about farm production costs and incomes as well as family expenses and other expenditures of each respondent, which were collected by the field visits and structured interviews, was neither enough nor accurate. There was a problem about the data collection since respondents did not have any farm accounting. Moreover, their field management practices were not in accordance with the academic advice. They estimated data from their familiarity and experience. Thus, it was necessary to partially use the available relevant secondary data from government agencies for devising alternative agricultural water management schemes of the on-farm pond based on the academic advice. Although these secondary data were not as exact as the primary data collected from respondents themselves; they were still correlated. Besides, these secondary data were trustworthy and complete.

While, the reliability and the completeness of the tool were good. Their score was 4.24 out of 5 points. Preferred and recommended alternative schemes were selected through the AHP technique which analyzed complex decisions based on mathematics and expert judgement (Adham et al., 2016). Therefore, it enhanced the effectiveness of the tool in terms of reliability and completeness.

4.4.2 Efficiency

The efficiency of the selected decision support tool was evaluated in terms of the sufficiency, the diversity, and the inclusion. The results show that the sufficiency of the tool was good. Its score was 4.08 out of 5 points. Meanwhile, the diversity and inclusion of the tool were also good. Their score was 4.28 out of 5 points. The tool provided enough information about alternative schemes for the respondents to make a rational decision. Besides, the provided information varied and included all aspects, which were economic, social, and environmental. The assessment criteria, sub-criteria, and indicators of the tool helped respondents consider alternative schemes in diverse but inclusive aspects. Furthermore, the tool applied the AHP technique, which is appropriate for the problem with a large number of alternatives and multiple criteria in both quantitative and qualitative (Baker et al., 2001). Hence, respondents were able to make a rational and appropriate selection of the alternative scheme.

4.4.3 Satisfaction

The satisfaction of the selected decision support tool was evaluated in terms of the interest, the ease of understanding, the usefulness, the suitability, the applicability, the decision support, the concept presentation of the sustainable rain-fed agriculture referenced to the New Theory of His Majesty King Bhumibol Adulyadej The Great, the satisfaction, and the expectation for future use. The results show that the decision support of the tool was good. Its score was 4.44 out of 5 points, which was the highest score, compared to other attributes of the tool. Following the same trend, the interest, the applicability, and the concept presentation of the sustainable rain-fed agriculture referenced to the New Theory of His Majesty King Bhumibol Adulyadej The Great of the tool was also good. Their score was 4.40 out of 5 points. It shows that the tool was able to propose not only interesting information but also practical alternative schemes, which respondents could apply in their real life. Moreover, the tool was able to convey the concept of the sustainable rain-fed agriculture referenced to the New Theory of His Majesty King Bhumibol Adulyadej

The Great to respondents. Therefore, they felt that the tool was able to support their selection of the preferred alternative scheme.

Whereas, the usefulness, the satisfaction, and the expectation for the future use of the tool was good. Their score was 4.36 out of 5 points. It implies that respondents noticed that the information provided by the tool was useful for making a rational and appropriate selection of the alternative scheme. In addition, they were satisfied with the tool and expected to use it again in the future. The suitability of the tool was also good. Its score was 4.32 out of 5 points. It shows that the tool suited the interest of the respondents. While, the easy understanding of the tool was good. Its score was 4.04 out of 5 points, which was quite low compared to other attributes of the tool. There were several causes which might diminish the easy understanding of the tool. Firstly, the tool was the conceptual prototype, which was entirely new. Besides, it contained many assessment criteria, sub-criteria, and indicators as well as various alternative schemes. Moreover, it took not only the economic aspect into account, but also the social and environmental aspects. Therefore, it was not easy for respondents to comprehend the interrelation and the balance of these three aspects and the concept of the sustainable rain-fed agriculture referenced to the New Theory of His Majesty King Bhumibol Adulyadej The Great.

4.4.4 Recommendations for further improvement

Respondents did not give any recommendation for the further improvement of the selected decision support tool. It is possible that the tool was the conceptual prototype, which was entirely new. Therefore, respondents were not familiar with the rational and systematic decision-making process. However, based on the results from the beta testing, there were some attributes of the tool which needed to be improved.

It is necessary to enhance the accuracy of the tool. This problem occurred due to the application of the available relevant secondary data from government agencies for devising alternative schemes. Although they were partially used, they were not as precise as the primary data, which were derived from the decision maker. Therefore, it is recommended to provide the farm income and expense worksheet to the decision maker. They were able to record their farm accounting, including farm production costs and incomes as well as family expenses and other expenditures, throughout the year. It will increase the accuracy of the tool.

The ease of use and learnability are also the key attributes of the usability of the tool (ISO, 1998). Therefore, it is essential to develop the tool to be easier to understand and more user-friendly. Meanwhile, it is also vital to maintain the diversity and inclusion of assessment criteria, sub-criteria, and indicators of the tool in all aspects of the sustainable development. As they assessed the sustainability of the alternatives schemes and enabled respondents to make a rational and appropriate selection of the preferred one. Hence, it is recommended to balance these attributes of the tool in order to improve the tool functionality and enhance the user acceptance in the future.

4.5 Appropriate decision support tool for sustainable rain-fed agriculture referenced to the New Theory of His Majesty King Bhumibol Adulyadej The Great

As presented in Figure 4.23, the conceptual prototype of the decision support tool was designed based on the concept of the New Theory which is a guideline for the sustainable agricultural land and water management at the farm level for small farmers who are poor and own a little land in the rain-fed areas of Thailand (Chaipattana Foundation, 2014). This concept makes the tool well-matched with topographical and sociological conditions of Thai rain-fed agriculture. Besides, this concept is established on the concept of the Sufficiency Economy Philosophy, which emphasizes the principle of moderation, reasonableness, and risk management, by using knowledge and virtues to sustain one’s life (Chaipattana Foundation, 2014). It helps these farmers manage their limited agricultural resources sufficiently, rationally, and flexibly to fulfill their social and economic needs, which will lead to sustainable rain-fed agriculture in Thailand.

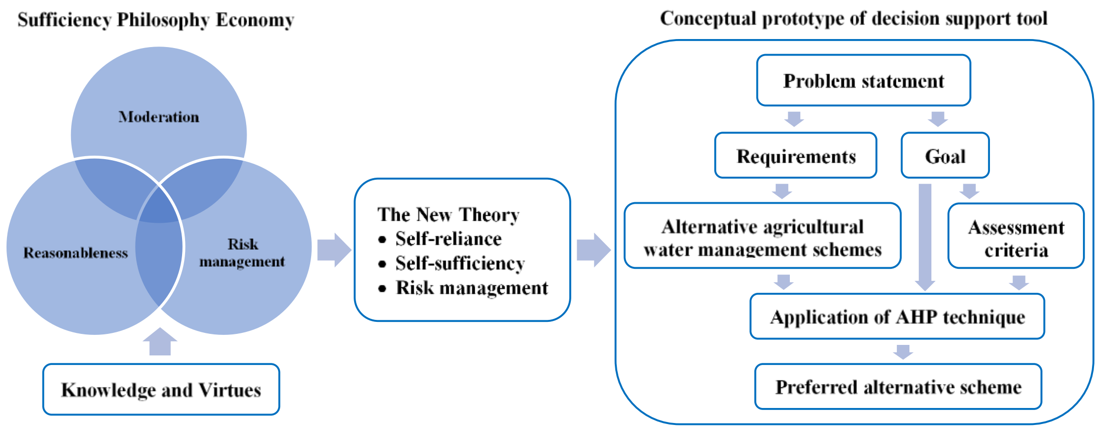

Figure 4.23 Appropriate decision support tool for sustainable rain-fed agriculture referenced to the New Theory of His Majesty King Bhumibol Adulyadej The Great

4.5.1 Components of the conceptual prototype of the decision support tool

Components of the conceptual prototype of the tool comprised the statement problem, requirements, goal, and assessment criteria. They were purposely designed for small semi-subsistence or part-commercial family farms in the rain-fed area of Thailand who were the decision maker of the tool. Their agricultural operating objective was to produce sufficient foods for the daily household consumption and generate cash incomes for the purchase of non-farm produced foods, farm inputs, and other essentials throughout the year (McConnell & Dillon, 1997).

4.5.1.1 Problem of the decision maker

The statement problem of the tool defined the problem of farmers in the rain-fed agricultural area in Thailand which was the imbalance of agricultural water demands and supply. This problem was identified in the desk review and confirmed in the field visit and structured interview of the study (MOAC, 2014; MOAC, 2016; OPM, 1999). The statement problem also proposed the solution to this problem. It is necessary to select the agricultural water management scheme of the on-farm pond which used limited agricultural resources most efficiently and productively. The application of the decision support tool helped the decision maker assess the sustainability of alternative schemes based on the concept of the sustainable agriculture and the New Theory. It ensured that the proposed alternative scheme used limited agricultural resources sufficiently, rationally, and flexibly to fulfill social and economic needs of the household.

4.5.1.2 Requirements of alternative agricultural water management schemes of the on-farm pond

Requirements of the tool were determined based on the concept of the Sufficiency Economy Philosophy, which emphasizes the principle of moderation, reasonableness, and risk management. The moderation of alternative schemes was controlled in terms of the water use based on the amount of rainfall in the area and available rainwater harvested in the on-farm pond with 1,260 m^3 storage capacity. While, the reasonableness of alternative schemes was focused on the selection of agricultural activities and crop types based on topographical and sociological conditions of the area. The risk management of alternative schemes was considered based on the optimal cultivated area of which the on-farm pond with 1,260 m^3 storage capacity was able to manage the water scarcity. These requirements helped the decision maker screen out alternative schemes with the imbalance of agricultural water demands and supply. This problem was often found in in the study area. These requirements also enhanced the agricultural resource use efficiency which enabled the achievement of the sustainable rain-fed agriculture in the study area.

4.5.1.3 Goal of the decision support tool

The goal of the tool was established to ensure that the preferred agricultural water management scheme of the on-farm pond, which was proposed to the decision maker, would not only solve the problem about the imbalance of agricultural water demands and supply; but also, enable the sustainable rain-fed agriculture referenced to the New Theory.

4.5.1.4 Assessment criteria of alternative agricultural water management schemes of the on-farm pond

Assessment criteria of the tool were developed based on topographical and sociological conditions of Thai rain-fed agriculture and goals of the New Theory which emphasizes the self-reliance, the self-sufficiency, and the risk management. There were three criteria and fifteen sub-criteria with the relative importance, weighted by the pairwise comparison method, which were applied in the AHP technique.

Among three criteria, criterion 1 "The pursuit of self-reliant agriculture based on limited agricultural land and water resources" was given the most importance. While, among fifteen sub-criteria, sub-criterion 1.1 "Land use efficiency", sub-criterion 1.5 "Water use efficiency", sub-criterion 2.1 "Food self-sufficiency", sub-criterion 3.1 "Mixed farming", and sub-criterion 3.2 "Multiple cropping" were prioritized as the five most important sub-criteria.

