CHAPTER 8

THE WATERSHED LEVEL MODEL

This chapter deals the formulation of the watershed level model of resource management. It describes the objectives at the watershed level and the analytic hierarchy process (AHP) results from the stakeholders at the watershed level as much as the government. NGOs offices were interviewed relating to their work with their citrus crop activities, their perceptions of the system and their objectives including helping the watershed population to coexist with the lowland population. This will include an explanation of the resource constraints, decision variables, coefficients variables and the formula model used at the watershed level.

8.1 Objectives at the watershed level

At the watershed level, all the stakeholders are aware of the importance of the environment in order to reduce chemical use that will cause soil erosion, diseases, harmful insects accumulating in the soil and high nitrate levels in the water from sewage. The forest officers in the watershed focus on the increase in forest trees and forest areas to promote wildlife, food stocks, revenue from non-timber forest products and stream water in the future. The study made the assumption that the environmental objectives at the watershed level were more prominent than the social or the economic-related objectives. These objectives were broken down into 5 attributes and 8 objective goals as follows:

1. The economic objective considered the main criteria as productivity, autonomy and stability:
    1.1 Productivity was measured by the Annual Equivalent Value (baht/rai)
    1.2 Autonomy was measured by independence from external inputs (baht/rai)

2. The social objective was judged by the social contribution of employment (man-days).
3. The environmental objective was judged by stability and resilience:
    3.1 Stability was measured by nitrogen use (ton/rai), expenditure on pesticides (baht/rai), soil erosion (ton/rai) and revenue variation (baht/rai).
    3.2 Resilience was judged by the alternatives for revenue from non-timber forest products (man/days).

8.2 Analytic Hierarchy Process (AHP) at the watershed level

This study used the AHP method developed by Thomas L. Saaty in the 1970s (Saaty, 2010) and used this method to determine the weights of the goals at the farm level by the participatory method of the stakeholders at the watershed level. Using this method, the scores for the evaluated weight objective goals were obtained. The process is as follows:

1. Define the problem by using the 8 objective goals at the watershed level, namely, Annual Equivalent Value, employment, independence from external inputs, expenditure on pesticides, nitrogen use, soil erosion, revenue variance and revenue from non-timber forest products. These objective goals were earlier determined in the conceptual formwork of this study.

2. Construct a set of pairwise comparison matrices from the objective goals. Based on the principle of comparative judgments, the results are applied to determine the relative importance of the objective goals and the relative preference of the alternatives through pairwise comparisons. AHP uses a fundamental level of absolute numbers to express individual preferences or judgments (Chapter 6, Table 6.1).

3. Use the participatory method by including ideas from the focus groups and stakeholders who are all involved in the citrus crop activities. I took thirteen stakeholders from the Chiang Mai Agricultural Research and Development

Center, the agricultural office, the national park, local administrative organizations, the Bank for Agriculture and Agricultural Co-Operatives (BAAC), and agricultural merchants (Table 7.1). The focus group was started on 29 February, 2013.

The focus groups started by explaining the background of the study and the objectives of the research. The meaning of each objective goal was explained and the scores by using pairwise comparisons were measured (Chapter 6**,** Table 6.1). There were many people participating, multiple judgments were combined by taking the geometric means of individual judgments. Pairwise comparison judgments were made based on the best information available and the decision maker's intuition, knowledge and experience.

4. The results of the pairwise comparisons for the given objective goals were put in a matrix. The numbers in the matrix are the AHP level values as can be seen from the definitions in Chapter 6, Table 6.1. Once a pairwise comparison matrix is generated, the AHP derives the weights vector for the relevant elements from the principal of the matrix. Using this method and a software program called *Ror Tor Sor* developed by Ekasingh et al (2006, 2007), the weights of objective goals evaluated were then obtained.

5. The stakeholders were given the pairwise score which was calculated by the software program *Ror Tor Sor*. The results found that the highest weight value was revenue from non-timber forest products at 22.67 followed by nitrogen use (0.2008) and annual equivalent value (0.0603). The details are shown in Figure 8.1.

