

## **CHAPTER 3**

### **RESEARCH METHODS**

In this study, citrus-based farming systems were used to gather information related to their demographic, bio-physical and socio-economic factors to attain the objectives. The combination of qualitative and quantitative data analysis was applied to explore the citrus-based farming systems levels and the problems faced by citrus-based farmers.

#### **3.1 Conceptual framework for the study**

This study used a system research method which consisted of the system boundaries and hierarchies in the Fang watershed. This was broken down into the farm and watershed levels. The sustainability and system properties were the three pillars of evaluation consisting of the economic, the social and the environmental factors which resulted in five properties of sustainable systems which were productivity, autonomy, social contribution, stability and resilience. Subsequent indicators are developed at the farm and the watershed levels for each property in the sustainable systems. The indicators at each level used the goal constraints and determined the weigh values. The study will use the Analytic Hierarchy Process (AHP) method to determine the weights of the goals at the farm and the watershed levels by the participation of the stakeholders at each level. A unit of analysis (resource management unit, RMU) was selected for the four farm types, (2 farm sizes and 2 types of technology). They used the agricultural system classification and order hierarchy of resources and cropping systems. They were analyzed by multiple goal linear programming (MGLP) at the farm and the watershed levels and the results were analyzed in the trade-off analysis. The final result was multi-level optimal resource management. The framework for this study is shown in Figure 3.1 to Figure 3.3.

