RD10-00U-P(j)

PN-ACQ-230

INTERACTIVE MULTIPLE GOAL LINEAR PROGRAMMING: A MARRIAGE OF LINEAR PROGRAMMING AND MULTI-CRITERIA ANALYSIS[1]

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INTERACTIVE MULTIPLE GOAL LINEAR PROGRAMMING: A MARRIAGE OF LINEAR PROGRAMMING AND MULTI-CRITERIA ANALYSIS[1]

by

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February 2001

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[1] This publication was made possible through a grant provided by the U. S. Agency for International Development (USAID) under the terms of Grant No. 492-G-00-00-00001-00. The opinions expressed herein are those of the author and do not necessarily reflect the views of the U. S. Agency for International Development.

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TABLE OF CONTENTS

List of Tables

List of Figures

1. INTRODUCTION 1

2. THE IMGLP METHODOLOGY 2

3. AN ILLUSTRATION 4
   - 3.1 Zero Round Optimization 5
   - 3.2 Impact of Resource Sharing 6
   - 3.3 Impact of Technology 7
   - 3.4 Scenario Analysis 8

4. CONCLUDING REMARKS 9

References

LIST OF TABLES

Table 1 Results of Zero Optimization Rounds using IMGLP

Table 2 Results of Subsequent Optimization Rounds using IMGLP

Table 3 Goal Achievement and Resource Allocation under Zero-Round Optimization

Table 4 Effect of Resource Sharing on Goal Achievement and Resource Allocation, 2000

Table 5 Impact of Technology and Resource Allocation

Table 6 List of Possible Objectives for SIFR

LIST OF FIGURES

Figure 1 Operational Framework of Land Use Planning and Analysis

Figure 2 Impact of Change in Available Labor on Goal Achievements

Figure 3 Impact of Change in Irrigated Area on Goal Achievements

INTERACTIVE MULTIPLE GOAL LINEAR PROGRAMMING: A MARRIAGE OF LINEAR PROGRAMMING AND MULTI-CRITERIA ANALYSIS

1. INTRODUCTION

Optimization problems with a single objective function and constraints that are linear in the decision variables will fit very nicely for a linear programming model in the determination of the optimal solution. In most optimization problems, however, there are several objectives that the stakeholders want to satisfy at the same time, some of which are conflicting with each other. What they want is to seek a good compromise among the several objectives. Charnes, et al. (1968) proposed a technique called goal programming to handle these types of situations.

Goal programming is a unique approach to the problem of trying to achieve a set of simultaneously unattainable goals. This technique entails minimizing the sum of the deviations (positive and negative) from the management goals instead of maximizing or minimizing a single objective function as in the case of linear programming. Goal programming finds its applications to various multiple goal allocation problems. Lee and Clayton (1972) demonstrated its use in multi-criteria school busing model. Rosario (1987) applied goal programming in river basin land use allocation. Finally, Balangue (1979) applied it on land use allocation for Mt. Makiling. Often, however, when exploring options for land use, the goals are not very clear. Moreover, it is not clear which goal should have the highest priority. Both the goals of the options and the prioritization of the objectives depend on the policy view of the stakeholders. This shortcoming of goal programming can be filled up through the use of multi-criteria analysis (MCA).

MCA gained its acceptance because of the difficulty of conducting cost-benefit analysis. However, it carries with it different problems. Although the processes for normalization appear unexceptionable, the scoring of the normalized results itself appears to lack a theoretical rationale. There is clearly a significant risk of the outcome being arbitrary depending on who is chosen to express the weights. Some studies use experts with and without iterative procedures (such as Delphi), some use decision-makers, some use stakeholders, while some use public opinion. Although MCA is able to prioritize land uses, it can not and will not be able to quantify the benefits and costs of the different land uses to society.

A more suitable tool for this kind of multiple criteria problem is the Interactive Multiple Goal Linear Programming (IMGLP). This tool can simultaneously handle multi-criteria as long as the criteria can be expressed mathematically and at the same time is capable of optimizing the multiple objective functions specified. De Wit et al. (1988), state that:

> *"...satisfactory solutions from the point of view of the **user** may be obtained in subsequent iteration cycle by tightening one of the goal restrictions and repeating the iteration cycle for the other objectives. This stepwise maximization of the objectives under increasingly tighter restrictions on the other goal reduces the solution space. In that way, the cost of satisfying one objective in terms of what must be sacrificed on the*

other objectives is expressed. At the end, the user is faced with a solution space in which he can not improve on any of his objectives without sacrificing on the others..."