The pursuit of self-reliant agriculture based on limited agricultural land and water resources is the objective of the New Theory (Chaipattana Foundation, 2014). It is a solid foundation for the fulfilment of the remaining criteria and sub-criteria. The self-reliant agriculture can be achieved through mixed farming and multiple cropping, which diversify agricultural activities and disperse the production system throughout the year. It increases the farm productivity which provides adequate foods for the daily household consumption. It also generates cash income from the sale of both food surpluses to the household consumption and cash crops raised specifically for this purpose. It not only uses limited agricultural resources efficiently, balancing farm water demands and supply; but also reduces internal and external risks and uncertainties, which leads to sustainable rain-fed agriculture.

4.5.2 The devising of alternative agricultural water management schemes of the on-farm pond

Alternative schemes were devised based on requirements of the tool. Besides, they needed to fulfill as many criteria as possible. Each alternative scheme had different abilities to fulfill criteria. Agricultural activities of each alternative scheme were selected based on the amount of rainfall in the area and available rainwater harvested in the on-farm pond with 1,260 m^3 storage capacity. Besides, they should comply with the number of household members engaged in the agricultural work of the decision maker. Moreover, they needed to ensure the household food self-sufficiency and income generation.

Meanwhile, crop types proposed in each alternative scheme were selected based on topographical and sociological conditions of each area. There were factors needed to be considered in the selection of crop types. These factors were derived from the desk review and screened out by the expert judgement. They were the household preference for the daily consumption, local crops, cash crops with low water demand and good market price, the crop duration, the crop growing season, crop water requirements throughout the growing season, the coincidence between rainfall and crop water use periods, the production cost, the gross profit, the net profit, and the market price.

These alternative schemes helped the decision maker manage their limited agricultural resources efficiently, and productively to fulfill social and economic needs of the household. Besides, they enabled the decision maker to be self-reliant, self-sufficient, and resilient to internal and external uncertainties, which led to sustainable rain-fed agriculture.

4.5.3 The assessment, selection, and validation of alternative agricultural water management schemes of the on-farm pond

The decision support tool applied the AHP technique as its multi-criteria decision making technique because it is appropriate for the problem with a large number of alternatives and multiple criteria in both quantitative and qualitative (Baker et al., 2001). It is a structured technique for analyzing complex decisions based on mathematics and expert judgement, so inputs of the tool can be obtained from both actual measurements and subjective opinions (Adham et al., 2016). This attribute is appropriate for assessment criteria of the tool which consisted of a variety of measurements and scales of different indicators as presented in Table 4.10. A comparable scale between indicators was identified and applied in the AHP technique in order to make the assessment criteria more objective and reliable for applying in the selected decision support tool.

Alternative agricultural water management schemes were evaluated by assessment criteria through the application of the AHP technique. The score of each alternative scheme reflected its sustainability referenced to the New Theory, in terms of self-reliance, self-sufficiency, and sustainable rain-fed agriculture. The scheme, that was prioritized among criteria and acquired the highest total score, was preferred and recommended for the selection. The preferred alternative scheme was validated with the problem statement, requirements, and goal of the tool. It enabled the balance of agricultural water demands and supply by using limited agricultural resources efficiently and productively to fulfill social and economic needs of the household, which promoted the self-reliant agriculture. It diversified agricultural activities and dispersed the production system throughout the year by mixed farming and multiple cropping, which reduced internal and external uncertainties and enhanced sustainable rain-fed agriculture. It also provided enough foods for the daily household consumption and generated cash income from the sale of both food surpluses to the household consumption and cash crops raised specifically for this purpose, which enable the household self-sufficiency.

4.5.4 The usability of the conceptual prototype of the decision support tool

The conceptual prototype of the decision support tool was tested for its usability, in terms of effectiveness, efficiency, and satisfaction, at the study area. The field usability testing examined how the conceptual prototype of the tool fitted into the user's environment for a specific time period and how the user's environment affected the conceptual prototype usage by determining the tool functionality and user acceptance. The results show that the overall usability of the tool was good. The total score from all attributes of the tool was 4.26 out of 5 points.

The attributes of the conceptual prototype, which had the highest score, was the decision support, following by the interest, the applicability, and the concept presentation. It showed that the tool was able to support a decision making regarding agricultural water management of the on-farm pond. It provided interesting information and practical alternative schemes which the decision maker could apply in real life. It also conveyed the concept of the sustainable rain-fed agriculture referenced to the New Theory of His Majesty King Bhumibol Adulyadej The Great to the decision maker. Data and information proposed by diverse but inclusive assessment criteria evidently helped the decision maker understand aspects of sustainable rain-fed agriculture referenced to the New Theory. Besides, alternative schemes which were devised based on the concept of the New Theory and topographical and sociological conditions of the decision maker, were practical to apply by themselves. Therefore, the tool was able to support the decision maker to select the preferred alternative scheme.

On the contrary, the attributes of the conceptual prototype, which had the lowest score, was the accuracy, following by the ease of use and learnability. They are the key attributes of the usability of the tool (ISO, 1998). On the one hand, it is essential to develop the tool to be easier to understand and more user-friendly. On the other hand, it is vital to maintain the diversity and inclusion of assessment criteria, sub-criteria, and indicators of the tool in all aspects of sustainable rain-fed agriculture referenced to the New Theory. As they assessed the sustainability of alternatives schemes and enabled the decision maker to make a rational and appropriate selection of the preferred one. Hence, it is recommended to balance these attributes of the tool in order to improve the tool functionality and enhance the user acceptance in the future.

CHAPTER V
CONCLUSIONS AND RECOMMENDATIONS

This chapter will be divided into four interrelated parts, starting from a summary of the study, key findings of the study, recommendations from research findings, to suggestions for future research. They will be presented as follows.

5.1 Summary of the study

The study aimed to select an appropriate decision support tool for sustainable rain-fed agriculture referenced to the New Theory of His Majesty King Bhumibol Adulyadej The Great. The decision support tool was purposely designed for farmers in the rain-fed agricultural areas, who were small semi-subsistence or part-commercial family farms. They were the decision makers for the tool. The tool helped them assess the sustainability of their agricultural water management schemes of the on-farm ponds and make a rational and appropriate selection based on the concept of the sustainable agriculture and the New Theory.

In order to acquire the appropriate decision support tool, this research applied mixed methods, both qualitative and quantitative, for collecting data. These methods included the desk review, the field visit, workshops for the expert judgement, the structured interview, and the self-administrated questionnaire. It reviewed literature about the sustainable agriculture, the New Theory of His Majesty King Bhumibol Adulyadej The Great, the agricultural water management of the on-farm pond, the decision making, the new product development, and the usability. Then, the field visit was held in the unirrigated area of Khao Wong district, Kalasin province, which was the study area of this research. It helped better understand information and data obtained from the desk review, specific topographical and sociological conditions of the study area, and the context for which the conceptual prototype of the selected appropriate decision support tool was used.

After that, three workshops for the expert judgement were convened. The expert team was selected from different fields of endeavor or perspectives, including academics, farmers, NGOs, and government officers. They represented experience and expertise in sustainable agriculture, water resource management, the New Theory, and the topographical and sociological conditions of Thailand. The first workshop was convened to reach a consensus about the problem statement, requirements, and the goal of the tool. The second workshop was convened to develop and select the assessment criteria, sub-criteria, indicators, and the classification of values for each indicator in terms of sustainability classes. The third workshop was convened to find out factors affecting the agricultural water management of the on-farm pond. These factors were used for designing the structured interview questions and devising alternative agricultural water management schemes of the on-farm pond.

Then, the structured interview and the self-administrated questionnaire were held at the unirrigated area of Song Plueai sub-district, Khao Wong district, Kalasin province. The sample group of this research comprised 25 agricultural holders with qualified characteristics from Song Plueai sub-district. The structured interview was applied for collecting the data required for devising alternative schemes of the sample group. While, the self-administrated questionnaire was applied for collecting data about the usability of the conceptual prototype of the selected appropriate decision support tool in the beta testing and recommendations for the further improvement.

5.2 Key findings of the study

The key finding of the study was the conceptual prototype of the selected appropriate decision support tool for sustainable rain-fed agriculture referenced to the New Theory of His Majesty King Bhumibol Adulyadej The Great. It was purposely designed for farmers in the rain-fed agricultural area, who were the decision makers of the tool. They did agriculture as small semi-subsistence or part-commercial family farms, which aimed to produce sufficient foods for the daily household consumption and generate cash incomes for the purchase of non-farm produced foods, farm inputs, and other essentials throughout the year.

Components of the tool, including the problem statement, requirements, the goal, assessment criteria, sub-criteria, indicators, and sustainability classes, were set up based on this agricultural operating objective. These components were also established on the concept of the sustainable agriculture and the New Theory in order to make the tool compatible with topographical and sociological conditions of Thai rain-fed agriculture. They were the consensus of the expert team from workshops for the expert judgement.

The problem statement was defined based on the condition and problem of the decision maker of the tool which was the imbalance of farm water demands and supply. It also proposed the solution and desired condition to the problem, which was the application of the decision support tool for selecting preferred alternative agricultural water management scheme of the on-farm pond. It would lead to sustainable rain-fed agriculture referenced to the New Theory, which is the desired condition of the tool. Requirements of the tool were determined based on the concept of the Sufficiency Economy Philosophy, which emphasized the principle of moderation, reasonableness and risk management. These requirements helped the decision maker screen out alternative agricultural water management schemes with the imbalance of farm water demands and supply as well as the agricultural resource use inefficiency. While, the goal of the tool was established to ensure that the preferred alternative scheme would help the decision maker solve the problem about the imbalance of farm water demands and supply and enable the sustainable rain-fed agriculture.

Assessment criteria were developed based on topographical and sociological conditions of Thai rain-fed agriculture and goals of the New Theory. They helped the decision maker evaluate the sustainability of agricultural water management schemes referenced to the New Theory and select the preferred one which used the limited harvested rainwater most efficiently and productively to fulfill needs of the household. There were three criteria and fifteen sub-criteria. Among three criteria, criterion 1 “The pursuit of self-reliant agriculture based on limited agricultural land and water resources” was given the most importance. While, among fifteen sub-criteria, sub-criterion 1.1 “Land use efficiency”, sub-criterion 1.5 “Water use efficiency”, sub-criterion 2.1 “Food self-sufficiency”, sub-criterion 3.1 “Mixed farming”, and sub-criterion 3.2 “Multiple cropping” were prioritized as the five most important sub-criteria.