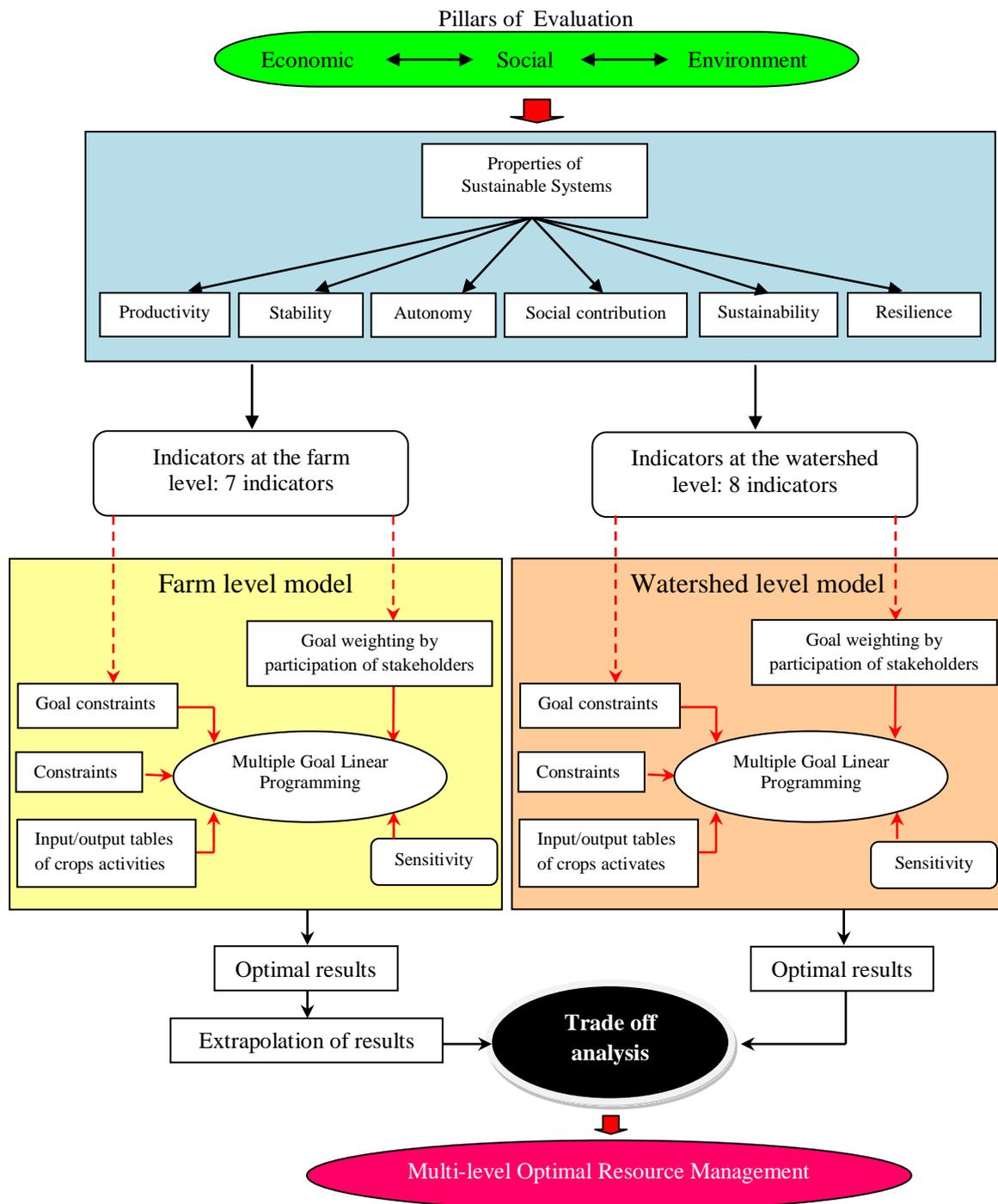


Figure 3.1 The conceptual framework

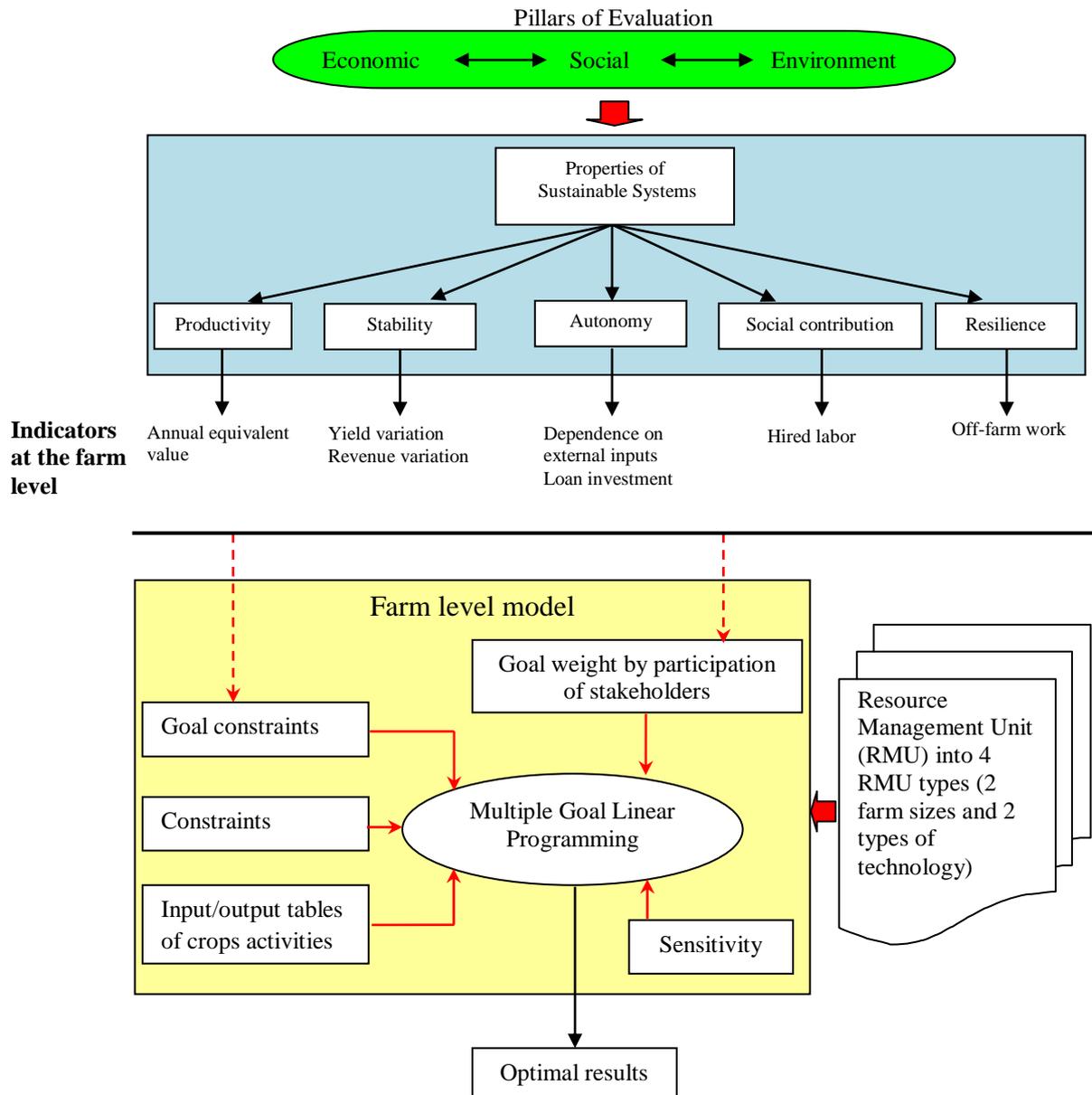


Figure 3.2 Farm level model

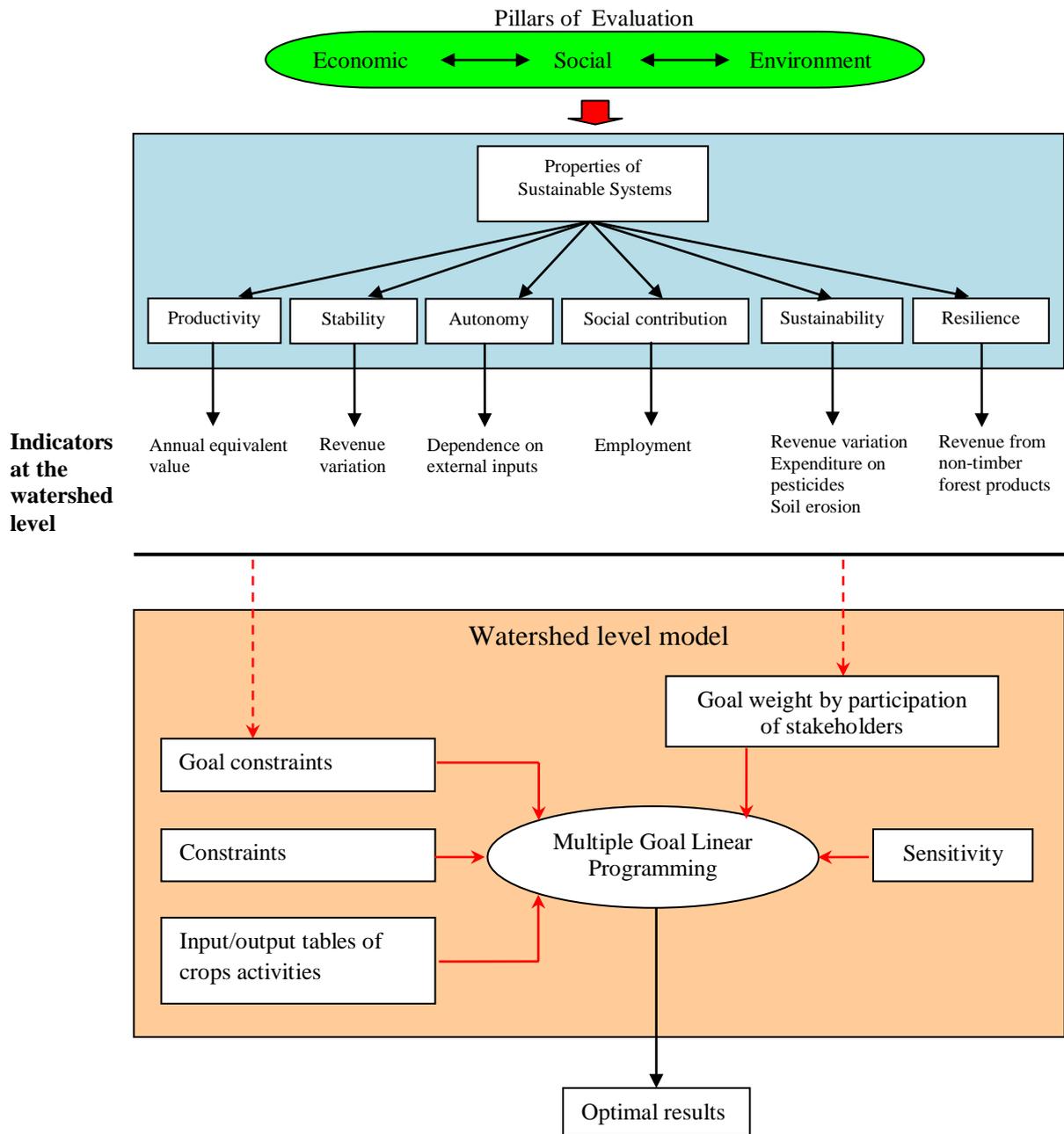


Figure 3.3 Watershed level model

### 3.2 Site selection

This study was conducted in the Fang watershed, Chiang Mai province. The Fang watershed is a major citrus producing area. The citrus produced in this area have good qualities and strong market demand, but the crop activities have affected the environment.

### 3.3 Sampling technique

The sample for the study selected the citrus-based farmers randomly from the study area and comprised a total of 1,529 households (Chiang Mai Agricultural Office, 2012). The evaluation of the land-use systems takes the inputs and outputs of each farm size (small farm (SF)  $\leq$  30 rai (4.8 hectares) and large farm (LF)  $>$  30 rai) and were quantified by two production technologies; T1: chemical usage (pesticide + fertilizer) and T2: chemical and bioextract usage (pesticide + fertilizer + bio extract). Both farm sizes and chemical usage were classified according to the Resource Management Unit (RMU) into 4 RMU types; RMU type 1 is a small farm with chemical usage (SFC), RMU type 2 is a small farm with chemical and bio extract usage (SFCB), RMU type 3 is a large farm with chemical usage (LFC), and RMU type 4 is a large farm with chemical and bioextract usage (LFCB). From these households, 153 citrus-based farmers were selected randomly giving a sample of 10 percent and were classified by the RMU types as shown in Table 3.1.