The primary goal of this paper is to provide an alternative methodology that will integrate LP and MCA in coming up with sets of land use options for the Samar Island Forest Reserve. The paper is organized as follows: Section II discusses the methodology of Interactive Multiple Goal Linear Programming (IMGLP); an example is provided in Section III to illustrate the application of the methodology to land use planning and impact assessment; finally, the paper concludes with some recommendations on the implementation of the methodology and a set of objectives which can be simultaneously pursued as well as information requirements for SIFR.

2. THE IMGLP METHODOLOGY

The IMGLP procedure consists of a number of optimization rounds. Each round comprises several optimization runs. In each optimization run, the model is optimized for one objective function, while the other objectives are used as constraints. Upper or lower bounds can be put on these **goal constraints.**

In the so-called **zero round** of the procedure, the model is optimized for each of the objective functions without putting any upper or lower bounds on the goal constraints. In this zero round, the feasible space (playing field) for the objective functions is determined. These extreme values of the objective functions are important in choosing upper or lower bounds for goal constraints in the scenarios. The compatibility of the objective functions are taken into consideration in the subsequent rounds by putting the upper or lower bounds on relevant (from the stakeholders' point of view) objective functions and performing optimization runs for various objective functions.

The result of the zero round can be tabulated as shown in ***Table 1***. The diagonal elements (bi) represent the best attainable values of each row in the matrix results. The worst values (Wi) correspond to the lowest value of row i in the matrix of results. For each goal, i, no lower value than Wi needs to be accepted. The initial freedom of choice for each objective, i.e., the difference between the best and worst, is made explicit in this way.

Table 1
Results of Zero Optimization Rounds using IMGLP

Zero Round	Results of the Optimization for Objective 1	i	N	Worst Value	Best Value
Objective 1	b_1			W_1	b_1
Objective i		bi		W_i	b_i
Objective N			b_N	W_N	b_N

The next step consists of selecting out of the W-vector, the objective with the worst value, which is considered the most unacceptable. This provides a higher lower bound for that objective. Let that one selected be Objective i. The optimum value obtained for goal i in the zero round forms the upper limit to which the right hand side of this objective can be raised. Suppose the desired lower bound of objective i is Mi, then a new cycle of optimization can be performed with this lower bound for objective i. The results of that optimization are given in ***Table 2***.

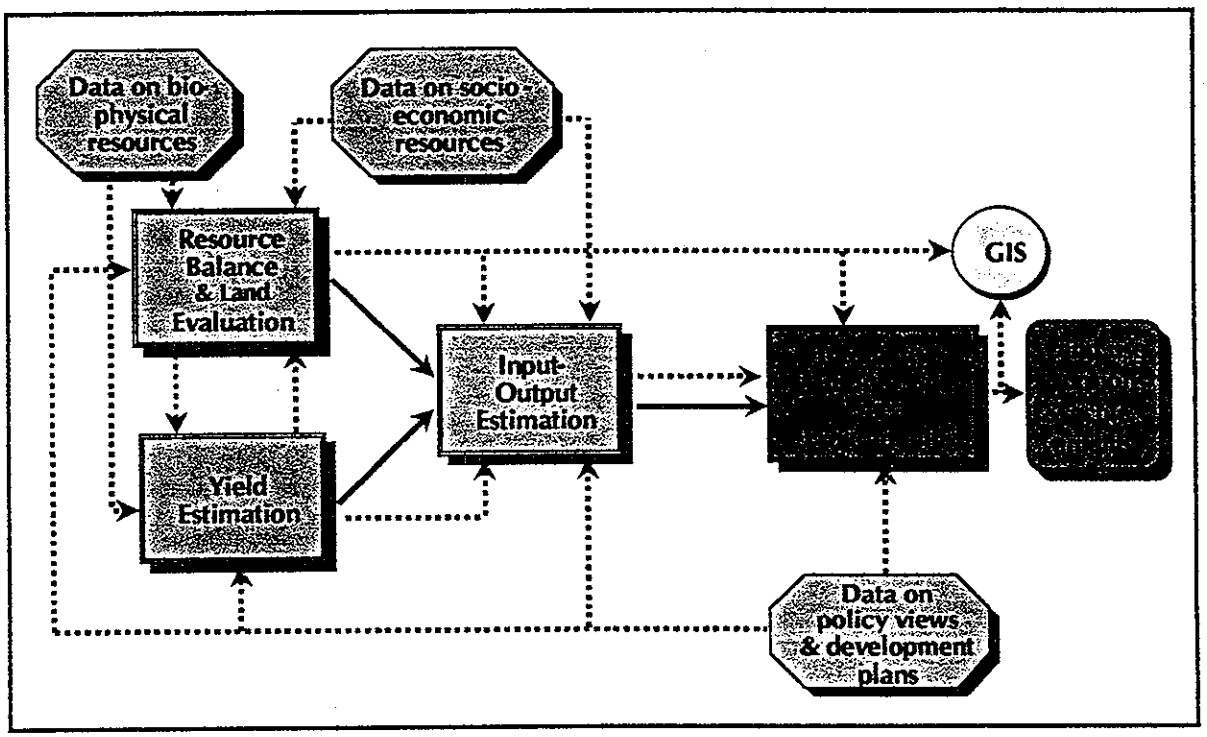
Table 2
Results of Subsequent Optimization Rounds using IMGLP