While, alternative agricultural water management schemes were devised based on requirements of the tool. It took the amount of rainfall in the area and available rainwater harvested in the on-farm pond with 1,260 m^3 storage capacity into account in order to balance farm water demands and supply. Besides, agricultural activities in alternative schemes were selected to ensure the household food self-sufficiency and income generation. At the same time, it is necessary to comply with the number of household members engaged in the agricultural work of the decision maker in order to enhance the self-reliant agriculture. Meanwhile, crop types proposed in each alternative scheme needed to be selected based on topographical and sociological conditions of each area. There were factors needed to be considered in the selection of crop types, including the household preference for the daily consumption, local crops, cash crops with low water demand and good market price, the crop duration, the crop growing season, crop water requirements throughout the growing season, the coincidence between rainfall and crop water use periods, the production cost, the gross profit, the net profit, and the market price. These factors were derived from the desk review and screened out by the expert judgement.

The decision support tool applied the AHP technique as its multi-criteria decision-making technique. It used assessment criteria to evaluate alternative schemes. The score of each alternative scheme reflected its sustainability referenced to the New Theory. The scheme, that was prioritized among criteria and acquired the highest total score, was preferred and recommended for the selection. The preferred alternative scheme was validated with the problem statement, requirements, and goal of the tool. It enabled the balance of agricultural water demands and supply by using limited agricultural resources efficiently and productively to fulfill social and economic needs of the household, which promoted the self-reliant agriculture. It diversified agricultural activities and dispersed the production system throughout the year by mixed farming and multiple cropping, which reduced internal and external uncertainties and enhanced sustainable rain-fed agriculture. It also provided enough foods for the daily household consumption and generated cash income from the sale of both food surpluses to the household consumption and cash crops raised specifically for this purpose, which enable the household self-sufficiency.

The conceptual prototype of the decision support tool was tested for its usability at the study area in order to examine its effectiveness, efficiency, and satisfaction in the user's environment for a specific time period. The result showed that the overall attributes of the tool was good with a total score 4.26 out of 5 points. The attributes of the conceptual prototype, which had the highest score, was the decision support, following by the interest, the applicability, and the concept presentation. On the contrary, the attributes of the conceptual prototype, which had the lowest score, was the accuracy, following by the ease of use and learnability. Therefore, it is necessary to improve these attributes in order to enhance the tool functionality and the user acceptance in the future.

5.3 Recommendations from research findings

The result of the research found that there are some recommended actions for the achievement of the sustainable rain-fed agriculture of Thailand.

5.3.1 Recommendations for agricultural holders

It is recommended that agricultural holders should have a farm and family accounting. It not only enhances the accuracy of the decision support tool. It also helps them realize their financial position, including expenses, incomes, and profits of their farm and household. Besides, it assists them in tracing and assessing the performance of farm activities, which helps them plan their farm activities in the future efficiently and productively.

For agricultural holders who possess more than five rais of the cultivated area or those who have a large household, they should use their local wisdom to increase the storage capacity of their on-farm pond provided by the Land Development Department. The on-farm pond with 1,260 m^3 storage capacity can manage risks from the water scarcity for 8,000 m^2 or five rais of the rice cultivation during dry spells in the rainy season. Its yields cannot fulfill the annual household consumption expenditures of the large household. Hence, in cases where the soil characteristics of the area are appropriate, they should dredge up their on-farm pond to a four-meter depth as per the advice of the New Theory. It increases the storage capacity without any further loss of their productive land. Meanwhile, if possible, they should also expand their on-farm pond to be large enough to fulfill the year-round farm water requirements and match the size of their available cultivated area, which optimizes the resource use efficiency. Besides, a larger storage capacity increases opportunities for agricultural holders to be self-reliant and self-sufficient in their annual household consumption and income generation.

In addition, it is suggested that agricultural holders should reduce the water losses in the rainwater harvesting system since higher temperatures lead to an increase in the evaporation. Therefore, they should grow perennial trees above the edge of the on-farm pond and aquatic plants in the on-farm pond to reduce evaporation loss from the on-farm pond. Moreover, they should improve the water distribution system to reduce water losses through the distribution. Furthermore, they should apply the irrigation techniques which use water efficiently, including the sprinkler irrigation and the drip irrigation. Although, these irrigation methods are costlier than the surface irrigation which they are currently using. They save more water than the conventional method. Besides, they should supply the amount of water which complies with actual crop water requirements.

Moreover, it is advised that agricultural holders should select crops with a low water requirement and a short growing season or drought-tolerant crops. They consume less water and better adapt to the unpredictable weather and water shortages, which reduce risks from the crop failure and enhances the output per drop of water. Besides, they should plan the coincidence between rainfall periods and crop water use periods, so they can use the rainfall more beneficially and optimize the storage capacity of the on-farm pond. Furthermore, they should improve the soil fertility of the cultivated area. It increases the organic matter and the water holding capacity of the soil, which improves not only crop yields but also water use efficiency.

Furthermore, it is suggested that agricultural holders should unite as groups or cooperatives, which is the second phase of the New Theory. It helps them manage farm inputs, the manpower, the equipment, and farm outputs collaboratively, which reduces production costs and increases the crop production efficiency. Besides, it increases the power of the group in negotiations with the market for both the provision of farm inputs and the sales of farm outputs. Moreover, it enables the setting up of funds for the pond excavation which helps agricultural holders expand the storage capacity of their on-farm pond to match their available cultivated area. It not only optimizes the resource use efficiency; but also ensures household self-sufficiency. United groups also empower them to cooperate with capital providers and external businesses, which is the third phase of the New Theory. This cooperation broadens the occupational networks and economic activities in the community, which enhances sustainably the self-reliance of the community. This process develops the community from a subsistence economy to a commercial one through the application of the full concept of the New Theory.

5.3.2 Recommendations for government agencies

It is recommended that government agencies should not only provide the on-farm pond to agricultural holders. They should also advise them how to manage the water harvested in the on-farm pond efficiently and sufficiently as well as how to balance farm water demands and supply. Besides, they should provide agricultural holders basic and applicable academic knowledge and technology about field management practices for the agricultural water use efficiency, including crop water requirements, the irrigation scheduling, and effective irrigation methods. They should also guide them how to apply the New Theory for managing their agricultural resources in practice efficiently, which helps them practice rain-fed agriculture sustainably.

Moreover, it is suggested that government agencies should update data related to rainfall characteristics, the evaporation, and crop water requirements in Thailand due to the climate variability in recent decades. They should also provide crop water requirements of more crops which are cultivated in Thailand, since there are now around 40 crops which provided values of crop water requirements. These data enhance the accuracy of the agricultural water management scheme of the on-farm pond.

In addition, in order to achieve the second and third phase of the New Theory, it is suggested that government agencies should encourage agricultural holders to unite as groups or cooperatives. It is also advised that government agencies should set up the fund to help the group of agricultural holders expand the storage capacity of their on-farm pond to match their available cultivated area. Meanwhile, they should conduct a feasibility study about the provision of small reservoirs for the community to fill on-farm ponds of agricultural holders in the rain-fed agricultural areas and flood and drought prone areas. It is a part of the full concept of the water resource management of the New Theory, which is "small reservoir filling pond". This concept reduces vulnerabilities from relying only on the rainwater which fills the on-farm pond only once a year during the rainy season. It also reduces risks from the variation of the intra-seasonal or inter-seasonal distribution of the rainfall in the rain-fed areas. Besides, these small reservoirs also reduce impacts from the extreme weather in flood and drought prone areas. Additionally, government agencies should educate and support the group of agricultural holders to process their agricultural products as well as provide them agricultural processing machines and equipment. Agricultural processing extends the shelf life of and adds value to agricultural products, which increases farm and household incomes. Besides, these processing agricultural products reduce the cost of living of agricultural holders, in terms of the annual household consumption expenditures.

5.3.3 Recommendations for non-governmental agencies

It is recommended that non-governmental agencies, including non-profit organizations and private sector, should collaborate with government agencies to disseminate basic and applicable agricultural knowledge and technology as well as the application of the New Theory to agricultural holders. It enables them to manage their limited agricultural resources efficiently and sustainably. Furthermore, they should support agricultural holders to expand their on-farm ponds. The appropriate expansion of the on-farm pond is costly. Besides, it requires experts and engineers, who specialize in the rainwater harvesting system and the on-farm pond excavation, to estimate and balance farm water demands and supply for agricultural holders.

5.4 Suggestions for future research

The selected appropriate decision support tool was purposely designed for farmers in the rain-fed agricultural area, who were small semi-subsistence or part-commercial family farms. Hence, it may not suit farmers in the irrigated area, specialized family farms, commercial family farms, or commercial estates due to different farm types, orientations, and operating objectives. Therefore, future research should modify this decision support tool to conform to other types of farmers. Besides, the assessment criteria of the tool focused mainly on social and economic aspects, so future research should emphasis more on environmental criteria. It will enhance the sustainable agriculture in the rain-fed area of Thailand.

Moreover, the result of the field usability testing showed that the conceptual prototype of the tool was needed to be improved its accuracy, ease of use, and learnability. Thus, future research should enhance the tool functionality in order to increase the performance and applicability of the tool in field realities as well as the user acceptance of the tool in the future. In addition, the conceptual prototype of the tool was tested only with agricultural holders, who acquired the on-farm pond with 1,260 m^3 storage capacity, at Song Plueai sub-district, Khao Wong district, Kalasin province. Therefore, future research should conduct the beta testing in other regions of Thailand as well as with agricultural holders, who acquire the on-farm pond with various storage capacities. It will enhance the accuracy and reliability of the result of the field usability testing.

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APPENDICES

APPENDIX A

SURVEY

The survey of agricultural holders acquiring the on-farm pond with 1,260 m^3 storage capacity of the on-farm pond construction project in the unirrigated area of Kalasin Land Development Station

Remarks The purpose of this survey is to collect data about the on-farm pond with 1,260 m^3 storage capacity which agricultural holders acquired from the on-farm pond construction project in the unirrigated area of Kalasin Land Development Station, Land Development Department. Please answer these questions and tick (✓) an option in response to the following statements.

Part 1 Demographic information

Name..Phone number..

Address No..............Village..........Village No......Sub-district..........................
Khao Wong district, Kalasin province

Location of the on-farm pond Village..........Village No......Sub-district..............
Khao Wong district, Kalasin province

Universal Transverse Mercator (UTM) of the on-farm pond..........................

Part 2 General information of the on-farm pond

1. Which sources of water does your on-farm pond collect water from?

☐1. Rainfall

☐2.Rainfall and other sources of water, such as river, stream, ground water, canal, reservoir, irrigation system, etc.

☐3. There are no sources of water.

2. Does your on-farm pond allow the surface runoff to flow into?

☐1. Yes ☐2. No

3. Does your on-farm pond have a leaking problem and cannot store the water?

☐1. Yes ☐2. No

4. Can you use water stored in the on-farm pond for the whole year?

☐1. Yes ☐2. No

5. If there is a decision support tool for planning the agricultural water management of the on-farm pond, are you interested and willing to participate in the beta testing of the tool?