Table 3.1 Sample of the study area

RMU type	Total households* (HH)	10% of total households (HH)
SFC	580	58
SFCB	472	47
LFC	258	26
LFCB	219	22
Total	1,529	153

Source: \*Chiang Mai Agricultural Office, Sep 30, 2012

### **3.4 Data collection**

Data collection was carried out from mid-October to the end of December 2012. To fulfill the objectives of the study, both primary and secondary data were collected.

#### **3.4.1 Primary data**

Primary data was collected through a household survey by questionnaires and the coordinates were plotted with the Global Positioning System (GPS) of the citrus farms in each RMU type. Furthermore, in this study, Analytic Hierarchy Process (AHP) was used to determine the weights of the goals at the farm and the watershed level by the participatory method of stakeholders at each level. Using this method, the scores for the evaluated weight objective goals were obtained.

#### **3.4.2 Secondary data**

Secondary data was collected to achieve a better understanding of the present situation of citrus-based farming in the Fang watershed. Climate and rainfall, citrus yield and price, the citrus production situation and the effects on the environment, population and other related information were gathered from institutions and references.

### **3.5 Methodology**

In this study, MESMIS methodology (Lopez-Ridaura et al., 2005b) was used to evaluate the multi-level sustainability at the farm level and the watershed level. At the farm level, the stakeholders are farmers whose highest priority is profit or the economic aspects while at the watershed level, stakeholders from the many agencies involved (i.e. the agricultural office, national parks, NGOs and administrative organizations) prioritize the environment and social aspects instead of the economic aspect. Therefore, the indicators measuring the sustainability of these scales are different and are explained as follows:

### **3.5.1 Levels of analysis and objectives of the stakeholders at different levels**

1. The farm household level: as in most agricultural regions of the world, farm households in the Fang watershed are the direct managers of the land and take the ultimate decisions on resource allocation. Farm households manage their natural and human resources in order to improve their livelihood and satisfy their objective for the generation of income. In this study, the stakeholders at the farm level are the farmers of the citrus orchards. Land resource management is determined by selecting 2 farm sizes (small farm (SF) and large farm (LF)) in order to evaluate their activities in the resource management of the citrus orchards and the impact of production activities on the environment of the watershed.
2. The watershed level: the primary stakeholders are the government and NGOs who were interviewed relating to coordinating with the farmers regarding their citrus orchard activities, their perceptions of the system and their objectives. The main objective of the stakeholder on the watershed level is to maintain the environment and in order to do this, there needs to be a reduction in chemical use that causes soil loss, diseases and harms the insects which can be found in the soil and the nitrate combination in the water from sewage. The forest officers in the watershed focus on the increase of forest trees and the forest areas to promote wildlife, food stock, revenue from non-timber forest products and stream water in the future.

### **3.5.2 Quantification of indicators: defining and quantifying land-use activities**

To evaluate land-use systems, the inputs and outputs of each farm size (small farm (SF)  $\leq 30$  rai (4.8 hectare) and large farm (LF)  $> 30$  rai) are quantified by two production technologies: T1: chemical usage (pesticide + fertilizer) and T2: chemical and bioextract usage (pesticide + fertilizer + bioextract). Both farm sizes and chemical usage are classified according to the Resource Management Unit (RMU) into 4 RMU types:

RMU type 1-Small farms with chemical usage: SFC.

RMU type 2-Small farms with chemical and bioextract usage: SFCB.

RMU type 3-Large farms with chemical usage: LFC.

RMU type 4- Large farms with chemical and bioextract usage: LFCB.

The quantification of the indicators applied by RMU type at the farm level is shown in Table 3.2. The quantification of the indicators at the watershed level is shown in Table 3.3.

Table 3.2 Indicators at the farm household level. Goal arrows indicate whether multiple-goal linear programming minimizes (↓) or maximizes (↑)

Pillars	Category	Indicators	Unit per rai	Goals	RMU type			
					SFC	SFCB	LFC	LFCB
Economic	Productivity	Annual equivalent value (AEV)	baht	↑	...	...	...	...
	Stability	Yield variation (YV)	kg	↓	...	...	...	...
		Revenue variation (RV)	baht	↓	...	...	...	...
	Autonomy	Loan investment (LI)	baht	↓	...	...	...	...
	Resilience	Revenue of off-farm work (OFF)	baht	↑	...	...	...	...
Social	Social contribution	Hired labor (HL)	man-days	↓	...	...	...	...
	Autonomy	Dependence on external inputs (IIEI)	baht	↓	...	...	...	...

Table 3.3 Indicators at the watershed level. Goal arrows indicate whether multiple-goal linear programming minimizes (↓) or maximizes (↑)

Pillars	Category	Indicators	Unit per rai	Goal
Economic	Productivity	Annual equivalent value (AEV)	baht	↑
	Stability	Revenue variation (RV)	baht	↓
Social	Social contribution	Employment (EM)	man-days	↑
	Autonomy	Dependence on external inputs (IIEI)	baht	↓
Environmental	Sustainability	Nitrogen use (N)	kg	↓
		Expenditure on pesticides (EP)	baht	↓
		Soil erosion (SE)	ton	↓
	Resilience	Revenue from non-timber forest products (NTFP)	baht	↑

### 3.5.3 Selecting the indicators for different levels

For a multi-level sustainability evaluation, a set of sustainable systems indicators for the farm and watershed levels were identified. These properties are related to the performance of the system itself –*productivity and social contribution* – and its ability to cope with changes in its environment, co-existing systems or its internal functioning –*autonomy, stability and resilience*. In this study, the indicators for two levels (the farm level and the watershed level) were selected as listed in Table 3.4.

The ***Productivity*** of agricultural activities takes into account the annual equivalent value (AEV) which was used at both at the farm level and the watershed level. The evaluation of the AEV was calculated from the Net Present Value (NPV) and was obtained in a formula. This was equivalent to the annual value in each year of cropping systems production even though for some cropping systems like in fruit tree production, revenue

is forth coming in certain years. AEV converts all revenues over cost in the life of such cropping systems into annual equivalent value (Klemperer, 1996)

Table 3.4 Indicators at the farm level and the watershed level in the Fang watershed for different sustainability attributes

Attributes	Farm level	Watershed level
Productivity	Annual equivalent value (baht/rai)	Annual equivalent value (baht/rai)
Social contribution	Hired labor (man-days/rai)	Employment (man-days/rai)
Autonomy	Dependence on external inputs (baht/rai) Loan investment (baht/rai)	Dependence on external inputs (baht/rai)
Stability	Yield variation (kg/rai) Revenue variation (baht/rai)	Revenue variation (baht/rai)
Sustainability		Nitrogen use (kg/rai) Expenditure on pesticide (baht/rai) Soil erosion (ton/rai)
Resilience	Revenue of off-farm work (baht/man-days)	Revenue from non-timber forest products (baht/man-days)

The *Social contribution* was signified by hired labor (HL) at the farm level and full-time employment in the watershed level.