	AEV	HL	IIEI	EP	N	SE	RV	NTFP	Weight value
AEV	1	2	4	1/7	1/4	1/3	1	1/9	0.0603
HL	1/2	1	3	5	1/2	1	1/2	1/2	0.0857
IIEI	1/4	1/3	1	5	1/5	1/2	1/4	1	0.0649
EP	7	1/5	1/5	1	1	1/3	1/5	1/5	0.0667
N	4	2	5	1	1	4	5	1	0.2008
SE	3	1	2	3	1/4	1	9	1/8	0.1610
RV	1	2	4	5	1/5	1/9	1	3	0.1339
NTFP	9	2	1	5	1	8	1/3	1	0.2267

Figure 8.1 The weight values at the watershed level

8.3 Goal constraints at the watershed level

The study determined 8 indicators at the watershed level which were taken into account for the analysis by MGLP using the goal constraints. The results of goal constraints were analyzed by linear programming for each goal objectives and this is shown in Table 8.1.

Table 8.1 Goal constraints at the watershed level

Goal constraints	Watershed level
Annual equivalent value (GA) (baht)	8,100,025,415
Employment (GH) (man-days)	9,748,885
Independence from external inputs (GI) (baht)	29,703,198,011
Expenditure on pesticide (GE) (baht)	6,682,992,866
Nitrogen use (GN) (kg)	29,768,859
Soil erosion (GS) (ton)	227,189
Revenue variance (GR) (baht)	179,381,411,666
Revenue from non-timber forest products (GF) (baht)	420,949,787

The study evaluated the optimal resource management using both the equal weight and the AHP methods. The equal weigh method determined the weight value of any goals equally as 0.125 from 1 (1 divided by 8 = 0.125). The AHP method was given the

weight value by participatory stakeholders which were mentioned above and the results are shown in Figure 8.1. The goal constraints and the weigh value are relevant to analysis with MGLP as follows:

- The annual equivalent value goal (GA) was maximized. The linear programming assessed the annual equivalent value and determined a goal constraint of 8,100,025,415 baht. The negative deviation would be equal to 0.125 from a 1 score (12.5 percent) by the equal weigh method or 0.0603 from 1 score (6.03 percent) by the AHP method (Table 8.1). The optimal resources management would minimize the negative deviation from the weight value result from either the equal weight or the AHP methods. This means that the optimal resources management would have annual equivalent value close to 8,100,025,415 baht. The others which were maximized were the employment goal (GH) and the revenue from non-timber forest products. These was given a goal constraint of 9,748,885 man-days and 420,949,787 baht respectively.

- The independence from external inputs goal (GI) was minimized and the linear programming assessed the independence from external inputs had a goal constraint of 29,703 million baht. The optimal resources management would minimize the positive deviation of the weight value result from the equal weight method (12.5 percent) or the AHP method (6.49 percent, Table 8.1). This means that the optimal resource management would have independence from external inputs lower or equal to 29,703 million baht. The other goal that was minimized was the goal of expenditure on pesticides (GE) which was set at 6,682 million baht. The nitrogen use goal (GN) was set at 29,768,859 kilograms, the soil erosion goal (GS) was set at 227,189 tons and the goal constraint for the revenue variance (GR) was set at 179,381 million baht.

8.4 Resource constraints at the watershed level

The resource constraints at the watershed level included land units, labor, capital and loan constraints. These were calculated by samples from all farm types at the farm level as a representative for the watershed level and the details are as follows:

8.4.1 Land constraints

The Fang watershed has a total area of 84,418 hectares. This study classified the land units in the watershed according to the figures from the *Chiang Mai Agricultural Office* (2013) into four types: irrigated upland (17,131 hectares), rainfed upland (41,415 hectares), irrigated lowland (19,378 hectares) and rainfed lowland (6,494 hectares). The lowlands mainly consist of the flood-plains on which paddy is grown. The uplands include all land above the flood-plain regardless of the steepness. This has normally been deforested but is not suitable for paddy so other crops are grown. The data is shown in Table 8.2.

Table 8.2 Land constraints at the watershed level

Land unit	Area (hectare)
Irrigated upland	17,131
Rainfed upland	41,415
Irrigated lowland	19,378
Rainfed lowland	6,494
Total	84,418

Source: Chiang Mai Agricultural Office, 2013

8.4.2 Household labor constraints

The agricultural communities in Fang watershed have a total of 23,215 households (Chiang Mai Community Development Office, 2013). The study found that an average household would consist of 2.02 agricultural laborers and a figure for the labor work on the farms was set at 25 man-days per month. This study assumed that exchanged labor with neighbors equaled the total household labor because it was repaid by equal exchange. The total household labor at the watershed therefore equaled 1.17 million man-days per month.