☐1. Yes ☐2. No

APPENDIX B

INTERVIEW SCHEDULE

Title Planning the agricultural water management of the on-farm pond for sustainable rain-fed agriculture referenced to the New Theory of His Majesty King Bhumibol Adulyadej The Great

Remarks This interview schedule is a part of the development of the selected appropriate decision support tool for sustainable rain-fed agriculture referenced to the New Theory of His Majesty King Bhumibol Adulyadej The Great. The purpose is to apply the acquired data for planning the agricultural water management of the on-farm pond for respondents as well as recommending respondents about the agricultural land and water management referenced to the New Theory for sustainable rain-fed agriculture. The interview schedule consists of 6 parts as below:

Part 1 Demographic information

Part 2 Household member and agricultural workers

Part 3 Sources of capital for agriculture, household expenditure, the sale of agricultural products, and advices from government agencies about the New Theory

Part 4 The usage of area of holding and on-farm pond

Part 5 Production cost, incomes, and net profit

Part 6 Agricultural land and water management referenced to the New Theory for sustainable rain-fed agriculture

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Part 1 Demographic information

1. Name..

2. Address No.................Village.............Village No......Sub-district..............
   Khao Wong district, Kalasin province

3. Phone number.................................... E-mail...

4. Sex

   ☐1. Male ☐2. Female

5. Age...years old

6. Education

   ☐1. No education ☐2. Lower than elementary education

   ☐3. Elementary education ☐4. Secondary education

   ☐5. High school education/Vocational education

   ☐6. High vocational education/Diploma ☐7. Bachelor's degree

   ☐8. Higher than bachelor's degree

   ☐9. Other, please specify...

7. Major occupation (consuming more than half of working hour)

   ☐1. Farmer ☐2. Freshwater culture

   ☐3. Worker ☐4. Employee

   ☐5. Merchant ☐6. Government officer/State-enterprise employee

   ☐7. Household handicraft ☐8. Other, please specify...............................

8. Minor occupation (consuming more than half of working hour)

☐1. Farmer ☐2. Freshwater culture

☐3. Worker ☐4. Employee

☐5. Merchant ☐6. Government officer/State-enterprise employee

☐7. Household handicraft ☐8. Other, please specify..................................

Part 2 Household member and agricultural workers

1. Household member................................person (s)

- Household member in the work-force age (over 13 years old)........person (s)

- Household member engaged in agricultural work per household....person (s)

2. The employment of agricultural workers

2.1 The employment of agricultural workers

☐1. Employ.................person (s) ☐2. Not employ (go to item 2.4 below)

2.2 Types of employment

☐1. Seasonal employment ☐2. Occasional employment

☐3. Permanent employment

2.3 Payment

☐1. Cash......................Baht/day ☐2. Yield ☐3. Cash and yield

2.4 Joint labor for cultivation

☐1. Yes ☐2. No

Part 3 Sources of capital for agriculture, household expenditure, the sale of agricultural products, and advices from government agencies about the New Theory

1. Source of capital

☐1. Personal capital

☐2. Borrowing from.......................................Amount......................Baht

(Bank for Agriculture and Agricultural Cooperatives / Moneylender / Relatives / Village and city fund / Cooperative / Other, please specify.........)

2. Household expenditure per month

☐1. Under 5,000 Baht ☐2. 5,000-10,000 Baht

☐3. 10,001-15,000 Baht ☐4. 15,001-20,000 Baht

☐5. Over 20,000 Baht

3. Sale of agricultural product

☐1. By myself ☐2. By the middleman

☐3. By the farmer's group ☐4. Other, please specify....................

4. Problems about sale of agricultural product

☐1. No ☐2. Yes, please specify...................................

5. Income sufficiency from selling agricultural products

☐1. Sufficiency ☐2. Insufficiency, please specify...................

6. Advices from government agencies about the New Theory

☐1. No

☐2. Yes Source.........................Subject..

Part 4 The usage of area of holding and on-farm pond

1. Area of holding

1.1 Location Village............... Village No................ Sub-district.................
Khao Wong district, Kalasin province

1.2 Universal Transverse Mercator (UTM) of the on-farm pond.................

1.3 Land Tenure (such as title deed, NS3, SK1, rented, and others)
please specify....................................

1.4 Size of the area of holding.......... rai.................. ngan................ square wa

1.5 Accommodation and other purposes...... rai....... ngan.... square wa (3.4)

1.6 Agricultural land.............. rai........ ngan................ square wa (3.1+3.2+3.3)

1.7 Soil quality analysis prior to the cultivation

☐1. No ☐2. Yes, please specify...

2. On-farm pond

2.1 Area for the construction of the on-farm .... rai....... ngan.... square wa

2.2 Size of the on-farm pond width............... meters length.............. meters
depth.......................... meters slope...........................

2.3 The engineering structure of the on-farm pond is able to collect surface runoff flowing into the pond

☐1. Yes ☐2. No

2.4 The highest storage capacity............................... cubic meters (m^3)

2.5 Water level at the end of the rainy season (October)................ meters

2.6 The first time of the water application from the pond month...... year.....

2.7 The height of the pond berm (from the bottom of the pond)........meters

2.8 The highest water level (from the bottom of the pond)....meters month...

2.9 The lowest water level (from the bottom of the pond).....meters month...

2.10 Water quality analysis prior to the cultivation

☐1. No ☐2. Yes, please specify..

2.11 Problems and recommendations about the on-farm pond

☐1. No

☐2. Yes Problem...

Recommendations...

3. The usage of area of holding and on-farm pond

3.1 Area for lowland major rice cultivation and lowland alternative crop cultivation after the major rice cultivation

3.1.1 Lowland major rice cultivation..............rai........ngan....square wa

- Rice variety............................

- Growing season (month)...............................

- Methods of cultivation..................................

- Crop care and maintenance............................

- Supplemental irrigation

☐1. No

☐2. Yes Irrigation methods..

Frequency of irrigation.....................................

Irrigation amount..

- Harvest time (month)..................................

- The average yield.............................kilograms/rai

- The sufficiency of the rice yield for the household consumption

☐1. Sufficiency for the household consumption throughout the year

☐2. Insufficiency for the household consumption throughout the year The provision from other sources (more than one answer is possible)

☐1. Other cultivated areas (which do not apply rainwater harvested in this on-farm pond)

☐2. Buy from the local market

☐3. Other, please specify...

☐3. Sufficiency for the household consumption throughout the year with the surplus for selling

☐4. Other, please specify..

3.1.2 Lowland alternative crop cultivation after the major rice cultivation...................rai..................ngan.............................square wa

- Crop type..............................Crop variety..

- Cultivated area.....................rai...................ngan................square wa

- Growing season (month)..............................

- Methods of cultivation.................................

- Crop care and maintenance...........................

- Irrigation methods...

- Frequency of irrigation..............................

- Irrigation amount..............................

- Harvest time (month)..............................

- The average yield..............................kilograms/rai

- Yields from lowland alternative crop cultivation after the major rice cultivation

☐1. Household consumption ☐2. Sale

☐3. Household consumption and sale ☐4. Other, please specify

3.2 Area for mixed farming..............rai..............ngan..............square wa

- Cropping system ....

3.2.1 Perennial trees

- Plant variety..............................number of trees..............................

- Cultivated area..............rai..............ngan..............square wa

- Methods of cultivation..............................

- Plant care and maintenance..............................

- Irrigation methods..............................

- Frequency of irrigation..............................

- Irrigation amount..............................

- Harvest time (month)..............................

- The average yield..............................kilograms/rai

- Yields from perennial trees

☐1. No yields ☐2. Household consumption

☐3. Household consumption and sale ☐4. Other, please specify

3.2.2 Horticultural crops

- Crop type..................................Crop variety..

- Cultivated area........................rai.......................ngan..................square wa

- Growing season (month)..................................

- Methods of cultivation.....................................

- Crop care and maintenance...............................

- Irrigation methods...

- Frequency of irrigation....................................

- Irrigation amount..

- Harvest time (month)......................................

- The average yield..................................kilograms/rai

- Yields from horticultural crops

☐1. Household consumption ☐2. Sale

☐3. Household consumption and sale ☐4. Other, please specify

3.3 Livestock

3.3.1 Freshwater culture

- Types of aquatic animals.....................number of heads.........................

- Yields from freshwater culture

☐1. Household consumption ☐2. Sale

☐3. Household consumption and sale ☐4. Other, please specify

3.3.2 Rearing poultry

- Types of poultry.................................number of heads.......................

- Supplemental irrigation

☐1. No

☐2. Yes Irrigation methods...

Frequency of irrigation.....................................

Irrigation amount..

- Yields from rearing poultry

☐1. Household consumption ☐2. Sale

☐3. Household consumption and sale ☐4. Other, please specify

3.3.3. Rearing cattle and swine

- Number of heads................... rearing purposes

☐1. Working ☐2. Sale ☐3. Other, please specify........

- Supplemental irrigation

☐1. No

☐2. Yes Irrigation methods...

Frequency of irrigation.....................................

Irrigation amount ....

3.4 Accommodation ....rai ....ngan ....square wa

- Domestic water use

☐1. No ☐2. Yes Please specify ....

3.5 The water use sufficiency from the on-farm pond

☐1. Sufficiency

☐2. Insufficiency Cause ....

Please specify the month (s) with water insufficiency ....

Part 5 Production cost, incomes, and net profit

1. Total net profit from all agricultural activities ....Baht (1.1+1.2+1.3+1.4+1.5+1.6)

1.1 Net profit from lowland major rice cultivation ....Baht (A.- B.)

A. Incomes from lowland major rice cultivation (without expense deduction) ....Baht

B. Expenses from lowland major rice cultivation ....Baht

1.2 Net profit from lowland alternative crop cultivation after the major rice cultivation ....Baht (A.- B.)

A. Incomes from lowland alternative crop cultivation after the major rice cultivation (without expense deduction) ....Baht

B. Expenses from lowland alternative crop cultivation after the major rice cultivation ....Baht

1.3 Net profit from mixed farming.................................Baht (A.- B.)

A. Incomes from mixed farming (without expense deduction)..........Baht

B. Expenses from mixed farming.............................Baht

1.4 Net profit from freshwater culture.................................Baht (A.- B.)

A. Incomes from freshwater culture (without expense deduction)....Baht

B. Expenses from freshwater culture..........................Baht

1.5 Net profit from rearing poultry.................................Baht (A.- B.)

A. Incomes from rearing poultry (without expense deduction)..........Baht

B. Expenses from rearing poultry.............................Baht

1.6 Net profit from rearing cattle and swine..........................Baht (A.- B.)

A. Incomes from rearing cattle and swine (without expense deduction)
............Baht

B. Expenses from rearing cattle and swine...............Baht

1.7 Production cost and incomes spreadsheet

Plant type.................................Plant variety.................................

