CHAPTER 11

SENSITIVITY ANALYSES FROM THE OPTIMAL SOLUTION

This chapter deals with the sensitivity analyses taken from the results obtained by the equal weight method at the farm and watershed levels. This chapter describes the range of allowable increases and decreases from the optimal activities and constraints without changing the optimal solution and achieved objective goals.

11.1 Sensitivity analysis from the optimal solution at the farm level

The sensitivity analyses take the optimal results which we arrived at in chapter 7 and details how changes in the coefficients of the objective function affect the solution and how changes in the availability of the resources affect the solution. In Table 11.1, the three columns labeled "Objective coefficient", "Allowable increase", and "Allowable decrease" give us the range of values for which the solution remains optimal.

The second part of the sensitivity report examines how a change to the resource availability affects the optimal solution (Table 11.2). A change to the resource availability changes the size of the feasible region. Increasing the resource availability with positive coefficients moves the limits for the allowable increase. Decreasing the resource availability with positive coefficients moves the limits for the allowable decrease. The shadow price indicates how the objective function will change when the resource availability is changed. If the resource availability is used to the maximum, the shadow price will have either a positive or negative value (Table 11.3). If the resource availability is not used to its fullest extent, the shadow price will be zero.

Table 11.1 Allowable increases and decreases in crop activity for the small farms using chemicals

Activity		Optimal	Reduced	Objective	Allowable	Allowable
Land unit (rai)	Crop	value	cost	coefficient	increase	decrease
Irrigated upland	Coffee	5.17	0.00	0.00	0.00	0.00
	Sweet corn-sweet corn	2.63	0.00	0.00	0.00	0.00
Rainfed upland	Coffee	1.23	0.00	0.00	2.08	0.00
Irrigated lowland	Citrus	3.91	0.00	0.00	4.09	23.50
	Rice-sweet corn	1.21	0.00	0.00	6.38	13.80
Rainfed lowland	Rice	0.18	0.00	0.00	0.00	0.00
	Lychee	0.87	0.00	0.00	0.00	0.00
Total area		15.20	-	-	-	-
Off-farm work (man-days/year)		67.25	0.00	0.00	0.00	0.00

11.1.1 Sensitivity analyses results from the equal weight method for the small farms using chemicals

1. Assessing the allowable increases and decreases for crop activities

The results for the change in the range of values for the crop activities are shown in Table 11.1. The optimal production plan remains unchanged:

- For the rainfed upland, the model assessed what would happen if the coffee production area increased by 2.08 rai or decreased to 0 rai from 1.23 rai. The optimal plan would not change.

- For the irrigated lowland, the model assessed what would happen if the citrus production area increased to 8 rai (3.91+4.09 rai) or decreased to -19.59 rai (3.91-23.50 rai). The area of crop production cannot be negative so realistically, the increase or decrease in the citrus production could result in an area of between 8 rai and 0 rai. Similarly, rice followed by sweet corn could be increased to 7.59 rai (1.21+6.38 rai) or decreased to -12.59 rai (1.21-13.80 rai) but realistically, the increase or decrease can be between 7.59 and 0 rai. In both cases, the solution remains optimal.

- For the other land units and crop activities, the model assessed that any increase or decrease from the optimal values would change the optimal solution.

- For the off-farm work activity, the model assessed that any increase or decrease from 67.3 man-days per year would change the optimal solution.

2. Assessing the allowable increases and decreases for resource constraints

2.1 Land unit constraints

The results found that the shadow price for the irrigated upland was -37,588 baht per rai. This indicates that if the irrigated upland was increased by 1 rai (from 7.80 to 8.80

rai), the corresponding profit at the optimal solution would increase by 37,588.31 baht. Similarly, if the irrigated upland was decreased by 1 rai (from 7.80 to 6.80 rai) the profit at the optimal solution would decrease by 37,588.31 baht. In both cases, if the size of the area changed by more than the allowable range, the optimal solution would change to a new value. As long as the irrigated upland availability is between 9.02 rai (7.8+1.22) and 7.39 rai (7.8-0.41 rai), the shadow price is valid. If there were an increase or decrease in the range of values from 9.02 to 7.39 rai, the optimal solution would be unchanged. The other results are shown in the Table 11.2.