The *Autonomy* indicator was represented here by the Dependence on external inputs (IIEI). The IIEI indicator is used at both the farm and the watershed levels. External inputs include pesticides, fertilizers and organic matter incorporated into the soil and non-renewable energy use (Acosta-Alba et al., 2011). At the farm level, another indicator used for measuring autonomy was loan investment.

The *Stability* indicators were defined in the framework at the farm level as yield variation (YV) and revenue variation (RV) was used both at the farm and the watershed levels.

The *Sustainability* indicator at the watershed level was evaluated by three indicators as followed:

The first indicator was the approximate amount of nitrate leached ( $\text{NO}_3$ ) and was measured by how many kilograms of nitrogen fertilizer were used per rai.

The second indicator was the expenditure on pesticides and was measured by the expenditure on pesticides per rai.

The third indicator was measured by how many kilograms of soil erosion per rai.

The *Resilience* of a system was defined as its capability to remain productive under normal variations in the environmental and economic conditions in the Fang watershed. At the farm level, the resilience was measured by the adaptability of the farmers to a change in revenue when problems such as drought, flooding, soil erosion or decrease in prices occurred. These problems would have a serious impact on the farmers' livelihood, especially given that the economic factor was given such a high priority. It is possible to adapt to an impact on the resilience indicator by gaining extra revenue from off-farm work activities such as tourism and handicrafts. At the watershed level, the stakeholders gave greater importance to the environmental factor. This study determined that the resilience was measured according to the aim of increasing the forest area which in turn would increase the revenue from non-timber forest products (NTFP).

To determine the indicators which were used at the farm and the watershed levels, a set of 7 goals was taken into account at the farm level and 8 goals at the watershed level. The indicators were analyzed by the formulas and the results were taken into account with the goal coefficients for analysis with multiple-goal

programming to find the optimal resource management at the farm and watershed levels. The analyses of indicators are shown with the formulas as follows:

### 3.5.3.1 Indicators at the farm household level

1. Annual equivalent value (AEV): this is the annual revenue which is received every year from fruit production. The annual equivalent value (AEV) was an analysis by equation as follows:

$$AEV = NPV \left( \frac{r}{1-(1+r)^{-n}} \right) \quad \text{Klemperer, 1996} \quad \dots\dots (3.1)$$

Where  $AEV$  = Annual Equivalent Value (baht/rai)  
 $NPV$  = Net Present Value (baht/rai)  
 $r$  = Interest rates (baht)  
 $n$  = Years

In the case of annual crop, gross margin is used as AEV.

$$\text{Gross margin} = \text{Revenue} - \text{Variable costs}$$

Net present value was used for measuring the return from an investment. In the case that net present value is greater than 0, it means that the investment is worthwhile. In contrast, the investment is not worthwhile if net present value is lower than 0. The computation was done by using the equation below.

$$NPV_F = \sum_{t=1}^n \frac{R_t}{(1+r)^t} - \sum_{t=0}^n \frac{C_t}{(1+r)^t} \quad \dots\dots (3.2)$$

Where  $NPV_F$  = Net present value of net return throughout the project  
 $B_t$  = Value of the revenue in year t  
 $Revenue$  = Average yield (kilogram/rai) multiplied by the average price of citrus (baht/kilogram).  
 $C_t$  = Value of production costs in year t  
 Variable costs included the following:

- Labor costs: household labor, waged labor and exchanged labor.
- Expenditure on chemicals, pesticides and fungicides, herbicides, hormones and supplements.
- Expenditures on fuel and materials:
  - Fuel used for water supply, mowing, pesticide spraying and transportation.
  - Materials included stock, ropes and bags.

Fixed costs included the following:

- Included of production equipment:
  - Shovels, mowers, sprayers, water pumps, accessories and water supply systems.
  - Sprayer accessories, sprayer hoses, nozzles, buckets and/or cement tanks.
  - Included of plant equipment, knives, hoes and shovels.
  - Included of harvesting equipment, short shears, long shears, saws, baskets and ladders.
- Permanent labor, included in the value of reservoirs and buildings.

- $r$  = Discount rate
- $t$  = Time span of citrus production, year 1, 2, 3, ..., n
- $n$  = Project period of citrus planting

2. Hired labor (HL): the hired labor for crop production was calculated as follows:

$$HL = \frac{\sum_{j=1}^n \sum_{i=1}^m \sum_{k=1}^l L_{kij} X_{ij}}{\sum_{j=1}^n \sum_{i=1}^m X_{ij}} \dots\dots\dots (3.3)$$

Where  $HL$  = Hired labor (man–days/rai)

- $L_{aij}$  = Hired labor for the  $kth$  activities ( $k = 1, \dots, l$ ) for the  $jth$  plants ( $j = 1, \dots, n$ ) in the  $ith$  season ( $i = 1, \dots, m$ ) (man-days)
- $X_{ij}$  = The area of the  $jth$  plants in the  $ith$  season (rai)

3. Dependence on external inputs (*IIEI*): these included pesticides, fertilizers, chemicals, supplements etc. and was calculated from the following equation:

$$IIEI = \frac{\sum_{j=1}^n \sum_{i=1}^m \sum_{k=1}^l A_{kij} X_{ij}}{\sum_{j=1}^n \sum_{i=1}^m X_{ij}} \dots\dots\dots (3.4)$$

- Where  $IIEI$  = Dependence on external inputs (baht/rai)
- $A_{dij}$  = Value of inputs from  $kth$  activities for the  $jth$  plants in the  $ith$  season (baht/rai)
- $X_{ij}$  = The area of the  $jth$  plants in the  $ith$  season (rai)

4. Loan investment (*LI*): the loan investment was the amount borrowed from the institutions and the formula used is as follows:

$$LI = \frac{\sum_{j=1}^n \sum_{i=1}^m \sum_{k=1}^l C_{kij} X_{ij}}{\sum_{j=1}^n \sum_{i=1}^m X_{ij}} \dots\dots\dots (3.5)$$

- Where  $LI$  = Loan investment (baht/rai)
- $C_{vij}$  = Loan investment from  $kth$  activities for the  $jth$  plants in the  $ith$  season (baht/rai)
- $X_{ij}$  = The area of the  $jth$  plants for the  $ith$  season (rai)

5. Yield variation (*YV*): this used data from between 2010 and 2012 and was calculated as follows:

$$YV = SD(Y) = \sqrt{\frac{\sum_{y=1}^3 \sum_{j=1}^n \sum_{i=1}^m (Y_{ijy} - \bar{Y})^2}{N-1}} \dots\dots\dots (3.6)$$

- Where  $YV$  = Yield variation (kg/rai)

- $Y_{ijy}$  = Yield of the  $j$ th plants in the  $i$ th season from the  $y$ th year (ton/rai)
- $y$  = Years ( $y = 2009, 2010, 2011$ )
- $\bar{Y}$  = Average yield (ton/rai)
- $N$  = Population
- $SD$  = Standard deviation (kg/rai)