Cultivated area....................rai....................ngan...............square wa

Growing season (month).....................   Crop duration..............days

Items	Amount	Unit	Price per unit	Total expenses
Material cost				
Seeds/Seedlings/Breedings				
Soil improvement (Lime/Marl)				
Fertilizer				
- Organic fertilizer				
- Inorganic fertilizer: Combination.....................				
Pesticide				
- Insecticides				
- Herbicides				
- Chemicals for plant disease control				
- Plant growth accelerator				
Water irrigation equipment				
-				
-				
-				
Other, please specify				
Total material cost				
Labor cost				
Land preparation				
Transplantation				
Plant caring				
Harvesting				
Processing (Thresh/Milling)				
Other, please specify				
Total labor cost				
Miscellaneous cost				
Agricultural equipment repairs and maintenance				
Machinery rental				
Feeds				
Fuel				
Other, please specify				
Total miscellaneous costs				
Total production costs				
Total production incomes				
Net Profit				

Part 6 Agricultural land and water management referenced to the New Theory for sustainable rain-fed agriculture

1. Local plants

   1.1 Local plants……………………………………………………………

   1.2 Rare plants……………………………………………………………

2. Interesting plants

   2.1 Rice……………………………………………………………

   2.2 Field crops……………………………………………………………

   2.3 Perennial tree……………………………………………………………

   2.4 Horticultural crops……………………………………………………………

   2.5 Ornamental plants and herbs……………………………………………………………

   2.6 Plants for forest, soil, and water management……………………………………………

   2.7 Other, please specify……………………………………………………………

3. Interesting livestock

   3.1 Aquatic animals……………………………………………………………

   3.2 Poultry……………………………………………………………

   3.3 Cattle and swine……………………………………………………………

4. Agricultural land and water management scheme referenced to the New Theory of His Majesty King Bhumibol Adulyadej The Great

   ……………………………………………………………………………………………
   ……………………………………………………………………………………………
   ……………………………………………………………………………………………

Recommendations

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Land readjustment for agricultural water management of the on-farm pond (Please identify cultivated areas as well as farm activities and other activities which apply rainwater harvested in the on-farm pond, including plant types)

APPENDIX C

SELF-ADMINISTRATED QUESTIONNAIRE

Title The usability of the selected appropriate decision support tool for sustainable rain-fed agriculture referenced to the New Theory of His Majesty King Bhumibol Adulyadej The Great

Remarks This self-administrated questionnaire is a part of the development of the selected appropriate decision support tool for sustainable rain-fed agriculture referenced to the New Theory of His Majesty King Bhumibol Adulyadej The Great. The purpose is to evaluate the usability of the conceptual prototype of the selected appropriate decision support tool. The acquired data will be used to improve the selected appropriate decision support tool in the future. The self-administrated questionnaire consists of 3 parts as below:

Part 1 Demographic information

Part 2 The usability of the selected appropriate decision support tool for sustainable rain-fed agriculture referenced to the New Theory of His Majesty King Bhumibol Adulyadej The Great

- Operational definition for the usability testing

  - **Usability** is the extent to which the selected appropriate decision support tool can be used by respondents to make a rational and appropriate selection of the agricultural water management scheme of the on-farm pond with effectiveness, efficiency, and satisfaction

  - **Effectiveness** is the accuracy, reliability, and completeness of the results of the alternative agricultural water management schemes of the on-farm pond, presented by the selected decision support tool, which will be used to support the decision making

- **Efficiency** is the sufficiency, diversity, and inclusion of the results of the alternative agricultural water management schemes of the on-farm pond, presented by the selected decision support tool, which will be used to support the decision making

- **Satisfaction** is the positive attitude of respondents to the usability of the selected decision support tool.

Part 3 Recommendations for further improvement

Part 1 Demographic information

1. Name..

2. Address No.................Village.............Village No.....Sub-district..................
   Khao Wong district, Kalasin province

3. Phone number....................................

Part 2 The usability of the selected appropriate decision support tool for sustainable rain-fed agriculture referenced to the New Theory of His Majesty King Bhumibol Adulyadej The Great

Instruction: Please tick (✓) an option form 1-5 on the rating scale (1 =Very poor 2=Poor 3=Fair 4=Good 5=Very good) in response to the following statements

Usability	Very good	Good	Fair	Poor	Very poor
	5	**4**	**3**	**2**	**1**
Effectiveness					
1.The tool is able to present the results of the alternative agricultural water management schemes of the on-farm pond **accurately**					
2.The tool is able to present the results of the alternative agricultural water management schemes of the on-farm pond **reliably**					
3.The tool is able to present the results of the alternative agricultural water management schemes of the on-farm pond **completely**					
Efficiency					
4.The tool is able to present the results of the alternative agricultural water management schemes of the on-farm pond **sufficiently** for making a rational decision					
5. The tool is able to present the results of the alternative agricultural water management schemes of the on-farm pond **diversely and inclusively in all aspects, including social, economic, and environmental**					
Satisfaction					
6. The tool is able to present the **interesting** results of the alternative agricultural water management schemes of the on-farm pond					
7. The tool is able to present the results of the alternative agricultural water management schemes of the on-farm pond **easily understood**					
8. The tool is able to present the **useful** results of the alternative agricultural water management schemes of the on-farm pond for making a rational decision					
9. The tool is able to present the alternative agricultural water management schemes of the on-farm pond which are **suitable for your interest**					
10. The tool is able to present the **applicable** alternative agricultural water management schemes of the on-farm pond					
11. The tool is able to **support a decision making** of agricultural water management of the on-farm pond					
12. The tool is able to present the concept of **sustainable rain-fed agriculture referenced to the New Theory of His Majesty King**					

Usability	Very good	Good	Fair	Poor	Very poor
	5	4	3	2	1
Bhumibol Adulyadej The Great					
13. Overall, I am **satisfied** with the selected decision support tool for sustainable rain-fed agriculture referenced to the New Theory of His Majesty King Bhumibol Adulyadej The Great					
14. I **expect to use this tool again in the future** for supporting my decision making of selecting alternative agricultural water management schemes of the on-farm pond					

Part 3 Recommendations for further improvement

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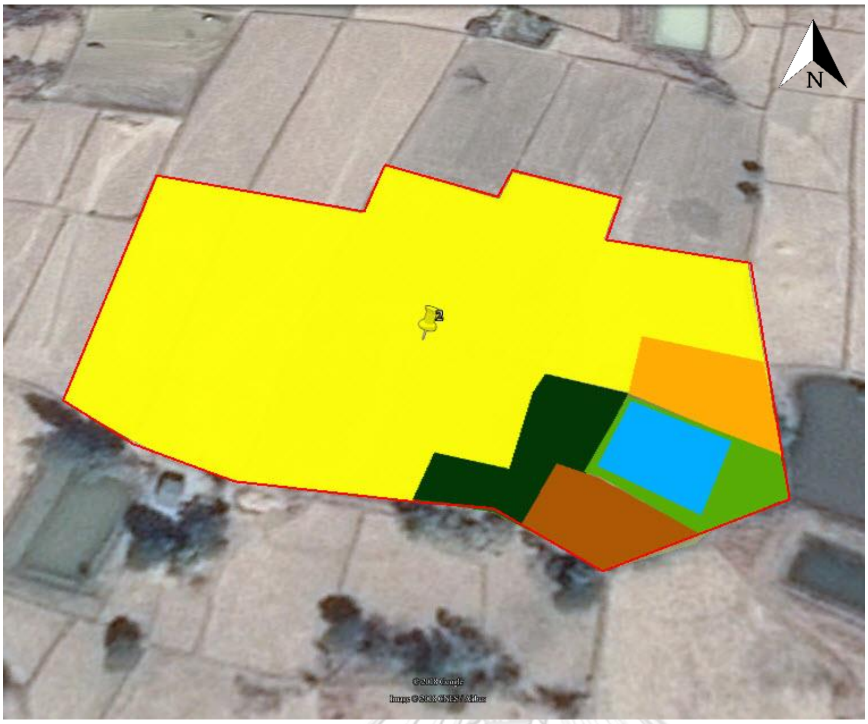
APPENDIX D

MAPS OF THE AREA OF HOLDING OF RESPONDENTS

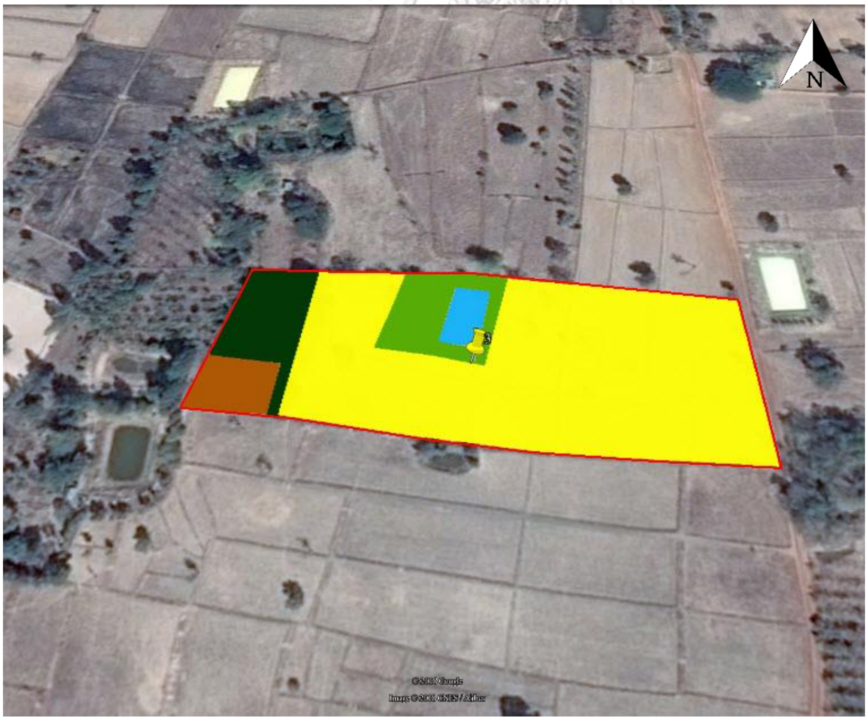
Maps of the area of holding of respondents with details about the agricultural land division for farm activities are represented in colors.