1th Round	Lower Bound	Results of the Optimization for Objective 1	i	N	Worst Value	Best Value
Objective 1	$>W_1$	b_1			W_1	b_1
Objective i	$>M_i$		b_i		W_i	b_i
Objective N	$>W_N$			b_N	W_N	b_N

The whole process of optimization consists of subsequent rounds as described above. In each step, the costs of safeguarding a minimum level for a particular objective in terms of attainable level for the other objectives are revealed. This information helps in deciding which minimum requirement to tighten next, and to what extent. In this way, the feasible combinations of goal values can be explored until only one combination is left. In general, the procedure is stopped at an earlier stage, leaving an area within which all the objective functions have acceptable values: the *window of opportunities* or *space of solutions*.

However, multiple goal analysis is just one activity in land use planning. Land use planning comprises various components. The systems methodologies for improving land use planning are being operationalized in land use planning and analysis. It is intended as a decision support system for strategic planning. The IMGLP technique (De Wit, et al., 1988) is used to determine optional land use for development planning and can deal with conflicts in land use objectives based on pronouncements of different stakeholders in the area. Land use planning and analysis is composed of three major parts, namely; (1) land evaluation including assessment of resource availability, land suitability, yield estimation, and input-output estimation per production activities; (2) scenario formulation based on policy views and development plans; and (3) optimization through the application of an IMGLP model (Laborte, et al., 1999). The schematic structure of the system is presented in *Figure 1*. The following section illustrates the application of the methodology.

Figure 1
Operational Framework of Land Use Planning and Analysis



3. AN ILLUSTRATION

To illustrate the methodology, data from the province of Ilocos Norte is utilized in formulating an agricultural land use plan for the province.

The province of Ilocos Norte is considered as one of the highly diversified provinces of the Philippines. In the study, 17 agricultural crops are considered, namely; rice, white and yellow corn, garlic, mungbean, peanut, tomato, tobacco, cotton, sweet potato, onion, sweet pepper, eggplant, vegetables, root crops, sugarcane, and watermelon. The combinations of these products in cropping systems, e.g. rice-garlic, rice-garlic-mungbean, produced 23 land use types. The existing land use types considered were based on the inventory of current cropping systems in the irrigated, rainfed and upland ecosystems.

The goals and priorities of the whole province and its component municipalities were derived from existing development plans of the province. These were validated during consultations and meetings with the different stakeholders (Francisco et al., 1998). The priority goals identified and articulated by the stakeholders are as follows:

a. Crop production
   1) Maximize rice production
   2) Maximize non-rice production
   3) Maximize water use efficiency

b. Socio-economic
   4) Maximize employment in agriculture
   5) Maximize farmer's income
   6) Maximize provincial income

c. Environment
   7) Minimize soil erosion
   8) Minimize pesticide use
   9) Minimize fertilizer use
   10) Minimize nitrate leaching

The goals/objectives were translated into mathematical expression and formulated as a multiple objective linear programming model.