8.4.3 Hired labor constraints

In the Fang watershed in 2013, there was total employment for 33,817 people. This was divided between migration labor such as from Myanmar and Lao PDR (8,094 people) (Chiang Mai Employment Office, 2013) and employment labor in the local area (25,723 people) (Chiang Mai Community Development Office, 2013). The study determined that labor work on the farm should be set at 25 man-days per month. The total employment labor at the watershed therefore equaled 845 thousand man-days per month (Table 8.3).

Table 8.3 Hired labor constraints at the watershed level

Specification	Migration labor*	Employment from the local area**	Total employment
Labor (No. of people)	8,094	25,723	33,817
Farm work at 25 man-days/month	25	25	25
Total	202,350	643,075	845,425

Source: * Chiang Mai Employment Office, 2013

** Chiang Mai Community Development Office, 2013

8.4.4 Capital constraints

The capital constraints were calculated from the net income from crop production and off-farm activities minus loan and interest repayments, household consumption and savings. The money which remained was taken for investment in crop production.

The household consumption in this study used the basic needs of food consumption as suggested by Chaiwinit (2009). The value was adjusted for inflation by using the Consumer Price Index (CPI) from The Bank of Thailand (2014). Based on 2010, this study took a figure of 3.1 percent. The adjusted value was given to the index of food consumption requirements which ranks priorities by age and gender (Wironsri, 1988). The index to assess the family size was used for the weight consumption value at the watershed level.

The results found that an average revenue per household at the watershed level was 339,730 baht. Loan and interest repayments were deducted (136,340 baht) as were household consumption (80,577 baht) and savings of 10 percent (12,281baht). An average watershed revenue therefore equaled 110,532 baht per household (Table 8.4). This was multiplied by 23,215 households who farmed in the watershed and so the capital constraints therefore equaled 2,566 million baht.

Table 8.4 Capital constraints at the watershed level

Description	Baht /household
An average revenue	339,730
Minus loan and interest repayments	136,340
Minus household consumption	80,577
Minus Savings 10%	12,281
Average capital	110,532
Number of total households *	23,215
Total capital constraints at the watershed level	2,566,001,076

Source: *Chiang Mai Community Development Office, 2013

8.4.5 Loan constraints

At the watershed level, there were a total of 23,215 farming households and this study determined 4 sources of loans:

The Agricultural Cooperatives and Bank for Agriculture and Agricultural Co-operatives (BAAC). The criteria set by BAAC gave a maximum personal loan of 200,000 baht per household. This was multiplied by the total number of households in the watershed to arrive at a figure of 4,642 million baht.

The Agricultural Co-operatives. The criteria set by the Agricultural Cooperatives gave a maximum personal loan of 20,000 baht per household. This was multiplied by the total number of households in the watershed to arrive at a figure of 464 million baht.

The village fund. The criteria set by the village fund gave a maximum personal loan of 30,000 baht per household. This was multiplied by 95 percent of the total households in the watershed (22,053 households) to arrive at a figure of 661 million baht.

The commercial banks. The criteria set by the commercial banks gave a maximum overdraft for large farms of 5,000,000 baht. This was multiplied by 5 percent of the total households in the watershed (1,161 households) to arrive at a figure of 5,805 million baht (Table 8.5).

Table 8.5 Loan constraints at the watershed level

Description	Baht
BAAC	
Loan per household (baht)	200,000
Number of farming households	23,214
Total loan (baht)	4,642,800,000
Interest rate (%)	7.50
Agricultural Cooperatives	
Loan per household (baht)	20,000
Number of farming households	23,214
Total loan (baht)	464,280,000
Interest rate (%)	8.50
Village funds	
Loan per household (baht)	30,000
Number of eligible households (95 % of total households)	22,053
Total loan (baht)	661,590,000
Interest rate (%)	12.00
Commercial banks	
Loan per household (baht)	5,000,000
Number of eligible households (5 % of total households)	1,161
Total loan (baht)	5,805,000,000
Interest rate (%)	8.00

The conclusions from the resource constraints shown above suggest that there are 59 constraints at the farm level (Appendix B). These can be divided as follows:

R_1 - R_4 Land use constraints classified by irrigated upland, rainfed upland, irrigated lowland and rainfed lowland (rai).