- Accommodation and other purposes
- Upland perennial cash crops
- On-farm pond
- Mixed farming above the edge of the on-farm pond and surrounding
- Upland annual cash crops
- Upland cash crops in the rainy season
- Lowland major rice
- Lowland alternative crops after the major rice cultivation

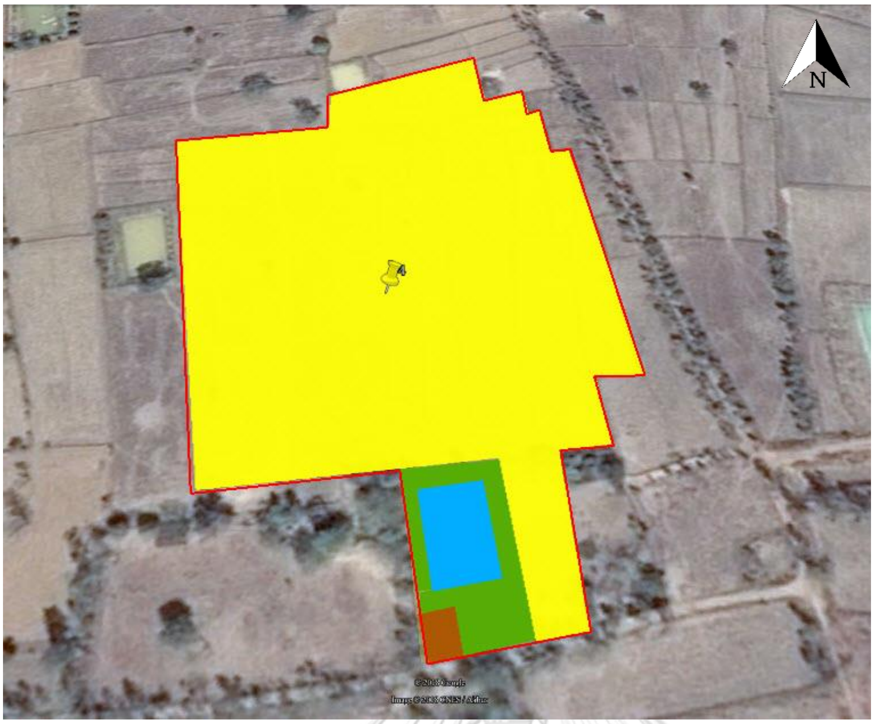
Map of the area of holding of respondent AH01



Map of the area of holding of respondent AH02



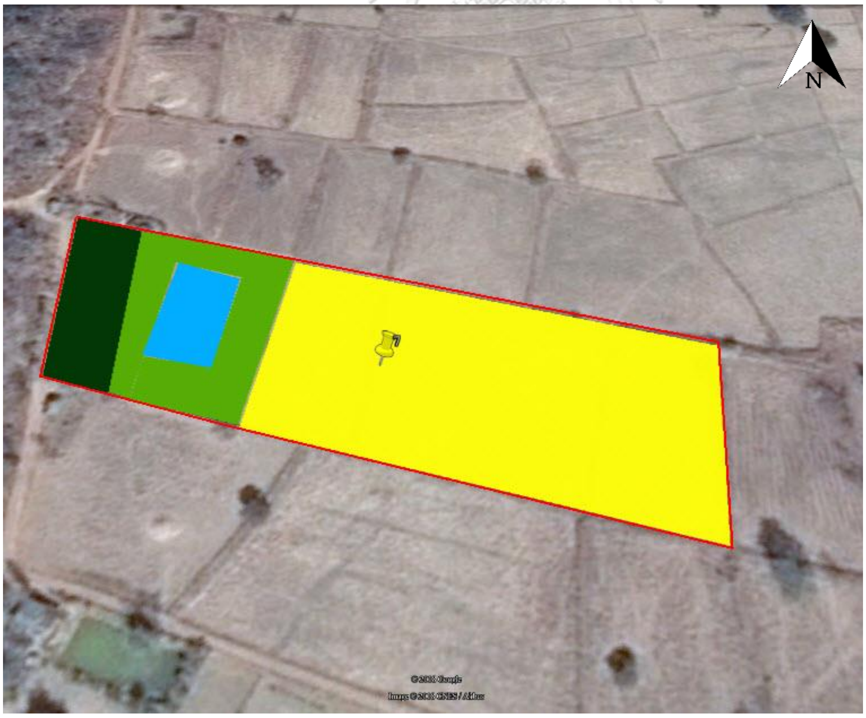
Map of the area of holding of respondent AH03



Map of the area of holding of respondent AH04

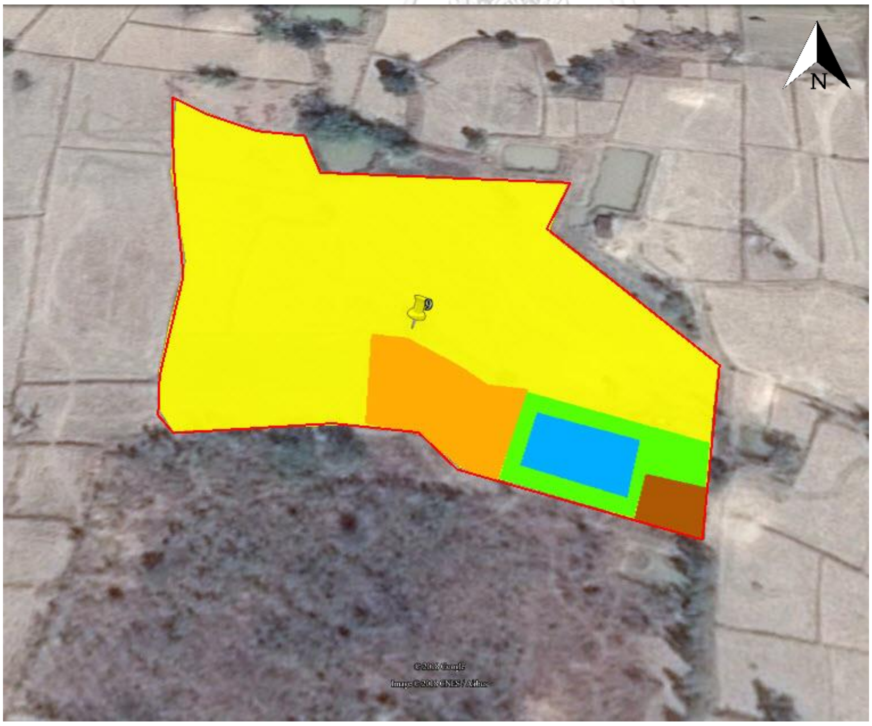
Map of the area of holding of respondent AH05

Map of the area of holding of respondent AH06



Map of the area of holding of respondent AH07

Map of the area of holding of respondent AH08



Map of the area of holding of respondent AH09

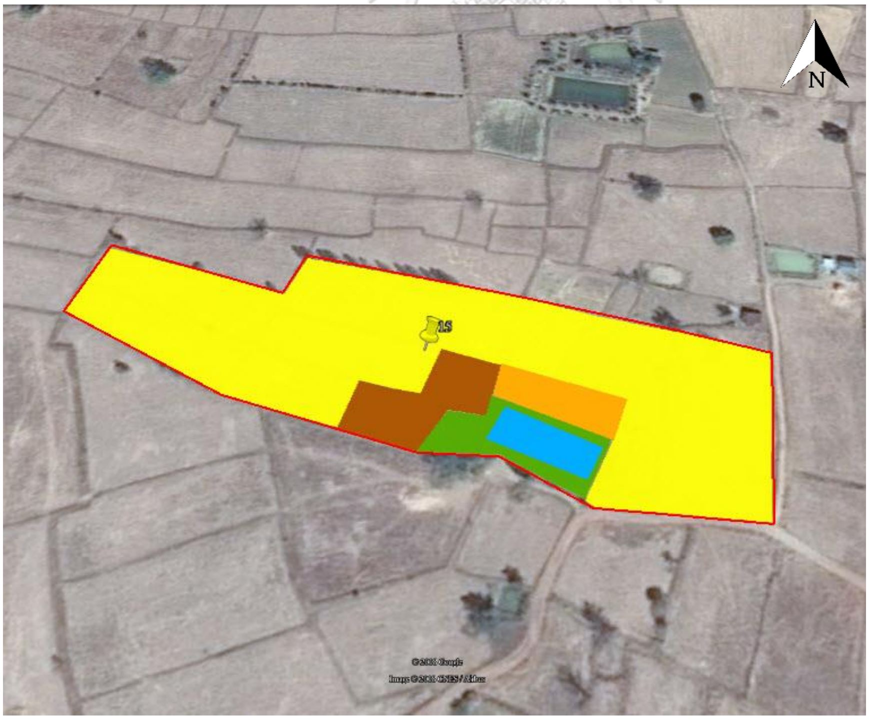
Map of the area of holding of respondent AH10

Map of the area of holding of respondent AH11

Map of the area of holding of respondent AH12

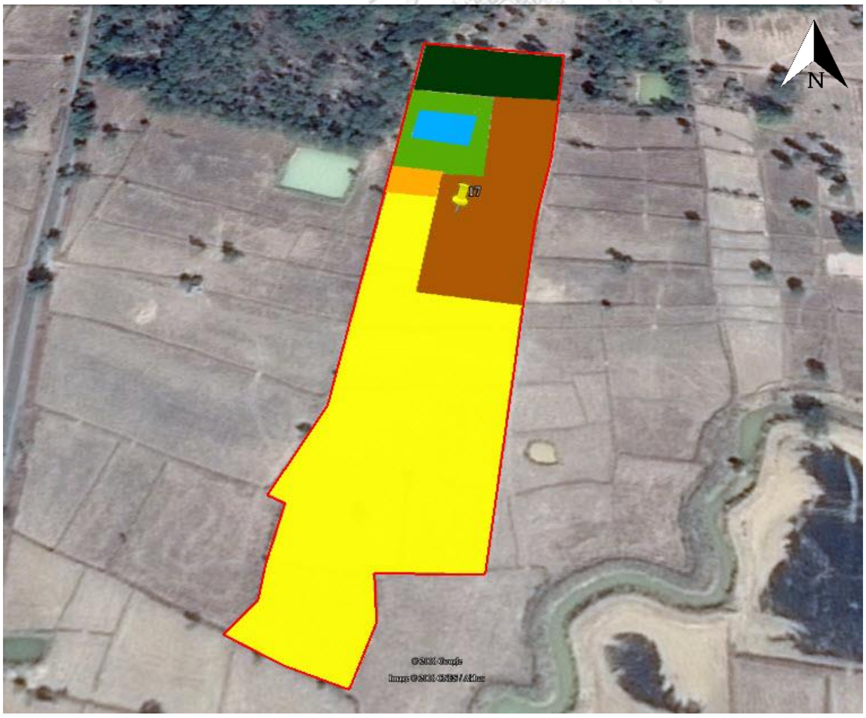
Map of the area of holding of respondent AH13