Two crop production technology scenarios were considered in this example: average farmer's practice (medium technology) and best farmer's practice (high technology). Scenarios indicating the possibility of sharing limited resources in the province such as labor and irrigation water were also considered. Labor-sharing assumes that labor force can freely move among adjacent municipalities of the province due to ease in mobility in most parts of the region. Sharing of water resources is assumed possible among adjacent land units served by the same existing irrigation systems.

The sets of objective functions and constraints were translated into mathematical equation and optimization was done using XPRESS MP (Dash Associates, 1999) mathematical programming software. For illustrative purpose only the results of the optimization and scenario analysis for two objective functions, namely maximizing income, maximizing rice production and their implications on the other objectives will be discussed.

3.1 Zero Round Optimization

Result of zero-round are summarized in ***Table 3***. Under all objective functions optimized, all available land for agriculture is fully allocated. Maximization of income allocates all the land resources to rice-tomato cropping system. On the other hand maximizing rice production yields a land allocation all devoted to rice production (rice-rice and rice-rice-rice). In terms of labor and water utilization, rice production maximization is more labor-using and water-using than income maximization. The labor allocation for rice production is 11% (5,005,000 m-day/year) higher than income maximization. As can be expected, the water utilization when rice production is maximized is higher compared to income maximization because rice is a semi-aquatic plant. Maximizing employment yields an agricultural land use which are more labor intensive such as rice-white corn-mungbean, rice-garlic-mungbean and rice-eggplant cropping patterns.

The trade-off between two conflicting goals can also be analyzed from the results of optimization. A one metric ton increase in rice production corresponds to P0.11M decrease in income, 10 man-days increase in labor utilization, 0.39 kg a.i. decrease in pesticide utilization and 20kg decrease in fertilizer usage.

Table 3
Goal Achievement and Resource Allocation under Zero-Round Optimization

Goals	Unit	MaxInc	MaxRice	MaxEmp
Rice	ton	56 4,339	**1,364,704**	549,932
Non-Rice	ton	5,086,872	-	786,535
Employment	10^3m-day	23,200	28,205	**43,784**
Soil Erosion	10^3m^3	563,050	563,050	629,999
Pesticide	kg a.i.	377,449	65,674	158,702
Fertilizer	ton	70,445	51,151	60,740
N Fertilizer	ton	33,177	34,521	33,245
Provl Income	10^6Pesos	92,166	7,659	17,876
Farmer Income	10^6Pesos	**92,711**	7,324	18,160
Resource Allocation				
Land	%	100	100	100
Labor	%	51	62	82
Water	%			
Wet		-	7	2
Dry		37	166	92
Technology	%	high-98%	high-100%	high-96%
LUT allocation	%	rice-tom-100%	2Rice-64% 3Rice-36%	rice-WC-Mg-36% rice-gar-Mg-24% rice-Eggplat-9% other LUTs-31% notalloc-0%

Note: bold figures are values of the objective function optimized

3.2 *Impact of Resource Sharing*

Labor and water are important factors in crop production. In addition to material inputs, this dictates the level of output that can be realized from crop production. The possibility of allowing sharing of these resources within the province was also analyzed and their impact on the goal achievements were compared with that of no resource sharing. The results are presented in ***Table 4***. The results show that if resources can be shared, provincial income will increase by 1.7B pesos (25%) and rice output will increase by 250,000 metric tons (64%). If the province will pursue income maximization, the land utilization will increase by 15% while water use will increase by 59% as a result of increase output. Further more, there will be increase in area planted for rice and other crops.

Table 4
Effect of Resource Sharing on Goal Achievement and Resource Allocation, 2000

Goals	Unit	MaxInc[1]	MaxRice[1]	MaxInc[2]	MaxRice[2]
Rice	ton	206,212	**392,618**	296,533	**642,546**
ProvIncome	10^6Pesos	**6,700**	3,151	**8,400**	4,800
Resource Allocation					
Land	%	87	38	100	52
Labor	%	15	10	18	15

Table 4 (continued)

Goals	Unit	MaxInc[1]	MaxRice[1]	MaxInc[2]	MaxRice[2]
LUT allocation	ha				
Rice		775	36,463	961	51,362
Rice + upland crops		48,604	10,667	65,553	13,561
Upland crops		65,515	1,378	62,933	11,585