Table 11.2 Allowable increases and decreases in land units
for the small farms using chemicals

Land unit (rai)	Optimal land use	Shadow price	Constraints R.H. side	Allowable increase	Allowable decrease
Irrigated upland	7.80	- 37,588.31	7.80	1.22	0.41
Rainfed upland	1.23	- 39,668.02	1.23	0.79	0.26
Irrigated lowland	5.12	- 29,194.26	5.12	0.66	0.22
Rainfed lowland	1.05	- 14,553.97	1.05	0.92	0.30
Total	15.20	-	15.20	-	-

2.2 Household labor constraints

For the sensitivity analysis of the household labor constraints, the results found that when household labor was used to its maximum value in each month, the shadow price would change according to the additional amount of hired labor needed. If the shadow price was 0, this meant that the model assessed the household labor as being sufficient for that month. If we look at June, the household labor is used to its maximum extent and the shadow price is -364.14 baht. This indicates that if household labor is increased by 1 man-day (from 51.75 to 52.75 man-days), the corresponding profit at the optimal plan will increase by 364.14 baht. If household labor is decreased by 1 man-day (from 51.75 to 50.75 man-days) the profit at the optimal plan will decrease by 364.14 baht as there will be a corresponding increase in hired labor. In both cases, if household labor

changes by more than the allowable range, the optimal solution changes to a new value. As long as household labor is within 52.42 (51.75+0.67 man-days) to 49.73 man-days (51.75-2.02 man-days), the shadow price is valid. If there were an increase or decrease within the range of values from 52.42 man-days to 49.73, the optimal plan would be unchanged. The other results are shown in the Table 11.3.

2.3 Hired labor constraints

The quantity of hired labor is related to the household labor constraint. If there is insufficient household labor, or the available household labor can be more profitably employed in off-farm work, hired labor will be needed, especially for the planting and harvesting. The results found that the shadow price for hired labor corresponded with the shadow price for household labor. The shadow price changed from 0 when the need for hired labor was greater than the constraint. During December for example, the citrus is harvested and there is the need for more labor than the constraint allows which results in a shadow price of -728.33 baht. This indicates that if hired labor is increased by 1 man-day (from 50 to 51 man-days), the corresponding profit at the optimal plan will decrease by 728.33 baht. If hired labor is decreased by 1 man-day (from 50 to 49 man-days) the profit at the optimal plan will increase by 728.33 baht. In both these cases, if the quantity of hired labor changes by more than the allowable range, the optimal solution changes to a new value. As long as hired labor is within the 52.57 to 49.14 man-days range, the shadow price is valid. If there were an increase or decrease within the range of values from 52.57 to 49.14 man-days, the optimal plan was unchanged. The other results are shown in the Table 11.3.

Table 11.3 Allowable increases and decreases for household and hired labor
for the small farms using chemicals

Activities	Household labor /hired labor (man-days)				
	Optimal value	Shadow price	Constraints R.H. side	Allowable increase	Allowable decrease
Household labor					
January	41.58	0.00	51.75	43.59	6.41
February	51.75	0.00	51.75	43.70	6.30
March	24.50	-219.46	51.75	5.13	3.35
April	48.63	0.00	51.75	30.44	19.56
May	6.93	0.00	51.75	45.68	4.32
June	51.75	-364.14	51.75	0.67	2.02
July	28.04	0.00	51.75	39.74	10.26
August	32.65	0.00	51.75	33.55	16.45
September	12.38	0.00	51.75	39.36	10.64
October	51.75	-203.00	51.75	3.91	0.78
November	15.27	0.00	51.75	unlimited	3.27
December	45.64	-728.33	51.75	2.49	0.83
Hired labor					
January	43.59	0.00	50.00	unlimited	6.41
February	43.70	0.00	50.00	unlimited	6.30
March	50.00	-219.46	50.00	5.13	3.35
April	30.44	0.00	50.00	unlimited	19.56
May	50.00	0.00	50.00	unlimited	4.32
June	50.00	-364.14	50.00	0.67	2.02
July	50.00	0.00	50.00	unlimited	10.26
August	33.55	0.00	50.00	unlimited	16.45
September	39.36	0.00	50.00	unlimited	10.64
October	50.00	-203.00	50.00	3.91	0.78
November	46.73	0.00	50.00	27.08	3.27
December	50.00	-728.33	50.00	2.57	0.86

2.4   Owner investment and loan constraints

The results found that after we take into account all owner investments and outside loans, the shadow price is 0. This indicates that the money investment is sufficient and its does not affect the profit for the optimal solution. The model did not recommend the agricultural co-cooperative and the village fund as a source of loans. With the owner investment, the model assessed an allowable decrease to -90,666.48 baht or an unlimited increase, but realistically, the increase or decrease can be between unlimited and 0 baht. The BAAC loan allowed an increase to 94,556.76 baht or a decrease to 74,370.72 baht which, in both cases, were within the allowed range and so the solution remained optimal (Table 11.4).