R_5 - R_{18} Household labor constraints per month (man-days)

R_{17} - R_{28} Hired labor constraints per month (man-days)

R_{29} - R_{40} Capital constraints per month (baht)

R_{41} - R_{44} Loan constraints of BAAC, agricultural cooperatives, village funds and the commercial banks (baht)

R_{45} - R_{53} Revenue from cropping systems (baht)

R_{54} Food consumption constraints (baht)

R_{55} Annual Equivalent Value from cropping systems (baht)

R_{56} - R_{59} Loan and interest repayments to BAAC, agricultural cooperatives, village funds and commercial banks (baht)

8.5 Decision variables at the watershed level

The models at the watershed level contain 67 decision variables composing of cropping systems, off-farm employment, hired labor, capital transfers, revenue distribution, loan and interest repayments. The activities are shown as follows;

X_1 Citrus production in the irrigated upland (rai)

X_2 Citrus production in the irrigated lowland (rai)

X_3 Longan production in the irrigated upland (rai)

X_4 Longan production in the irrigated lowland (rai)

X_5 Lychee production in the irrigated upland (rai)

X_6 Lychee production in the rainfed upland (rai)

X_7 Lychee production in the irrigated lowland (rai)

X_8 Lychee production in the rainfed lowland (rai)

X_9 Coffee production in the irrigated upland (rai)

X_{10} Coffee production in the rainfed upland (rai)

X_{11} Tea production in the irrigated upland (rai)

X_{12} Tea production in the rainfed upland (rai)

X_{13} Rice production in the rainfed lowland (rai)

X_{14} Sweet corn – sweet corn production in the irrigated upland (rai)

X_{15} Sweet corn - onion production in the irrigated upland (rai)

X_{16}	Sweet corn - sweet corn production in the rainfed upland (rai)
X_{17}	Sweet corn - onion production in the rainfed upland (rai)
X_{18}	Rice - rice production in the irrigated lowland (rai)
X_{19}	Rice - sweet corn production in the irrigated lowland (rai)
X_{20}	Rice - garlic production in the irrigated lowland (rai)
X_{21}	Rice - onion production in the irrigated lowland (rai)
X_{22}	Rice - sweet corn - sweet corn production in the irrigated lowland (rai)
X_{23}	Rice - garlic - sweet corn productions in the irrigated lowland (rai)
X_{24}	Rice - onion - sweet corn productions in the irrigated lowland (rai)
X_{25}	Off-farm work (man-days)
X_{26} - X_{37}	Hired labor activities from January to December (man-days)
X_{38} - X_{49}	Capital transfers from January to December (baht)
X_{50} - X_{53}	Loan activities from the Bank for Agriculture and Agricultural Co-operatives (BAAC), Agricultural cooperatives, Village funds and the commercial banks (baht)
X_{54}	Food consumption (baht)
X_{55} - X_{63}	Revenue from crop production (baht)
X_{64} - X_{67}	Loan and interest repayments to BAAC, agricultural cooperatives, village funds and commercial banks (baht)
X_{68}	Net annual revenue from crop production (baht)

This study did not divide the land use of citrus production which used bioextract for evaluation at the watershed level. Most of the farms in the Fang watershed involved in citrus production used chemicals; although bioextract was used, it was a small proportion overall although the use of bioextract would decrease chemical use and production costs. Although chemical use is necessary for disease control, a larger proportion of bioextract would have a beneficial effect on the environment as well as decreasing the reliance on external inputs.

8.6 Coefficients at the watershed level

Agriculture in the Fang watershed is made up from 2 major components, fruit production and cash crops:

1. The majority of the cash crops grown in the Fang watershed are rice, onions, garlic and sweet corn. These used the same variable coefficients which were used for all the farm types as explained in chapter 6.5.
2. A variety of fruit trees such as citrus, longan and lychee are planted in the Fang watershed.

For the longan and lychee figures, the watershed model used the same variable coefficients which were used for all the farm types as explained in chapter 6.5. For the citrus crop, the watershed model used the variable coefficients which were calculated on an average from 149 households from all 4 farm types.

The alternative crops this study selected were tea and coffee which are environmentally friendly as well as providing yield and revenue equal to or greater than the major crops grown in the Fang watershed. The production of these alternative crops would have the additional benefit of not affecting the farmer's health by avoiding chemical use. In this study, the watershed model used the variable coefficients which were used for all the farm types as explained in chapter 6.5.