Map of the area of holding of respondent AH14

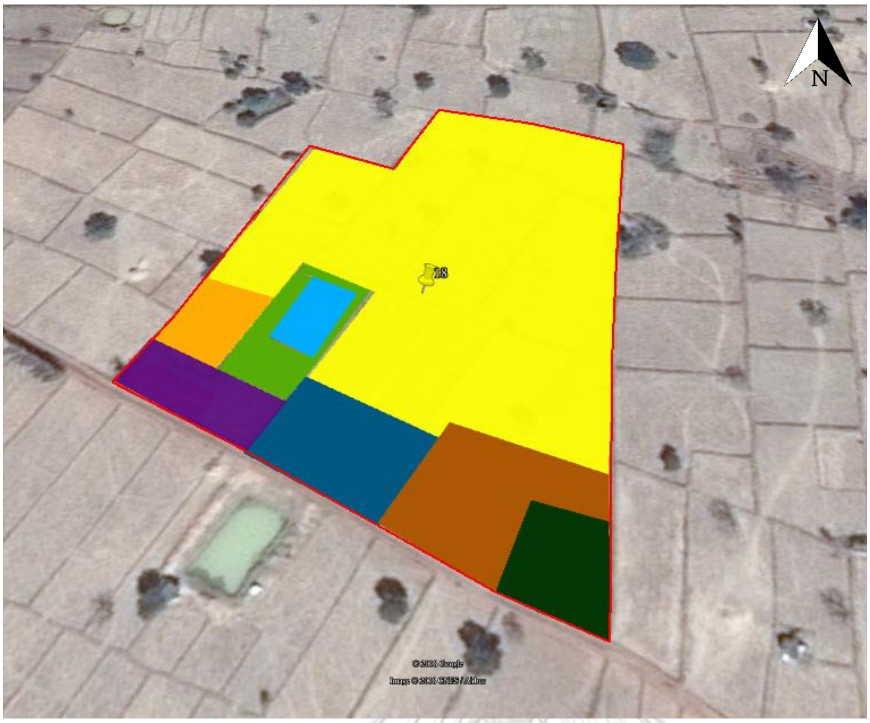


Map of the area of holding of respondent AH15

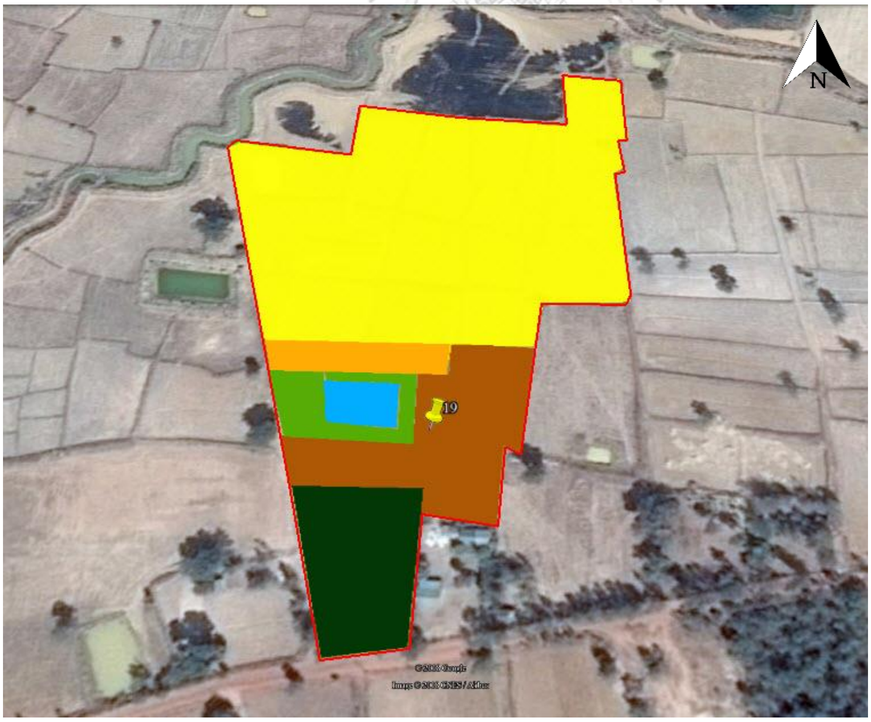
Map of the area of holding of respondent AH16



Map of the area of holding of respondent AH17

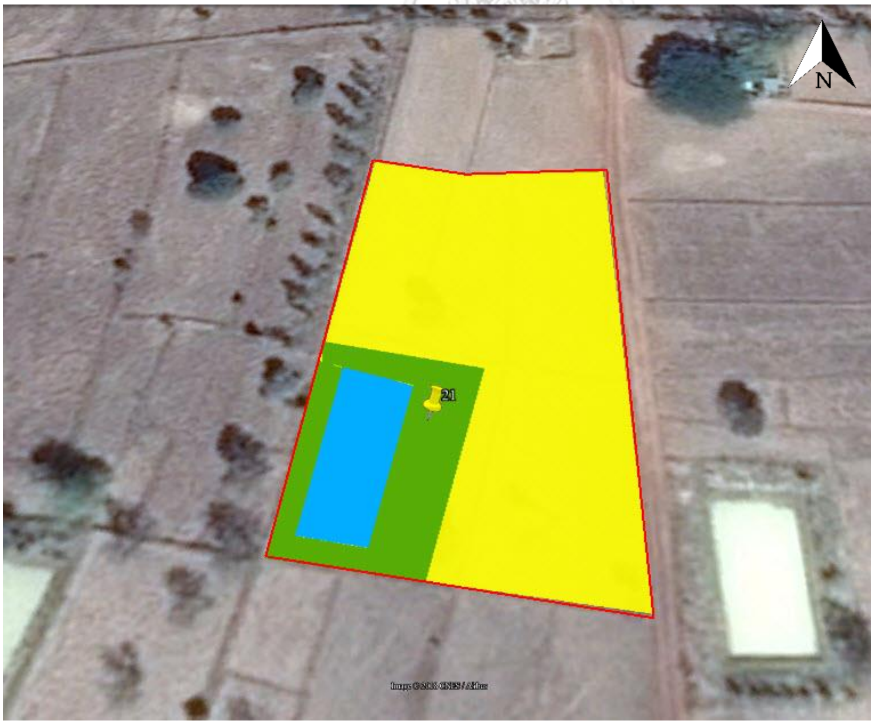


Map of the area of holding of respondent AH18



Map of the area of holding of respondent AH19

Map of the area of holding of respondent AH20



Map of the area of holding of respondent AH21

Map of the area of holding of respondent AH22

Map of the area of holding of respondent AH23

Map of the area of holding of respondent AH24

Map of the area of holding of respondent AH25

APPENDIX E

ACTUAL AGRICULTURAL WATER MANAGEMENT SCHEME OF THE ON-FARM POND OF RESPONDENTS

The actual agricultural water management scheme of the on-farm pond of the respondent AH01

Field No.	Crop types	Cultivated area (m²)	Crop water requirement (m³)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	RD6 glutinous rice	8,000	5,822.71												
2	Multiple cropping	208	224.96												
3	Mixed farming above the edge of the OFP	480	519.15												

Crop duration Yielding period

The actual agricultural water management scheme of the on-farm pond of the respondent AH02

Field No.	Crop types	Cultivated area (m²)	Crop water requirement (m³)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	RD6 glutinous rice	8,000	5,460.45												
2	Gaw Diaw	4,800	1,758.52												
3	RD15 non-glutinous rice	800	411.83												
3	Luffa gourd	300	126.34												
3	Garlic	300	92.09												
3	Sweet potato	200	70.92												
4	Mixed farming above the edge of the OFP	480	519.15												

Crop duration Yielding period

The actual agricultural water management scheme of the on-farm pond of the respondent AH03

Field No.	Crop types	Cultivated area (m²)	Crop water requirement (m³)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	RD6 glutinous rice	12,800	9,935.53												
2	Mixed farming above the edge of the OFP	1,600	1,730.50												

Crop duration Yielding period

The actual agricultural water management scheme of the on-farm pond of the respondent AH04

Field No.	Crop types	Cultivated area (m²)	Crop water requirement (m³)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	RD6 glutinous rice	22,400	16,303.59												
2	Mixed farming above the edge of the OFP	960	1,038.30												

Crop duration Yielding period

The actual agricultural water management scheme of the on-farm pond of the respondent AH05

Field No.	Crop types	Cultivated area (m²)	Crop water requirement (m³)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	RD6 glutinous rice	12,800	9,316.34												
2	Mixed farming above the edge of the OFP	480	519.15												

Crop duration Yielding period

The actual agricultural water management scheme of the on-farm pond of the respondent AH06

Field No.	Crop types	Cultivated area (m²)	Crop water requirement (m³)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	RD20 glutinous rice	17,600	8,117.01												
1	Tomato	480	266.34												
2	Multiple cropping	400	432.62												
3	Mixed farming above the edge of the OFP	1,328	1,436.31												

Crop duration Yielding period

The actual agricultural water management scheme of the on-farm pond of the respondent AH07

Field No.	Crop types	Cultivated area (m²)	Crop water requirement (m³)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	RD6 glutinous rice	6,400	4,658.17												
2	Mixed farming above the edge of the OFP	1,600	1,730.50												

Crop duration Yielding period

The actual agricultural water management scheme of the on-farm pond of the respondent AH08

Field No.	Crop types	Cultivated area (m²)	Crop water requirement (m³)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	RD6 glutinous rice	16,000	9,028.04												
2	Mixed farming above the edge of the OFP	2,560	2,768.80												

Crop duration Yielding period

The actual agricultural water management scheme of the on-farm pond of the respondent AH09

Field No.	Crop types	Cultivated area (m²)	Crop water requirement (m³)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	RD6 glutinous rice	16,000	11,645.42												
1	Tomato	480	260.58												
1	Sweet corn	480	147.42												
1	Peanut	480	207.34												
2	Mixed farming above the edge of the OFP	780	843.62												

Crop duration Yielding period

The actual agricultural water management scheme of the on-farm pond of the respondent AH10

Field No.	Crop types	Cultivated area (m²)	Crop water requirement (m³)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	RD6 glutinous rice	16,000	10,030.19												
1	Multiple cropping	1,600	1,036.68												
2	Mixed farming above the edge of the OFP	1,249	1,350.87												

Crop duration Yielding period

The actual agricultural water management scheme of the on-farm pond of the respondent AH11

Field No.	Crop types	Cultivated area (m²)	Crop water requirement (m³)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	RD6 glutinous rice	28,800	21,122.60												
1	Sweet corn	208	68.88												
1	Chilli	208	89.52												
1	Coriander	208	29.78												
1	Peanut	208	94.10												
2	Mixed farming above the edge of the OFP	2,550	2,757.98												

Crop duration Yielding period

The actual agricultural water management scheme of the on-farm pond of the respondent AH12

Field No.	Crop types	Cultivated area (m²)	Crop water requirement (m³)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	RD6 glutinous rice	9,600	7,040.87												
1	Waxy corn	400	120.72												
1	Pumpkin	208	41.73												
1	Peanut	400	168.75												
2	Mixed farming above the edge of the OFP	1,974	2,135.00												

Crop duration Yielding period

The actual agricultural water management scheme of the on-farm pond of the respondent AH13

Field No.	Crop types	Cultivated area (m²)	Crop water requirement (m³)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	RD6 glutinous rice	6,400	4,693.91												
1	Luffa gourd	208	98.41												
2	Mixed farming above the edge of the OFP	840	908.51												

Crop duration Yielding period

The actual agricultural water management scheme of the on-farm pond of the respondent AH14

Field No.	Crop types	Cultivated area (m²)	Crop water requirement (m³)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	RD6 glutinous rice	1,600	1,173.48												
1	Chilli	96	43.22												
2	Mixed farming above the edge of the OFP	1,658	1,793.23												