Table 11.4 Allowable increases and decreases for investments and loans
for the small farms using chemicals

Source of investment	Optimal value	Shadow price	Constraints R.H. side	Allowable increase	Allowable decrease
Owner investment	57,721.46	0.00	57,721.46	unlimited	148,387.94
BAAC	89,519.11	0.00	200,000.00	5,037.65	15,148.39
Agricultural co-operative	0.00	0.00	20,000.00	unlimited	15,008.78
Village fund	0.00	0.00	30,000.00	4,835.25	14,539.75

2.5   Goal constraints

The results for the goal constraints can be divided into two groups. The first group consisted of the goals which cached its limit (maximum of their constraints), namely, the annual equivalent value and the off-farm work goals. If the annual equivalent value decreased to 166,675.2 baht or the off-farm work decreased to 13,450.38 baht, (optimal value minus allowable decrease), the optimal solution was unchanged. The second group was made up from the remaining goals. In this group, the optimal value was a lot lower than the constraints and so the shadow price was 0 and was unlikely to change. If these goals were decreased to lower than the optimal value, the optimal solution will be changed (Table 11.5).

Table 11.5 Allowable increases and decreases for the goal constraints for the small farm using chemicals

Goal	Explanation	Optimal value	Shadow price	Constraints R.H. side	Allowable increase	Allowable decrease
GA	Annual equivalent value (baht)	231,317.41	0.00	231,317.41	unlimited	64,642.20
GH	Hired labor (man–days)	181.82	0.00	414.38	unlimited	232.55
GI	Independence from external inputs (baht)	154,436.67	0.00	412,665.89	unlimited	258,229.21
GL	Loan investment (baht)	72,731.51	0.00	273,044.60	unlimited	200,313.09
GY	Yield variance (kg)	9,094.16	0.00	18,215.77	unlimited	9,121.61
GR	Revenue variance (baht)	197,994.25	0.00	499,311.92	unlimited	301,317.67
GS	Off-farm work (baht)	18,860.08	0.00	18,860.08	unlimited	5,409.70

11.1.2 Sensitivity analyses results from the equal weight method for the small farms using chemicals and bioextract

1. Assessing the allowable increases and decreases for crop activities

The results for the change in the range of values for the crop activities where the optimal production plan remains unchanged are shown in Appendix D Table D1. For the irrigated upland, sweet corn followed by sweet corn could be increased or decreased within the range of 6.6 to 3.06 rai, for the irrigated lowland, rice followed by sweet corn and sweet corn allowed an increase or decrease within the range of 6.09 to 3.83 rai and for lychee production in the rainfed lowland, the model allowed for an increase or decrease between 10.62 to 0 rai. Within this range, the optimal plan was unchanged. For the off-farm work activity, any change for 62.83 man-days per year would affect the optimal solution.

2. Assessing the allowable increases and decreases for resource constraints

2.1 Land unit constraints

The results found that the shadow price for the irrigated upland was -45,598.56 baht per rai. This indicated that if the irrigated upland was increased or decreased by 1 rai, the corresponding profit at the optimal solution would increase or decrease by 45,598.56 baht. In both cases, if the size of the area changed by more than the allowable range, the optimal solution would change to a new value. As long as the irrigated upland availability is between 4.59 rai and 3.08, the shadow price is valid. If there were an increase or decrease within the range of values from 4.59 to 3.08 rai, the optimal solution would be unchanged. The other results are shown in Appendix D Table D2.

2.2 Household labor constraints

The results found that in March, the household labor is used to its maximum extent and the shadow price is -534.02 baht. This indicates that if the household labor was increased or decreased by 1 man-day, the corresponding profit at the optimal plan would increase or decreases by 534.02 baht. In both cases, if the household labor changes by more than the allowable range, the optimal solution changes to a new value. As long as the household labor is within 51.88 to 49.12 man-days, the shadow price is valid. If there were an increase or decrease within the range of values from 51.88 man-days to 49.12, the optimal plan was unchanged. The other results are shown in Appendix D Table D3.