8.6.1 Labor coefficients

The labor coefficients were analyzed by the time each crop needed for production per month. These activities included an average of household labor, exchange labor and hired labor man-days per rai per month. The cropping systems were given the sum of the labor coefficients for the crops in the systems and the data is shown in Appendix B Table B1.

8.6.2 Capital coefficients

The capital coefficients of crop production were analyzed by calculating the average of input factor costs to farmers for the crop production measured in baht per rai per month. The cropping systems were the total sum of the capital coefficients for each crop in the systems and the data is shown in Appendix B Table B2.

8.6.3 Revenue coefficients

The revenue coefficients were obtained from the yield multiplied by the sale price. The average monthly income per rai from the individual cash crops in the systems equaled the total sum per rai of the revenue coefficients for each crop in the systems and the data is shown in Appendix B Table B3.

8.7 Coefficients and constraints at the watershed level

In this study identified 8 objective goals as described in 9.1. The study calculated a figure for each goal averaged per rai for each crop by following the equation no. 3.9 to 3.15 as described in Chapter 3. The results are shown in Appendix B Table B4.

8.8 The watershed level model

The watershed model deals with Multiple Goal Linear Programming (MGLP). This study used the MGLP model for an optimal resource management of citrus-based farming systems at the watershed level. There is a natural assumption that the environmental objective at the watershed level is more prominent than the social or economic objectives. These are related to the 8 objective goals and then the weights are scored firstly by using the equal weight method, then by the AHP method and then the score is changed for multiple sensitivity analyses which predict future outcomes. The objective function with the MGLP model at the watershed level is the minimization of the total deviation from the goals as follows:

$$\min = (w_{w1}d_{w1}^{-} + w_{w2}d_{w2}^{-} - w_{w3}d_{w3}^{+} - w_{w4}d_{w4}^{+} - w_{w5}d_{w5}^{+} - w_{w6}d_{w6}^{+} - w_{w7}d_{w7}^{+} + w_{w8}d_{w8}^{-} \quad \ldots\ldots (9.1)$$

Where w_w represents the weight of *w*th goal,

d_w^- and d_w^+ are the negative and positive deviations of *f*th goal.

The constraints include:

1. Goals constraints

$$\sum_{u=1}^{4}\sum_{j=1}^{n}\sum_{i=1}^{3}(AEV_{crop\ iju} * Area_{crop\ iju}) + w_{w1}d_{w1}^{-} = GA \quad \ldots\ldots (9.2)$$

$$\sum_{u=1}^{4}\sum_{j=1}^{n}\sum_{i=1}^{3}(HL_{crop\ iju} * Area_{crop\ iju}) + w_{w2}d_{w2}^{-} = GH \quad \ldots\ldots (9.3)$$

$$\sum_{u=1}^{4}\sum_{j=1}^{n}\sum_{i=1}^{3}(IIEI_{crop\ iju} * Area_{crop\ iju}) - w_{w3}d_{w3}^{+} = GI \quad \ldots\ldots (9.4)$$

$$\sum_{u=1}^{4}\sum_{j=1}^{n}\sum_{i=1}^{3}(EP_{crop\ iju} * Area_{crop\ iju}) - w_{w4}d_{w4}^{+} = GE \quad \ldots\ldots (9.5)$$

$$\sum_{u=1}^{4}\sum_{j=1}^{n}\sum_{i=1}^{3}(N_{crop\ iju} * Area_{crop\ iju}) - w_{w5}d_{w5}^{+} = GN \quad \ldots\ldots (9.6)$$

$$\sum_{u=1}^{4}\sum_{j=1}^{n}\sum_{i=1}^{3}(SO_{crop\ iju} * Area_{crop\ iju}) - w_{w6}d_{w6}^{+} = GS \quad \ldots\ldots (9.7)$$

$$\sum_{u=1}^{4}\sum_{j=1}^{n}\sum_{i=1}^{3}(RV_{crop\ iju} * Area_{crop\ iju}) - w_{w7}d_{w7}^{+} = GR \quad \ldots\ldots (9.8)$$

$$\sum_{u=1}^{4}\sum_{j=1}^{n}\sum_{i=1}^{3}(NTFP_{crop\ iju} * Area_{crop\ iju}) + w_{w8}d_{w8}^{-} = GF \quad \ldots\ldots (9.9)$$

Where

GA	is the achievable goal level for the Annual Equivalent Value (AEV) from the cropping systems.
GH	is the achievable goal level for employment at the watershed level (HL).
GI and GE	are the achievable goal levels for independence from external inputs (IIEI) and the expenditure on pesticides (LI).
GN and GS	are the achievable goal levels for nitrogen use (N) and soil erosion (SE) respectively.
GR	is the achievable goal level dealing with revenue variance (RV).