6. Revenue variation (RV): the revenue variation used data from between 2010 and 2012 and can be expressed in the following formula:

$$RV = SD(R) = \sqrt{\frac{\sum_{y=1}^3 \sum_{j=1}^n \sum_{i=1}^m (R_{ijy} - \bar{R})^2}{N-1}} \dots\dots\dots (3.7)$$

- Where  $RV$  = Revenue variation (baht/rai)
- $R_{ijy}$  = Revenue of the  $j$ th plants in the  $i$ th season from the  $y$ th year (baht/rai)
- $y$  = Years ( $y = 2009, 2010, 2011$ )
- $\bar{R}$  = Average yield (baht/rai)
- $N$  = Population
- $SD$  = Standard deviation (baht/rai)

7. Revenue of off-farm work (OFF): this assumed that if revenue of off-farm work gave higher revenue than working on the farm, the farmers would engage in off-farm work. This was evaluated by the formula:

$$OFF = \sum_{m=1}^{12} \sum_{k=1}^l L_{km} \times W_{km} \dots\dots\dots (3.8)$$

- Where  $OFF$  = Revenue of off-farm labor (baht/man-days)
- $L_{km}$  = Off-farm labor of the  $k$ th activities from the  $m$ th month (man-days) ( $m = 1, \dots, 12$ )
- $W_{km}$  = Wages from off-farm work from the  $k$ th activities from the  $m$ th month (bath/man-days)

### 3.5.3.2 Indicators at the watershed level

1. Annual equivalent value (AEV): this is the annual revenue will is received every year from fruit tree production and is evaluated by the formula:

$$AEV = NPV \left( \frac{r}{1-(1+r)^{-n}} \right) \quad (\text{Klemperer, 1996}) \quad \dots\dots\dots (3.9)$$

Where  $NPV$  = Net Present Value (baht/rai)  
 $AEV$  = Annual Equivalent Value (baht/rai)  
 $r$  = Interest rates (baht)  
 $n$  = years

2. Employment (EM): employment at the watershed from crop activities were analyzed with the following formula:

$$EM = \frac{\sum_{f=1}^4 \sum_{j=1}^n \sum_i^m \sum_{k=1}^l L_{kij} X_{ij}}{\sum_{j=1}^n X_{ij}} \quad \dots\dots\dots (3.10)$$

Where  $EM$  = Employment (man–days/rai)  
 $L_{kij}$  = Hired labor from the  $kth$  activities for the  $jth$  plants in the  $ith$  season (man-days)  
 $X_{ij}$  = The area of the  $jth$  plants from the  $ith$  season (rai)  
 $f$  = RMU types ( $f$  = SFC, SFCB, LFC and LFCB)

3. Dependence on external inputs (IIEI): this was calculated from the cost of external inputs and this study applied the following equation:

$$IIEI = \frac{\sum_{f=1}^4 \sum_{j=1}^n \sum_i^m \sum_{k=1}^l A_{kij} X_{ij}}{\sum_{j=1}^n X_{ij}} \quad \dots\dots\dots (3.11)$$

Where  $IIEI$  = Dependence on external inputs (baht/rai)  
 $A_{dij}$  = Value of inputs from  $kth$  activities for the  $jth$  plants in the  $ith$  season (baht/rai)  
 $X_{ij}$  = The area of the  $jth$  plants from the  $ith$  season (rai)  
 $f$  = RMU types ( $f$  = SFC, SFCB, LFC and LFCB)

4. Nitrogen use (N): the nitrogen use was evaluated from the fertilizer compound and used as following equation:

$$N = \sum_{f=1}^4 \sum_j^n \sum_{i=1}^m \frac{(FER_{ij} \times NO_3)}{100 \text{ kg}} \dots\dots\dots (3.12)$$

- Where  $N$  = Nitrogen use (kg/rai)  
 $FER_{ij}$  = Fertilizer use for the  $j$ th plants in the  $i$ th season (kg/rai)  
 $NO_3$  = % of nitrogen use  
 $f$  = RMU types ( $f = \text{SFC, SFCB, LFC and LFCB}$ )

5. Expenditure on pesticides (EP): this analyzed from cost of pesticides that used in the crops production and the study consider the following:

$$EP = \frac{\sum_{f=1}^4 \sum_{j=1}^n \sum_i^m \sum_{k=1}^l P_{kij} X_{ij}}{\sum_{j=1}^n X_{ij}} \dots\dots\dots (3.13)$$

- Where  $EP$  = Expenditure on pesticides (baht/rai)  
 $P_{kij}$  = Value of pesticides in the  $k$ th activities from the  $j$ th plants in the  $i$ th season (baht/rai)  
 $X_{ij}$  = The area of the  $j$ th plants from the  $i$ th season (rai)  
 $f$  = RMU types ( $f = \text{SFC, SFCB, LFC and LFCB}$ )

6. Soil erosion (SE): the soil erosion considered as follows:

$$SE = R \times K \times LS \times C \times P \dots\dots\dots (3.14)$$

- Where  $SE$  = Soil erosion (ton/rai/year)  
 $R$  = Rainfall and runoff factor  
 $K$  = Soil erosion factor  
 $LS$  = Slope Length - gradient factor  
 $C$  = Crop and management factor  
 $P$  = Support practice factor

7. Revenue variation (RV): the revenue variation was carried data during 2010 to 2012 which can be expressed in the following formula:

$$RV = SD(R) = \sqrt{\frac{\sum_{f=1}^4 \sum_{y=1}^3 \sum_{j=1}^n \sum_{i=1}^m (R_{ijy} - \bar{R})^2}{N-1}} \quad \dots\dots\dots (3.15)$$

- Where  $RV$  = Revenue variation (baht/rai)  
 $R_{ijy}$  = Revenue from the  $j$ th plants in the  $i$ th season from the  $y$ th year (baht/rai)  
 $y$  = Years ( $y = 2009, 2010, 2011$ )  
 $\bar{R}$  = Average yield (baht/rai)  
 $N$  = Population  
 $SD$  = Standard deviation (baht/rai)  
 $f$  = RMU types ( $f = \text{SFC, SFCB, LFC and LFCB}$ )

8. Revenue from non-timber forest products (NTFP): this was the revenue from non-timber forest products as can be seen from the following equation:

$$NTFP = \sum_{m=1}^{12} \sum_{z=1}^k P_{mz} X_{mz} \quad \dots\dots\dots (3.16)$$

- Where  $NTFP$  = Revenue from non-timber forest products (baht/man-days)  
 $P_{mz}$  = Value from a non-timber forest product from the  $z$ th products in the  $m$ th month (baht)  
 $X_{mz}$  = The forest product from the  $z$ th products from the  $m$ th month

### 3.5.4 A Multi-Level Linear Programming model

Enoch (1976) designed a goal programming model which was a technique used for making decisions with multi-objectives. The purpose of the model was to find the least deviation between multiple objectives and compare the results for each target value until the best results were achieved. This method solved the problems under the

constraints we had. Mathematically, the multi-objective or the goal-programming approach can be expressed as:

$$\text{Minimize: } \sum_{i=1}^n (w_{1i} d_i^- + w_{2i} d_i^+)$$

*Subject to:*

$$AX + Id^- - Id^+ = G$$

$$BX \leq C$$

$$X_j \geq 0 \quad j = 1, \dots, m \text{ and } d_i^-, d_i^+ \geq 0 \quad i = 1, \dots, n$$

- Where:  $d^-, d^+$  The vectors (n x 1) of the negative and positive derivational variables respectively. These represents the solution's deviation from the goal vector, G(n x 1).
- $w_{1i}, w_{2i}$  The weight and/or priorities for the derivational variables. Lee (1971) has proposed a preemptive ranking, and Dyer (1972) has proposed a subjective cardinal scale.
- $A$  The matrix relation between the decision variables vector, X (m x 1), and the G(n x 1). In practice, the decision variables vector often represent inputs which are transformed by the A matrix to obtain the desired outputs or goals.
- $I$  The matrix (c x m) of coefficients which relate the decision variables to the constraint vector, C (c x 1).
- $n, m, \text{ and } c$  The number of goals, decision variables and constraints respectively.