2.3 Hired labor constraints

The results found that the shadow price for hired labor corresponded with the shadow price for household labor. The shadow price changed from 0 when the need for hired labor was greater than the constraint. During December, there is the need for more labor than the constraint allows. This results in a shadow price of -452.29 baht. This indicates that if the hired labor is increased or decreased by 1 man-day, the corresponding profit at the optimal plan would increase or decreases by 452.29 baht. In both these cases, if the quantity of hired labor changes by more than the allowable range, the optimal solution changes to a new value. As long as the hired labor is within the 50.37 man-days to 49.87 man-days range, the shadow price is valid. If there were an increase or decrease within the range of values from 50.37 man-days to 49.87 man-days, the optimal plan would be unchanged. The other results are shown in Appendix D Table D3.

2.4 Owner investment and loan constraints

The results found that the model did not recommend the agricultural co-cooperative and the village fund as a source of loans. With the owner investment, the model assessed an

unlimited increase or an allowable decrease to 0 baht. The BAAC loan allowed an unlimited increase or a decrease to 0 baht which, in both cases, were within the allowed range and so the solution remained optimal (Appendix D Table D4).

2.5   Goal constraints

The results can be divided into two groups for further analysis. The first group was made up of the annual equivalent value and the off-farm work goals as they reached the maximum of their constraints. If the annual equivalent value decreased to 157,467.49 baht or the value of off-farm work decreased to 12,566.43 baht, the optimal solution was unchanged. The second group was made up from the remaining goals. In this group, the optimal value was a lot lower than the constraints and so the shadow price was 0 and was unlikely to change. If these goals were decreased to lower than the optimal value, the optimal solution would change (Appendix D Table D5).

11.1.3 Sensitivity analysis results from the equal weight method for the large farms using chemicals

1.   Assessing the allowable increases and decreases for crop activities

The results found that optimal production plan remains unchanged when the changes are within the range of values for the crop activities as shown in Appendix D Table D6. For the irrigated lowland, if the citrus production area increased or decreased slightly, the solution would remain optimal. For the off-farm work activity, the model assessed that any increase or decrease from the optimal value would change the optimal solution.

2. Assessing the allowable increases and decreases for resource constraints

2.1 Land unit constraints

The results found that the shadow price for the irrigated upland was -26,415.40 baht per rai. This indicated that if the irrigated upland was increased or decreased by 1 rai, the corresponding profit at the optimal solution would increase or decrease by 26,415.40 baht. In both cases, if the size of the area changed by more than the allowable range, the optimal solution would change to a new value. As long as the irrigated upland availability is between 95.81 rai and 70.71 rai, the shadow price is valid. If there were an increase or decrease within the range of values from 95.81 to 70.71 rai, the optimal solution would be unchanged. The other results are shown in Appendix D Table D7.

2.2 Household labor constraints

The results found that when we looked at February, household labor was used to its maximum extent and the shadow price is -203 baht. This indicates that if the household labor was increased or decreased by 1 man-day, the corresponding profit at the optimal plan would increase or decreases by 203 baht. In both cases, if the household labor changes by more than the allowable range, the optimal solution changes to a new value. As long as the household labor is within 21.02 to 13.50 man-days, the shadow price is valid. If there were an increase or decrease within the range of values from 21.02 to 13.50 man-days, the optimal plan would be unchanged. The other results are shown in Appendix D Table D8.

2.3 Hired labor constraints

The results found that during December, there was a need for more labor than the constraint allowed. This results in a shadow price of -728.33 baht. This indicates that if the hired labor was increased or decreased by 1 man-day, the corresponding profit at the

optimal plan would increase or decreases by 728.33 baht. In both these cases, if the quantity of hired labor changes by more than the allowable range, the optimal solution would change to a new value. As long as the hired labor is within the 752.85 man-days to 734.55 man-days range, the shadow price is valid. If there were an increase or decrease within the range of values from 752.85 man-days to 734.55 man-days, the optimal plan would be unchanged. The other results are shown in Appendix D Table D8.

2.4   Owner investment and loan constraints

The results found that the model did not recommend the BAAC and the agricultural co-operative as a source of loans. The model allowed for an unlimited increase in the owner investment or a decrease to 0 baht without changing the optimal value. The loans from the commercial banks allowed an increase to 1,192,667.51 baht or decrease to 265,828.11 baht from 984,907.90 which, in both cases, were within the allowed range and so the solution remained optimal (Appendix D Table D9).