Crop duration Yielding period

The actual agricultural water management scheme of the on-farm pond of the respondent AH15

Field No.	Crop types	Cultivated area (m²)	Crop water requirement (m³)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	RD6 glutinous rice	14,400	10,561.30												
1	Sweet corn	800	241.44												
2	Mixed farming above the edge of the OFP	1,307	1,413.60												

Crop duration Yielding period

The actual agricultural water management scheme of the on-farm pond of the respondent AH16

Field No.	Crop types	Cultivated area (m²)	Crop water requirement (m³)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	RD6 glutinous rice	12,800	9,387.82												
2	Mixed farming above the edge of the OFP	1,024	1,107.52												

Crop duration Yielding period

The actual agricultural water management scheme of the on-farm pond of the respondent AH17

Field No.	Crop types	Cultivated area (m²)	Crop water requirement (m³)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	RD6 glutinous rice	11,200	8,214.34												
2	Gaw Diaw	400	215.36												
3	RD15 non-glutinous rice	2,000	1,111.14												
2	Peanut	400	165.61												
4	Mixed farming above the edge of the OFP	1,624	1,756.45												

Crop duration Yielding period

The actual agricultural water management scheme of the on-farm pond of the respondent AH18

Field No.	Crop types	Cultivated area (m²)	Crop water requirement (m³)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	RD6 glutinous rice	8,000	5,867.39												
2	RD15 non-glutinous rice	9,600	5,333.46												
2	Luffa gourd	920	388.73												
3	Multiple cropping	1,190	1,287.06												
4	Yard long bean	920	201.57												
4	Luffa gourd	920	380.73												
5	Mixed farming above the edge of the OFP	1,170	1,265.43												

Crop duration Yielding period

The actual agricultural water management scheme of the on-farm pond of the respondent AH19

Field No.	Crop types	Cultivated area (m²)	Crop water requirement (m³)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	RD6 glutinous rice	22,400	16,428.69												
1	Luffa gourd	1,098	474.23												
2	Mixed farming above the edge of the OFP	1,140	1,232.98												

Crop duration Yielding period

The actual agricultural water management scheme of the on-farm pond of the respondent AH20

Field No.	Crop types	Cultivated area (m²)	Crop water requirement (m³)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	RD6 glutinous rice	19,200	14,081.73												
1	Dry crops (Mixed farming)	562	316.06												
2	Mixed farming above the edge of the OFP	1,170	1,265.43												

Crop duration Yielding period

The actual agricultural water management scheme of the on-farm pond of the respondent AH21

Field No.	Crop types	Cultivated area (m²)	Crop water requirement (m³)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	Gaw Diaw	4,800	2,666.73												
2	Mixed farming above the edge of the OFP	1,024	1,107.52												

Crop duration Yielding period

The actual agricultural water management scheme of the on-farm pond of the respondent AH22

Field No.	Crop types	Cultivated area (m²)	Crop water requirement (m³)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	RD6 glutinous rice	6,400	4,693.91												
2	Mixed farming above the edge of the OFP	1,024	1,107.52												

Crop duration Yielding period

The actual agricultural water management scheme of the on-farm pond of the respondent AH23

Field No.	Crop types	Cultivated area (m²)	Crop water requirement (m³)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	RD6 glutinous rice	16,000	11,734.78												
2	Mixed farming above the edge of the OFP	1,707	1,846.22												

Crop duration Yielding period

The actual agricultural water management scheme of the on-farm pond of the respondent AH24

Field No.	Crop types	Cultivated area (m²)	Crop water requirement (m³)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	RD6 glutinous rice	11,200	8,214.34												
2	Mixed farming above the edge of the OFP	824	891.21												

Crop duration   Yielding period

The actual agricultural water management scheme of the on-farm pond of the respondent AH25

Field No.	Crop types	Cultivated area (m²)	Crop water requirement (m³)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	RD6 glutinous rice	6,400	4,693.91												
2	Mixed farming above the edge of the OFP	309	334.20												

Crop duration   Yielding period

APPENDIX F

ALTERNATIVE AGRICULTURAL WATER MANAGEMENT SCHEMES OF THE ON-FARM POND OF RESPONDENTS

The alternative agricultural water management scheme of the on-farm pond ALT01

Field No.	Crop types	Cultivated area (m^2)	Crop water requirement (m^3)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	RD6 glutinous rice	3,200	2,483.88												
1	Sweet corn	500	156.69												
1	Peanut	400	172.79												
1	Tomato	400	231.53												
2	Mixed farming above the edge of the OFP	400	432.62												

Crop duration (green) — Yielding period (yellow)

The alternative agricultural water management scheme of the on-farm pond ALT02

Field No.	Crop types	Cultivated area (m^2)	Crop water requirement (m^3)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	RD6 glutinous rice	3,200	2,483.88												
1	Sweet corn	700	219.36												
1	Morning glory	200	72.78												
1	Chilli	200	90.04												
1	Eggplant	100	44.55												
1	Pumpkin	200	41.48												
1	Luffa gourd	100	47.31												
1	Cucumber	100	40.71												
1	Yard long bean	150	36.99												
2	Mixed farming above the edge of the OFP	400	432.62												

Crop duration (green) — Yielding period (yellow)

The alternative agricultural water management scheme of the on-farm pond ALT03

Field No.	Crop types	Cultivated area (m^2)	Crop water requirement (m^3)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	RD6 glutinous rice	3,200	2,483.88												
1	Peanut	500	215.98												
1	Morning glory	200	72.78												
1	Chilli	200	90.04												
1	Eggplant	100	44.55												
1	Pumpkin	200	41.48												
1	Luffa gourd	100	47.31												
1	Cucumber	100	40.71												
1	Yard long bean	150	36.99												
2	Mixed farming above the edge of the OFP	400	432.62												

Crop duration (green) — Yielding period (yellow)

The alternative agricultural water management scheme of the on-farm pond ALT04

Field No.	Crop types	Cultivated area (m²)	Crop water requirement (m³)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	RD6 glutinous rice	3,200	2,483.88												
1	Tomato	400	226.77												
1	Morning glory	200	72.78												
1	Chilli	150	67.53												
1	Eggplant	150	66.82												
1	Pumpkin	200	41.48												
1	Luffa gourd	100	47.31												
1	Cucumber	100	40.71												
1	Yard long bean	100	24.66												
2	Mixed farming above the edge of the OFP	400	432.62												

Crop duration Yielding period

The alternative agricultural water management scheme of the on-farm pond ALT05

Field No.	Crop types	Cultivated area (m²)	Crop water requirement (m³)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	Gaw Diaw	8,000	4,781.34												
1	Sweet corn	900	266.35												
1	Peanut	600	241.07												
1	Tomato	600	319.40												
2	Mixed farming above the edge of the OFP	400	432.62												

Crop duration Yielding period

The alternative agricultural water management scheme of the on-farm pond ALT06

Field No.	Crop types	Cultivated area (m²)	Crop water requirement (m³)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	Gaw Diaw	8,000	4,781.34												
1	Sweet corn	1,600	473.51												
1	Morning glory	200	95.17												
1	Chilli	200	95.55												
1	Eggplant	150	61.87												
1	Pumpkin	200	38.91												
1	Luffa gourd	100	43.19												
1	Cucumber	100	36.98												
1	Yard long bean	150	33.86												
2	Mixed farming above the edge of the OFP	400	432.62												

Crop duration Yielding period

The alternative agricultural water management scheme of the on-farm pond ALT07

Field No.	Crop types	Cultivated area (m²)	Crop water requirement (m³)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	Gaw Diaw	8,000	4,781.34												
1	Peanut	1,200	482.14												
1	Morning glory	200	95.17												
1	Chilli	200	95.55												
1	Eggplant	150	61.87												
1	Pumpkin	150	29.19												
1	Luffa gourd	100	43.19												
1	Cucumber	100	36.98												
1	Yard long bean	150	33.86												
2	Mixed farming above the edge of the OFP	400	432.62												

Crop duration   Yielding period

The alternative agricultural water management scheme of the on-farm pond ALT08

Field No.	Crop types	Cultivated area (m²)	Crop water requirement (m³)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	Gaw Diaw	8,000	4,781.34												
1	Tomato	900	470.42												
1	Morning glory	200	95.17												
1	Chilli	200	95.55												
1	Eggplant	150	61.87												
1	Pumpkin	150	29.19												
1	Luffa gourd	100	43.19												
1	Cucumber	100	36.98												
1	Yard long bean	200	45.15												
2	Mixed farming above the edge of the OFP	400	432.62												

Crop duration   Yielding period

The alternative agricultural water management scheme of the on-farm pond ALT09

Field No.	Crop types	Cultivated area (m²)	Crop water requirement (m³)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	RD6 glutinous rice	1,600	1,241.94												
2	Gaw Diaw	6,400	3,825.07												
2	Sweet corn	500	147.97												
2	Peanut	400	160.71												
2	Tomato	400	212.94												
3	Mixed farming above the edge of the OFP	400	432.62												

Crop duration   Yielding period

The alternative agricultural water management scheme of the on-farm pond ALT10

Field No.	Crop types	Cultivated area (m²)	Crop water requirement (m³)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	RD6 glutinous rice	1,600	1,241.94												
2	Gaw Diaw	6,400	3,825.07												
2	Sweet corn	800	236.75												
2	Morning glory	150	71.38												
2	Chilli	150	71.66												
2	Eggplant	150	61.87												
2	Pumpkin	150	29.19												
2	Luffa gourd	100	43.19												
2	Cucumber	100	36.98												
2	Yard long bean	100	22.57												
3	Mixed farming above the edge of the OFP	400	432.62												

Crop duration   Yielding period

The alternative agricultural water management scheme of the on-farm pond ALT11

Field No.	Crop types	Cultivated area (m²)	Crop water requirement (m³)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	RD6 glutinous rice	1,600	1,241.94												
2	Gaw Diaw	6,400	3,825.07												
2	Peanut	600	241.07												
2	Morning glory	150	71.38												
2	Chilli	150	71.66												
2	Eggplant	150	61.87												
2	Pumpkin	150	29.19												
2	Luffa gourd	100	43.19												
2	Cucumber	100	36.98												
2	Yard long bean	100	22.57												
3	Mixed farming above the edge of the OFP	400	432.62												

Crop duration   Yielding period

The alternative agricultural water management scheme of the on-farm pond ALT12

Field No.	Crop types	Cultivated area (m²)	Crop water requirement (m³)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	RD6 glutinous rice	1,600	1,241.94												
2	Gaw Diaw	6,400	3,825.07												
2	Tomato	400	209.07												
2	Morning glory	150	71.38												
2	Chilli	150	71.66												
2	Eggplant	150	61.87												
2	Pumpkin	150	29.19												
2	Luffa gourd	150	64.79												
2	Cucumber	100	36.98												
2	Yard long bean	150	33.86												
3	Mixed farming above the edge of the OFP	400	432.62												

Crop duration   Yielding period

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