This step was analyzed by Multiple Goal Linear Programming (MGLP) which has been widely used to generate farm and watershed land-use systems using land-use activities as building blocks (Lu et al. 2004; Roetter et al. 2007; Nidumolu et al. 2007; Nikkami et al. 2009; Sadeghi et al. 2009; Acosta-Alba et al.2011). In this study, MGLP models used the indicator values of current and constraint functions for the optimization of land

use in each RMU type of farm at both the farm level and the watershed level (Table 3.3 and 3.4). In MGLP models, one main goal was defined by an objective function and the others were described by constraint functions (Janssen and van Ittersum, 2007). For the analysis an optimal resources management was conducted using the software program “Interactive Multiple Goal Programming for Land use Planning (IMGP-LPlan)” developed by Ekasingh et al. (2011) and the equation formula for the analysis is as follows:

### 3.5.4.1 Farm level model

#### 1. The Objective function

The objective function in the MGLP model at the farm level was the minimization of the total deviations from the goals as follows:

$$\min = (w_{f1}d_{f1}^- - w_{f2}d_{f2}^+ + w_{f3}d_{f3}^- - w_{f4}d_{f4}^+ - w_{f5}d_{f5}^+ - w_{f7}d_{f6}^+ + w_{f7}d_{f7}^- \dots (3.17)$$

Where  $w_f$  represents the weight of the  $f$ th goal,  $d_f^-$  and  $d_f^+$  are the negative and positive deviations of the  $f$ th goal. Based on the information collected from farmers, the priorities of the goals are classified into 5 categories. First: to develop the acreage of the citrus crop (productivity goal). Second: to decrease the hired labor which the farms need (social contribution goal). Third: to lower the dependency on external inputs (autonomy goal). Fourth: to decrease the instability of the farm’s economy (stability goal). Fifth: to increase the adaptability of the farm (resilience goal).

#### 2. Goal Constraints

1. Productivity goal constraint: the productivity goal constraint is as follows:

$$\sum AEV_{ij} X_{ij} + w_{f1}d_{f1}^- = GA \dots\dots\dots (3.18)$$

Where  $AEV_{ij}$  is the annual equivalent value for farmers from investment and  $X_{ij}$  is the area in the  $j$ th plants which form the  $i$ th season when GA is the achievable goal level to increase the annual equivalent value for the farm.

2. Social contribution goal constraint: the social contribution goal constraint is to decrease the hired labor (HL) and where GH is the achievable goal. This can be shown by the following equation:

$$\sum HL_{ij} X_{ij} - w_{f2} d_{f2}^+ = GH \quad \dots\dots\dots (3.19)$$

3. Autonomy goal constraint: The autonomy goal constraint is as follows:

$$\sum IIEI_{ij} X_{ij} - w_{f3} d_{f3}^+ = GI \quad \dots\dots\dots (3.20)$$

$$\sum LI_{ij} X_{ij} - w_{f4} d_{f4}^+ = GL \quad \dots\dots\dots (3.21)$$

Where  $IIEI_{ij}$  is the dependence on external inputs and  $LI_{ij}$  is the loan investment of farm of the  $j$ th plants in the  $i$ th season. GI is the achievable goal level to decrease dependence on external inputs and GL is the achievable goal level to increase the proportion of cash investment from the farmer.

4. Stability goal constraint: the stability goal constraint aims to decrease the instability of farm economics and the studies consider the following:

$$\sum YV_{ij} X_{ij} - w_{f5} d_{f5}^+ = GY \quad \dots\dots\dots (3.22)$$

$$\sum RV_{ij} X_{ij} - w_{f6} d_{f6}^+ = GR \quad \dots\dots\dots (3.23)$$

Where  $YV_{ij}$  is the yield variation and  $RV_{ij}$  is the revenue variation from  $j$ th plants in  $i$ th season. In addition, GY and GR are the achievable goal levels to decrease yield and revenue variation respectively.

5. Resilience goal constraint: the resilience goal at the farm level (GO) was to increase revenue of off-farm work (OFF). This study applied the following equation:

$$\sum_{m=1}^{12} OFF_{ij} X_{ij} + w_{f7}d_{f7}^- = GS \quad \dots\dots\dots (3.24)$$

At the farm level determined 7 indicators which were taken into account for the analysis by MGLP which were used for goal constraints. The results of the goal constraints were analyzed by linear programming for each goal objective which using the software program *IMGP-LPlan* developed by Ekasingh et al. (2011). This study will evaluate the optimal resource management by the equal weight and the AHP methods. The equal weigh method determined the weight value of all the goals equally at 0.1428 from 1 (1 divide 7 = 0.142857). The AHP method was given the weight values by participatory stakeholders

### 3. Resource Constraints

1. Land area constraints: The land area constraints at the farm level are divided into three groups. The first is concerned with yearly crops; the second is concerned with permanent crops and the third with the dry season which are grown in the irrigation areas. These constraints are introduced into the models as follows:

- 1.1 Irrigated upland area constraints;

$$\sum_{j=1}^n \sum_{i=1}^3 X_{ij} \leq IU_f \quad \dots\dots\dots (3.25)$$

Where  $IU_f$  is the total irrigated upland cultivable (rai) from the  $j$ th plants of the  $i$ th season at the farm level.

- 1.2 Rainfed upland area constraints;

$$\sum_{j=1}^n \sum_{i=1}^3 X_{ij} \leq RU_f \quad \dots\dots\dots (3.26)$$

Where  $RU_f$  is the total rainfed upland area (rai) from the  $j$ th plants of the  $i$ th season at the farm level.

1.3 Irrigated lowland area constraints;

$$\sum_{j=1}^n \sum_{i=1}^3 X_{ij} \leq IL_f \quad \dots\dots\dots (3.27)$$

Where  $IL_f$  is the total irrigated lowland area (rai) from the  $j$ th plants of the  $i$ th season at the farm level.

1.4 Rainfed lowland area constraints;

$$\sum_{j=1}^n \sum_{i=1}^3 X_{ij} \leq RL_f \quad \dots\dots\dots (3.28)$$

Where  $RL_f$  is the total rainfed lowland area (rai) from the  $j$ th plants of the  $i$ th season at the farm level.