2.5   Goal constraints

The results can be divided into two groups for further analysis. The first group was made up of the annual equivalent value and the off-farm work goals as they reached the maximum of their constraints. If the annual equivalent value decreased to 3,035,897.31 baht or the value of the off-farm work decreased to 78,437.57 baht, the optimal solution was unchanged. The second group was made up from the remaining goals. In this group, the optimal value was a lot lower than the constraints and so the shadow price was 0 and was unlikely to change. If these goals were decreased to lower than the optimal value, the optimal solution would be changed (Appendix D Table D10).

11.1.4 Sensitivity analyses results from the equal weight method for the large farms using chemicals and bioextract

1. **Assessing the allowable increases and decreases for crop activities**

The results found that if the crop activities for each land use changed from the optimal value, the optimal plan would be changed. The crop activities are shown in Appendix D Table D11.

2. **Assessing the allowable increases and decreases for resource constraints**

   2.1   Land unit constraints

The results found that the shadow price for the irrigated upland was -49,101.09 baht per rai. This indicates that if the irrigated upland was increased or decreased by 1 rai, the corresponding profit at the optimal solution would increase or decreases by 49,101.09 baht. In both cases, if the size of the area changes by more than the allowable range, the optimal solution would change to a new value. The results for the irrigated upland did not allow for an increase but did allow for a minimal decrease so if the irrigated upland is between 16.75 rai and 16.15 rai, the shadow price is valid. If there were an increase or decrease within the range of values from 16.75 to 16.15 rai, the optimal solution would be unchanged. The other results are shown in the Appendix D Table D12.

   2.2   Household labor constraints

The results found that when we looked at January, the household labor was used to its maximum extent and the shadow price was -92.21 baht. This indicates that if the household labor was increased or decreased by 1 man-day, the corresponding profit at the optimal plan would increase or decreases by 92.21 baht. In both cases, if the

household labor changes by more than the allowable range, the optimal solution changes to a new value. As long as the household labor is within 43.75 to 43.41 man-days, the shadow price is valid. If there were an increase or decrease within the range of values from 43.75 to 43.41 man-days, the optimal plan would be unchanged. The other results are shown in the Appendix D Table D13.

2.3 Hired labor constraints

The results found that during December for example, there is the need for more labor than the constraint allows. This results in a shadow price of -392.21 baht. This indicates that if hired labor is increased or decreased by 1 man-day from the optimal value, the corresponding profit at the optimal plan would increase or decreases by 392.21 baht. In both these cases, if the quantity of hired labor changes from the optimal value, the shadow price and the optimal plan would be changed. The other results are shown in Appendix D Table D13.

2.4 Owner investment and loan constraints

The results found that the model did not recommend the BAAC and the agricultural co-cooperative as a source of loans. With the owner investment, the model assessed an unlimited increase or a decrease to 0 baht from the optimal value of 480,800.54 baht. The loan from the commercial banks allowed an unlimited increase or a decrease to 0 baht which, in both cases, were within the allowed range and so the solution remained optimal (Appendix D Table D14).

2.5 Goal constraints

The results can be divided into two groups for further analysis. The first group was made up of the annual equivalent value and the off-farm work goals as they reached the maximum of their constraints. If the annual equivalent value decreased to 727,199.80 baht or the value of the off-farm work decreased to 18,570.69 baht, the optimal solution

was unchanged. The second group was made up from the remaining goals. In this group, the optimal value was a lot lower than the constraints and so the shadow price was 0 and was unlikely to change. If these goals were decreased to lower than the optimal value, the optimal solution will be changed (Appendix D Table D15).

11.2. Sensitivity analyses calculated from the equal weight method results for the watershed level

1. Assessing the allowable increases and decreases for crop activities

The results for the change in the range of values for the crop activities are shown in Table 11.6. The optimal production plan remains unchanged:

- For the irrigated upland, the sensitivity analysis allowed for citrus to have an unlimited increase or a decrease of 97,538 from the optimal at 107,073 rai.
- For the rainfed upland, the sensitivity analysis allowed for sweet corn followed by sweet corn to have an unlimited increase or a decrease of 86,450 rai from the optimal at 231,100 rai.
- For the irrigated lowland, the sensitivity analysis allowed for citrus to have an unlimited increase or a decrease of 94,317 rai from the optimal at 121,110 rai.
- For the rainfed lowland, the model assessed the area as being suitable for rice at 40,590 rai. The sensitivity analysis did not allow for any increase or decrease and so any change would affect the optimal solution.
- For the off-farm work activity, the model assessed that any increase or decrease from the optimal value of 746,991 man-days per year would change the optimal solution.