GF is achievable goal level for revenue from non-timber forest products (NTFP).

*j*th is the cropping systems and off-farm work (j = 1,…,25)

*i*th is the crop production in the cropping systems (i = 1,…,3)

*u*th is the land unit u = 1,…,4 of irrigated upland, rainfed upland, irrigated lowland and rainfed lowland respectively).

2. Resource Constraints

$$\sum_{j=1}^{n}\sum_{i=1}^{3} X_{ij} \leq IU_w \quad \text{…. (9.10)}$$

$$\sum_{j=1}^{n}\sum_{i=1}^{3} X_{ij} \leq RU_w \quad \text{…. (9.11)}$$

$$\sum_{j=1}^{n}\sum_{i=1}^{3} X_{ij} \leq IL_w \quad \text{..... (9.12)}$$

$$\sum_{j=1}^{n}\sum_{i=3}^{3} X_{ij} \leq RL_w \quad \text{..... (9.13)}$$

$$\sum_{u=1}^{4}\sum_{j=1}^{n}\sum_{i=1}^{3}\sum_{m=1}^{12} HH_{miju}\, X_{ij} \leq THH_w \quad \text{..... (9.14)}$$

$$\sum_{u=1}^{4}\sum_{j=1}^{n}\sum_{i=1}^{3}\sum_{m=1}^{12} Hired_{miju}\, X_{ij} \leq THired_w \quad \text{..... (9.15)}$$

$$\sum_{u=1}^{4}\sum_{j=1}^{n}\sum_{i=1}^{3}\sum_{m=1}^{12} CashIn_{miju}\, X_{ij} \leq OwnInvest_w \quad \text{..... (9.16)}$$

$$\sum_{u=1}^{4}\sum_{j=1}^{n}\sum_{i=1}^{4}\sum_{m=1}^{12} Loan_{miju}\, X_{ij} \leq AvailableLoan_s \quad \text{….. (9.17)}$$

$$RepayLoan_s \geq 0 \quad \text{….. (9.18)}$$

$$FoodCon \geq BasicNeed\_HH_f \quad \text{….. (9.19)}$$

$$\sum_{u=1}^{4}\sum_{j=1}^{n}\sum_{i=1}^{3}\sum_{m=1}^{12} Revenue_{miju}\, X_{ij} \geq 0 \quad \text{..... (9.20)}$$

$$\sum_{u=1}^{4}\sum_{j=1}^{n}\sum_{i=1}^{3} NetAnualRev_{iju}\, X_{ij} \geq 0 \quad \text{..... (9.21)}$$

Where

IU_w The total irrigated upland available (rai)

RU_w The total rainfed upland available (rai)

IL_w The total irrigated lowland available (rai)

RL_w The total rainfed lowland available (rai)

X_{ij}	The cropping systems and off-farm work from the *j*th systems of the *i*th crop (*j* = 1,…,25 and i = 1,…,3)
HH_{miju}	The household labor from the *j*th plants of *i*th crop in the *m*th month from the *u*th land unit (*m* = 1,…,12 and *u* = 1,…, 4)
THH_w	The household labor available (man-days)
$Hired_{miju}$	The employment from the *j*th plants of *i*th crop in the *m*th month from the *u*th land unit
$THired_w$	The employment available (man-days)
$CashIn_{miju}$	The cash investment from the *j*th plants of *i*th crop in the *m*th month from the *u*th land unit
$OwnInvest_w$	The total owner capital investment (baht)
$Loan_{miju}$	The loan investment from the *j*th plants of *i*th crop in the *m*th month from the *u*th land unit
$AvailableLoan_s$	Total loan available (baht) from *s*th source (*s* = 1,…,4)
$RepayLoan_s$	Total repayment of loan (baht) to *s*th source (*s* = 1,…,4)
$FoodCon_w$	The food consumption of the household
$BasicNeed\_HH_w$	The basic need of food consumption in the household at the watershed
$Revenue_{miju}$	The revenue (baht) from the *j*th plants of *i*th crop in the *m*th month from the *u*th land unit
$NetAnualRev_{iju}$	The net annual revenue from crop production at the watershed

The model at the watershed level contained 84 decision variables. Cropping systems and off-farm work have 25 variables, hired labor and capital transfer have 24 variables, loan and interest repayments have 8 variables, revenue has 9 variables and food consumption and annual profit have 2 variables and there are 18 deviations (Table 8.6).