2. Labor constraints: the labor requirement constraints on the farm are as follows:

$$\sum_{j=1}^n \sum_{m=1}^{12} \sum_{i=1}^3 LB_{mij} X_{ij} \leq TB_f \quad \dots\dots\dots (3.29)$$

Where  $LB_{mj}$  is the labor requirement of the  $m$ th month with the  $j$ th plants of the  $i$ th season and  $TB_f$  was the total adult labor available on the farm (man-days). An assumption is made that an exchange of labor with neighbors is equal to the total household labor because exchange labor will be repaid by an equal exchange. There is hired labor available if household labor and exchange labor is insufficient.

3. Cost constraints: the total cost arising from production activities. The formula is as follows:

$$\sum_{j=1}^n \sum_{m=1}^{12} \sum_{i=1}^3 CO_{mij} X_{ij} \leq TC_f \quad \dots\dots\dots (3.30)$$

Where  $CO_{mj}$  is the total cost of the  $m$ th month with the  $j$ th plants in the  $i$ th season and  $TC_f$  is the total capital available (owner capital and loans) in the household.

4. Profit constraints: the profit constraints are considered as follows:

$$\sum_{j=1}^n \sum_{i=1}^3 (Y_{ij} P_{ij} X_{ij} - CO_{ij} X_{ij}) \geq 0 \quad \dots\dots\dots (3.31)$$

Where  $P_{ij}$  is the price of the  $j$ th plants in the  $i$ th season.

### 3.5.4.2 Watershed level model

#### 1. The Objective functions

The objective function in MGLP model at the watershed level is the minimization of the total deviations from the goals as follows:

$$\min = (w_{w1}d_{w1}^- + w_{w2}d_{w2}^- + w_{w3}d_{w3}^- - w_{w4}d_{w4}^+ - w_{w5}d_{w5}^+ - w_{w6}d_{w6}^+ - w_{w7}d_{w7}^+ + w_{w8}d_{w8}^-) \quad \dots\dots\dots (3.32)$$

Where  $w_w$  represents the weight of  $w$ th goal,  $d_w^-$  and  $d_w^+$  are the negative and positive deviations of the  $w$ th goal. Based on information collected from stakeholders, the priority of goals are classified into 5 categories. First: to develop the acreage of the citrus crop (productivity goal). Second: to increase employment in the watershed level (social contribution goal). Third: to lower the dependency on external inputs (autonomy goal). Fourth: to maintain the environment of the watershed level (stability goal). Fifth: to increase the budget for conservation and environmental restoration in the watershed level (resilience goal).

## 2. The Goal Constraints

1. The productivity goal of this study is as follows:

$$\sum AEV_{ij} X_{ij} + w_{w1}d_{w1}^+ = GA \quad \dots\dots (3.33)$$

Where  $AEV_{ij}$  is the annual equivalent value for farmers from investment and  $X_{ij}$  is the area allocated for the  $j$ th plants in the  $i$ th season from an aggregate of the  $f$ th RMU type at the farm level. The model suggests the forest as an alternative to crops. The forest is environmentally friendly and a source of marketable food, non-timber forest products and a habitat for wildlife. An area is allocated for the  $j$ th plants in the  $i$ th season from an aggregate of the  $f$ th RMU types. GA is the achievable goal level to increase the annual equivalent value.

2. The Social contribution goal: the social contribution goal is the employment (EM) of labor in the watershed. GE is the achievable goal with the following equation:

$$\sum EM_{ij} X_{ij} + w_{w2}d_{w2}^+ = GE \quad \dots\dots (3.34)$$

3. The autonomy goal: the autonomy goal is as follows:

$$\sum IIEI_{ij} X_{ij} - w_{w3}d_{w3}^+ = GI \quad \dots\dots (3.35)$$

Where  $IIEI_{ij}$  is the dependence on external inputs in the  $j$ th plants from the  $i$ th season. GI is the achievable goal level to decrease dependence on external inputs.

4. The Stability goal: the stability goal concerns the economic and environmental effect on the watershed as can be seen from the following equations:

$$\sum N_{ij} X_{ij} - w_{w4}d_{w4}^+ = GN \quad \dots\dots (3.36)$$

$$\sum EP_{ij} X_{ij} - w_{w5}d_{w5}^+ = GP \quad \dots\dots\dots (3.37)$$

$$\sum SO_{ij} X_{ij} - w_{w6}d_{w6}^+ = GS \quad \dots\dots\dots (3.38)$$

$$\sum RV_{ij} X_{ij} - w_{w7}d_{w7}^+ = GR \quad \dots\dots\dots (3.39)$$

$N_{ij}$  is the amount of kilograms of nitrate used per rai,  $EP_{ij}$  is the expenditure on pesticides,  $SO_{ij}$  is the amount of soil erosion and  $RV_{ij}$  is the revenue variation from the  $j$ th plants in the  $i$ th season. GN is the achievable goal level to decrease nitrate use, GE is the achievable goal to decrease expenditure on pesticides, GS is the achievable goal level to decrease soil erosion and GR is the achievable goal level to decrease revenue variation.

5. The Resilience goal: the resilience goal in the watershed level (GF) is the revenue from *non-timber forest products* (NTFP) which can be expressed in the following formula:

$$\sum NTFP_i + w_{w8}d_{w8}^+ = GF \quad \dots\dots\dots (3.40)$$

GF is the achievable goal to increase non-timber forest products.

At the watershed level determined 8 indicators which were taken into account for the analysis by MGLP which were used for goal constraints. The results of the goal constraints were analyzed by linear programming for each goal objective which using the software program *IMGP-LPlan* developed by Ekasingh et al. (2011). This study will evaluate the optimal resource management by the equal weight and the AHP methods. The equal weigh method determined the weight value of all the goals equally at 0.125 from 1 (1 divide 8 = 0.125). The AHP method was given the weight values by participatory stakeholders.

### 3. The Resource Constraints

1. Land area constraints: Land area constraints in the watershed are divided into three groups. The first is concerned with yearly crops; the second is concerned with permanent crops and third with the dry crops grown in the irrigation areas. These constraints are introduced into the models as follows:

- 1.1 Irrigated upland area constraints;

$$\sum_{j=1}^n \sum_{i=1}^3 X_{ij} \leq IU_w \quad \dots\dots\dots (3.41)$$

Where  $IU_w$  is the total irrigated upland cultivable (rai) from the  $j$ th plants of the  $i$ th season at the watershed level.

- 1.2 Rainfed upland area constraints;

$$\sum_{j=1}^n \sum_{i=1}^3 X_{ij} \leq RU_w \quad \dots\dots\dots (3.42)$$

Where  $RU_w$  is the rainfed upland area (rai) from the  $j$ th plants of the  $i$ th season at the watershed level.

- 1.3 Irrigated lowland area constraints;

$$\sum_{j=1}^n \sum_{i=1}^3 X_{ij} \leq IL_w \quad \dots\dots\dots (3.43)$$

Where  $IL_w$  is the irrigated lowland area (rai) from the  $j$ th plants of the  $i$ th season at the watershed level.