Table 11.6 Allowable increases and decreases in crop activity at the watershed level

Land unit (rai)	Activity Crop	Optimal value	Reduced cost	Objective coefficient	Allowable increase	Allowable decrease
Irrigated upland	Citrus	107,073	0	0	unlimited	97,538
Rainfed upland	Coffee	231,100	0	0	unlimited	86,450
	Sweet corn- sweet corn	27,741	0	0	unlimited	0
Irrigated lowland	Citrus	121,110	0	0	unlimited	94,317
Rainfed lowland	Rice	40,590	0	0	0	0
Total area		527,614	-	-	-	-
Off-farm work (man-days)		746,991	0	0	0	0

2. Assessing the allowable increases and decreases for the resource constraints

1. Land unit constraints

The results found that the shadow price for the irrigated upland was -42,908 baht per rai. This indicates that if the irrigated upland was increased by 1 rai, the corresponding profit at the optimal solution would increase by 42,908 baht. Similarly, if the irrigated upland was decreased by 1 rai, the profit at the optimal solution would decrease by 42,908 baht. In both cases, if the size of the area changes by more than the allowable range, the optimal solution changes to a new value. As long as the irrigated upland availability is between unlimited and 77,304 rai ("optimal land use" minus the "allowable decrease" columns), the shadow price is valid. If there were an increase or decrease within the range of values from unlimited to 77,304 rai, the optimal solution would not change. The other results are shown in Table 11.7.

Table 11.7 Allowable increases and decreases for the land unit constraints
at the watershed level

Land unit (rai)	Optimal land use	Shadow price	Constraints R.H. side	Allowable increase	Allowable decrease
Irrigated upland	107,073	- 42,908	107,073	unlimited	29,769
Rainfed upland	258,841	- 39,264	258,841	unlimited	186,285
Irrigated lowland	121,110	- 22,982	121,110	unlimited	71,024
Rainfed lowland	40,590	- 22,053	40,590	unlimited	16,537
Total	527,614	-	527,614	-	-

2. Household labor constraints

The sensitivity analysis of the household labor constraints found that when the household labor was used to its maximum value in each month, the shadow price would change according to the additional amount of hired labor needed. If the shadow price

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was 0, this meant that the model assessed the household labor as being sufficient for that month. If we look at February, the household labor is used to its maximum extent and the shadow price was -203 baht. This indicates that if the household labor was increased or decreased by 1 man-day, the corresponding profit at the optimal plan would increase or decrease by 203 baht. In both cases, if the household labor changes by more than the allowable range, the optimal solution changes to a new value. As long as household labor is within unlimited to 1,142,398 man-days ("optimal value" minus the "allowable decrease" columns), the shadow price is valid. If there were an increase or decrease within the range of values from unlimited to 1,142,398 man-days, the optimal plan was unchanged. The other results are shown in Table 11.8.

3.   Hired labor constraint

The quantity of hired labor is related to the household labor constraint. If there is insufficient household labor, or the available household labor can be more profitably employed in off-farm work, hired labor will be needed, especially for the planting and harvesting. The results found that the shadow price for hired labor corresponded with the shadow price for household labor. The shadow price changed from 0 when the need for hired labor was greater than the constraint. During December, there is the need for more labor than the constraint allows. This results in a shadow price of -521 baht. This indicates that if the hired labor is increased or decreased by 1 man-day, the corresponding profit at the optimal plan will increase or decrease by 521 baht. In both these cases, if the quantity of hired labor changes by more than the allowable range, the optimal solution changes to a new value. As long as the hired labor is within the unlimited to 789,640 man-days, ("optimal value" minus "allowable decrease" columns), the shadow price is valid. If there was an increase or decrease within that range of values, the optimal plan was unchanged. The other results are shown in the Table 11.8.