Table 8.6 Decision variables for the watershed model

Decision variables	Number
Cropping systems and off-farm work	25
Hired labor and capital transfer	24
Loan and interest repayments	8
Revenue variables	9
Food consumption and annual profit	2
Deviations	16
Total	84

There are 67 constraints. Variable goal objectives have 8 constraints, land units have 4 constraints, household labor and hired labor have 24 constraints, capital has 12 constraints, loan and interest repayments have 8 constraints, revenue has 9 constraints and food consumption and annual profit have 2 constraints (Table 8.7).

Table 8.7 Constraints for the watershed model

Constraints.	Number
Goal constraints	8
Land units	4
Household labor and hired labor	24
Capital constraints	12
Loan and interest repayments	8
Revenue constraints	9
Food consumption and annual profit constraints	2
Total	67

This chapter analyzed the weight values, the constraints and the coefficients. The weight value results were used for the analysis by the AHP method. The study analyzed the goal constraints (annual equivalent value, hired labor and yield variance etc.) and the resource constraints (land use, household labor, hired labor and loans etc.). It also analyzed the goal coefficients and the resource coefficients which were taken into account in the model at farm level as shown in Table 8.8.

Table 8.8 Multiple-goal programming at the farm level model

Constraints/Activities			Crop activities	Off-farm work	hired labor	Cash flows	Loan	Food consumption	Revenue from crop production	Repayment of loan	Net annual revenue	Deviations		
			X_1 ... X_{24}	X_{25}	X_{26} ... $X3_7$	X_{38} ... X_{49}	X_{50} … X_{53}	X_{54}	X_{55} ... X_{63}	X_{64} ... X_{67}	X_{68}	X_{69} ... X_{84}		
Objective												N1 … P8		
Constraints	Unit	Row											Signal	RHS : B
Land use	rai	R_1 ... R_4	a_{ij} ... a_{ie}										<=	b_1 … b_4
Household labor	man-day	R_5 ... R_{16}	a_{ij} ... a_{ie}	1	-1 ... -1								<=	b_5 … b_{16}
Hired labor	man-day	R_{17} ... R_{28}			1 ... 1								<=	b_{17} ... b_{28}
Cash flows	baht	R_{29} ... R_{40}	a_{ij} ... a_{ie}		[W]	-1... 1	-1 … -1		-1 ... -1				=	b_{29} ... b_{40}
Loan	baht	R_{41} ... R_{44}					1 ... 1						<=	b_{41} ... b_{44}
Revenue from crop production	baht	R_{45} … R_{53}	[R]						1 ... 1				=	b_{45} …b_{53}
Food consumption	baht	R_{54}						-1					=	b_{54}
Net annual revenue	baht	R_{55}				-1		1		1 ….. 1	1		=	b_{55}
Repayment of loan	baht	R_{56} ... R_{59}					[-1+r]			1 ….. 1			=	b_{56} ... b_{59}
Annual equivalent value	baht	GA	[AVE]									1 ….. -1	<=	C_1
Employment	man-day	GH	[HL]									1 ….. -1	<=	C_2
Independence from external inputs	baht	GI	[IIEI]									1 ….. -1	<=	C_3
Expenditure on pesticide	baht	GE	[EP]									1 ….. -1	<=	C_4
Nitrogen use	kg	GN	[N]									1 ….. -1	<=	C_5
Soil erosion	baht	GS	[SOW]									1 ….. -1	<=	C_6
Revenue variance	baht	GR	[RV]									1 ….. -1	<=	C_7
Revenue from non-timber forest products		GF		[NTFP]								1 ….. -1	<=	C_8

[W] = wage, [R] = revenue from crop production (average yield minus price), [r] = interest rate, C = goal constraints, [AVE] = annual equivalent value, [HL] = hired labor, [IIEI] = independence from external inputs, [EP] = expenditure on pesticide, [N] = nitrogen use, [SOW] = soil erosion, [RV] = revenue variance, [NTFP] = revenue from non-timber forest products, N = negative and P = positive