- 1.4 Rainfed lowland area constraints;

$$\sum_{j=1}^n \sum_{i=1}^3 X_{ij} \leq RL_w \quad \dots\dots\dots (3.44)$$

Where  $RL_w$  is the rainfed lowland area (rai) from the  $j$ th plants of the  $i$ th season at the watershed level.

2. The labor constraint: the labor requirement constraints at the watershed level are as follows:

$$\sum_{m=1}^{12} LB_{mj} X_{jr} \leq TB_w \quad \dots\dots\dots (3.45)$$

Where  $LB_{mj}$  is the labor requirement for the  $m$ th month for the  $j$ th plants in the  $i$ th season and  $TB_w$  is the labor available at the watershed level.

3. Cost constraint: the cost constraint of production at the watershed level is as follows:

$$\sum_{m=1}^{12} CO_{mj} X_{jr} \leq TC_w \quad \dots\dots\dots (3.46)$$

Where  $CO_{mj}$  is the total cost of the  $m$ th month for the  $j$ th plants in the  $i$ th season and  $TC_w$  is the capital available at the watershed level.

### 3.5.5 Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) is a structured technique for organizing and analyzing complex decisions. Based on mathematics and psychology, it was developed by Thomas L. Saaty in the 1970s (Saaty, 2010) and has been extensively studied and refined since then. In this study, I will use AHP to determine the weights of the goals at the farm and the watershed levels by the participation of stakeholders at each level. Using this method, the scores for evaluated weight objective goals will be obtained. The basic principle of the analytic hierarchy process: in order to make a decision in an organized way to generate priorities, the decision first has to be broken down into the following steps.

1. Find the problem and determine the kind of knowledge sought.
2. Structure the decision hierarchy from the top with the goal of the decision, then the objectives from a broad perspective through the intermediate levels, (criteria on which subsequent elements depend), to the lowest level, (which usually is a set of the alternatives).

3. Construct a set of pairwise comparison matrices. Each element in the upper level is used to compare the elements in the level immediately below it.
4. Use the priorities obtained from the comparisons to weigh the priorities in the level immediately below. Do this for every element. Then for each element in the level below, add its weighed values and obtain its overall or global priority. Continue this process of weighing and adding until the final priorities of the alternatives in the bottom-most level are obtained.

To make comparisons, a scale of numbers is needed that indicate how many times more important or dominant one element is over another element with respect to the criterion or property to which they are compared. Table 3.5 exhibits the scale. A basic but very reasonable assumption is, that if attribute A is more important than attribute B and is rated at 9, then B must be less important than A and is valued at  $1/9$ . These pairwise comparisons are carried out for all factors to be considered, usually not more than 7 pairs, and the matrix is completed. The matrix is of a very particular form which neatly supports the calculations which then ensue. The next step is the calculation of a list of the relative weights or the goal objective values such as the annual equivalent value (AEV) and hired labor (HL), which are relevant to the set of goals in this study (technically, this list is called an eigenvector). If perhaps the annual equivalent value is more important than hired labor, then on a simple interpretation, an increase in household labor is called for, though that is not straightforward when hired labor is exchanged for the use of machines. The final stage is to calculate a Consistency Ratio (CR) to measure the consistency of the judgments between the goal objectives.

This study employed this AHP technique to determine weights of indicators at farm and watershed level by participatory method of stakeholders in each level. Using this method and a software program called *Ror Tor Sor* developed by Ekasingh et al (2006, 2007), the weights of the goals evaluated were then obtained.

Table 3.5 The fundamental scale of absolute numbers

Intensity of Importance	Definition	Explanation
1	Equal Importance	Two activities contribute equally to the objective
2	Weak or slight	Experience and judgment slightly favor one activity over another
3	Moderate importance	Experience and judgment moderately favor one activity over another
4	Moderate plus	Experience and judgment more than moderately favor one activity over another
5	Strong importance	Experience and judgment strongly favor one activity over another
6	Strong plus	Experience and judgment more than strongly favor one activity over another
7	Very strong or demonstrated importance	An activity is favored very strongly over another; its dominance demonstrated in practice
8	Very, very strong	An activity is favored very, very strongly over another
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
Reciprocals of above	If activity $i$ has one of the above non-zero numbers assigned to it when compared with activity $j$ , then $j$ has the reciprocal value when compared with $i$	
1.1–1.9	If the activities are very close	May be difficult to assign the best value but when compared with other contrasting activities, the size of the small numbers would not be too noticeable, yet they can still indicate the relative importance of the activities

### 3.5.6 Trade-off analysis

In this study, the relationship between the farm level and the watershed level are conducted by comparing the analyses at the two levels by the sum of the results in each RMU type at the farm level with the result of the analysis at the watershed level. Comparing the results of the summing of every RMU type at the farm level with those at watershed level will yield divergences between optimal resource management at the

farm level compared with optimal resource management at the watershed level. Different policies of land use management are explored to align the results of the two levels.

The relationship between the farm and watershed levels were obtained by comparing the watershed results and the extrapolated results from the farm level results obtained by the equal weight and AHP methods. The farm level results of optimal land use in each method were extrapolated to the watershed level based on the proportion of land occupied by each farm type.

The study was also finding the relationship between the trade-off analyses at the farm and watershed levels. With agricultural land use, conflicts between objectives are likely when planning to optimize the benefits using multiple-goal linear programming modeling. A trade-off analysis is used to find the relationships between objectives. The farm level selected the annual equivalent value goal in a trade-off with three goals. There was the dependence on external inputs, loan investment and revenue variance. The economic objective selected the goal of annual equivalent value in a trade-off with the goal of hired labor from the social objective. The trade-off between the social and environmental objectives selected the goal of hired labor in a trade-off with the goal of revenue of off-farm work. At the watershed level, the trade-off between the economic and environmental objectives selected the goal of annual equivalent value in a trade-off with the three goals of the expenditure on pesticides, nitrogen use and soil erosion. The trade-off analysis between the economic and social objectives selected the goal of revenue variance in a trade-off with employment. The trade-off between the social and environmental objectives selected the goal of employment in a trade-off with the three goals of the expenditure on pesticides, nitrogen use and soil erosion.

### **3.5.7 Sensitivity analysis**

Sensitivity analyses are useful when attempting to determine the impact the actual outcome of a particular variable will have if it differs from the result obtained previously. By creating a given set of scenarios, the analyst can determine how changes in one or more variable will impact the variable target. In this study, sensitivity analyses are determined how different values of an independent variable will impact a particular dependent variable under a given set of three assumptions. At the farm level, a sensitivity analysis was made:

1. Price variations due to market integration as a result of strategies within the ASEAN Economic Community.
2. Decreased dependence on external inputs by a policy to encourage farmers to use organic matter in their farm so as to decrease their costs and let them be more environmentally friendly.
3. Changing the coefficients in input/output tables of activities to optimize resource management at the farm level.

At the watershed level, sensitivities were made on

1. Increased labor availability due to stronger ties among the ASEAN Economic Community (AEC) in 2015.
2. Increased revenue from non-timber forest products by applying government policy.
3. Changing the coefficients in input/output tables of activities for optimized resource management at the watershed level.