Table 11.8 Allowable increases and decreases in household labor and hired labor constraints at the watershed level

Activities	Household labor /hired labor (man-days)				
	Optimal value	Shadow price	Constraints R.H. side	Allowable increase	Allowable decrease
Household labor					
January	1,172,358	0	1,172,358	unlimited	59,738
February	1,172,358	-203	1,172,358	unlimited	29,960
March	1,172,358	-364	1,172,358	unlimited	9,738
April	729,903	0	1,172,358	unlimited	243,931
May	928,426	0	1,172,358	unlimited	202,247
June	1,042,337	0	1,172,358	unlimited	130,021
July	1,142,398	0	1,172,358	unlimited	113,910
August	970,110	0	1,172,358	unlimited	202,247
September	978,783	0	1,172,358	unlimited	193,574
October	1,172,358	0	1,172,358	unlimited	100,061
November	789,640	0	1,172,358	unlimited	382,717
December	1,172,358	-521	1,172,358	unlimited	8,673
Hired labor				unlimited	
January	816,915	0	845,425	unlimited	133,358
February	830,722	-203	845,425	unlimited	115,522
March	845,425	-364	845,425	unlimited	83,001
April	310,115	0	845,425	unlimited	431,325
May	391,264	0	845,425	unlimited	437,781
June	677,014	0	845,425	unlimited	196,912
July	418,111	0	845,425	unlimited	124,685
August	202,731	0	845,425	unlimited	477,879
September	276,955	0	845,425	unlimited	437,843
October	631,505	0	845,425	unlimited	326,933
November	621,147	0	845,425	unlimited	296,973
December	845,425	-521	845,425	unlimited	55,785

4. Owner investment and loan constraints

The results found that after we take into account all owner investments and outside loans, the shadow price is 0. This indicates that the money investment is sufficient and its does not affect the profit for the optimal solution. The model did not recommend the agricultural co-operative, the village fund and commercial banks as a source of loans. With the owner investment, the model assessed an unlimited increase or an allowable decrease to 605 million baht ("optimal value" minus "allowable decrease" columns). The BAAC loan allowed for an unlimited increase or a decrease to 1,897 million baht which, in both cases, were within the allowed range and so the solution remained optimal (Table 11.9).

5. Goal constraints

The results can be divided into two groups for further analysis. The first group was made up of the annual equivalent value, employment, nitrogen use and the revenue from non-timber forest products goals as they reached the maximum of their constraints. If the annual equivalent value decreased to 1,165 million baht, employment decreased to 4,054,644 man-days, nitrogen use decreased to 8,854,700 kilograms or revenue from non-timber forest products decreased to 275 million baht, the optimal solution was unchanged. The second group was made up from the remaining goals. In this group, the optimal value was a lot lower than the constraints and so the shadow price was 0 and was unlikely to change. If these goals were decreased to lower than the optimal value, the optimal solution would be changed (Table 11.10).

Table 11.9 Allowable increases and decreases in owner and loan investment constraints at the watershed level

Source of investment (baht)	Optimal value	Shadow price	Constraints R.H. side	Allowable increase	Allowable decrease
Owner investment	2,566,001,076	0	2,566,001,076	unlimited	1,960,085,000
BAAC	2,910,372,823	0	4,642,800,000	unlimited	1,013,071,634
Agricultural co-operative	0	0	464,280,000	unlimited	186,478,285
Village fund	0	0	689,455,800	unlimited	291,015,481
Commercial banks	0	0	1,160,700,000	unlimited	946,748,877

Table 11.10 Allowable increases and decreases for the goal constraints at the watershed level

Goal	Explanation	Optimal value	Shadow price	Constraints R.H. side	Allowable increase	Allowable decrease
GA	Annual equivalent value (baht)	8,100,025,423	0	8,100,025,423	unlimited	6,934,688,326
GH	Employment (man–days)	9,748,888	0	9,748,888	unlimited	5,694,244
GI	Independence from external inputs (baht)	764,578,968	0	9,370,646,861	unlimited	436,358,739
GE	Expenditure on pesticides (baht)	287,518,018	0	3,067,153,184	unlimited	134,731,460
GN	Nitrogen use (kg)	20,066,411	0	20,066,411	unlimited	11,211,711
GS	Soil erosion (tones)	1,875	0	7,469	unlimited	5,581
GR	Revenue variance (baht)	452,708,709	0	8,975,011,150	unlimited	250,619,910
GF	Revenue from non-timber forest products (baht)	420,949,785	0	420,949,785	unlimited	145,329,520