Notes:
1 – without resource sharing
2 – with resource sharing
bold figures are values of the objective function optimized

3.3 *Impact of Technology*

The assumptions we made under this study are that in the near future, productivity gains can be realized because of the current efforts to promote production technologies. This would lead to production levels equivalent to best farmer's practice, which we equate in this study as high technology. To evaluate the impact of technology adoption, optimization was done under two scenarios, the medium technology (average farmer's practice) and the high technology (best farmer's practice). The result shows that with high technology, income will increase by 77% when income maximization is given priority by the province. Rice output will increase by 30% as a result of shifting from medium to high technology. Due to increase production efficiency, resource use did not increase but was able to get higher production and income (***Table 5***).

Table 5
Impact of Technology and Resource Allocation

Goals	Unit	MaxInc[1]	MaxRice[1]	MaxInc[2]	MaxRice[2]
Rice	Ton	306,739	**631,605**	409,835	**819,467**
Non-Rice	Ton	1,223,732	62,382	2,314,992	62,809
Employment	10^3m-day	13,414	13,922	14,304	16,729
Soil Erosion	10^3m^3	437,894	457,991	439,835	464,784
Pesticide	Kg a.i.	114,255	21,538	159,516	25,980
Fertilizer	Ton	34,531	32,508	41,750	31,982
N fertilizer	Ton	18,682	22,035	21,170	21,600
ProvIncome	10^6Pesos	22,719	3,347	40,608	4,996
FarmerIncome	10^6Pesos	**23,113**	3,553	**40,917**	4,880
Resource allocation					
Land	%	77	77	77	77
Labor	%	26	27	28	33
Water	%				
Wet		-	5	-	5
Dry		25	56	18	56

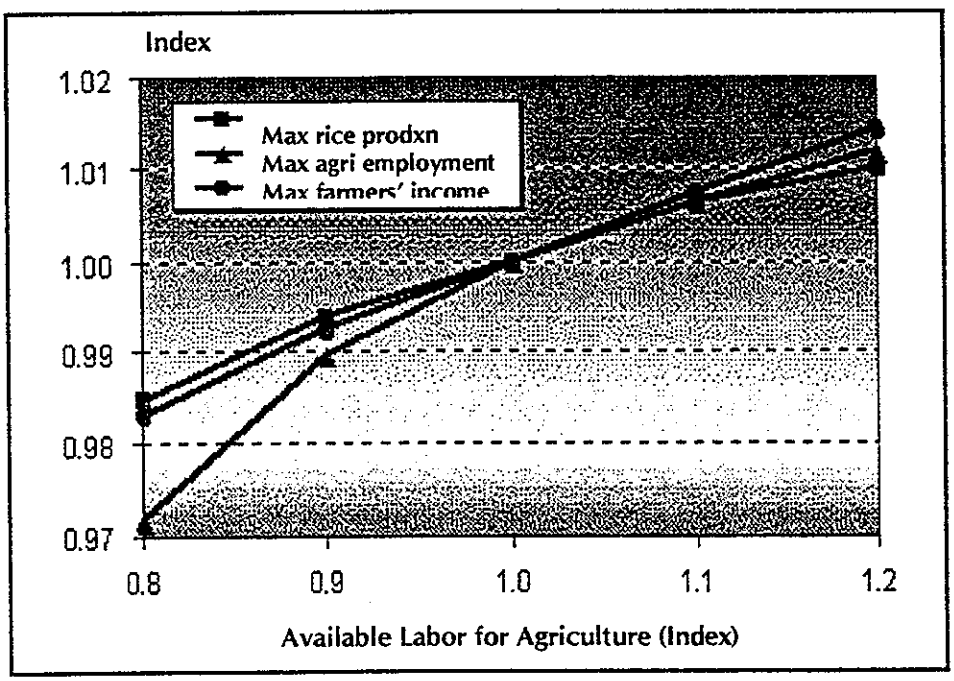
Notes:
bold figures are values of the objective function optimized
1 – medium technology
2 – high technology

3.4 Scenario Analysis

Different scenarios which will help strategic planners in their development strategies were done to answer specific *what-if* questions. ,e.g., *what* will be the goal achievements and resource allocation will change *if* resource, e.g., labor, and expansion of irrigated areas, availability increase or decrease.

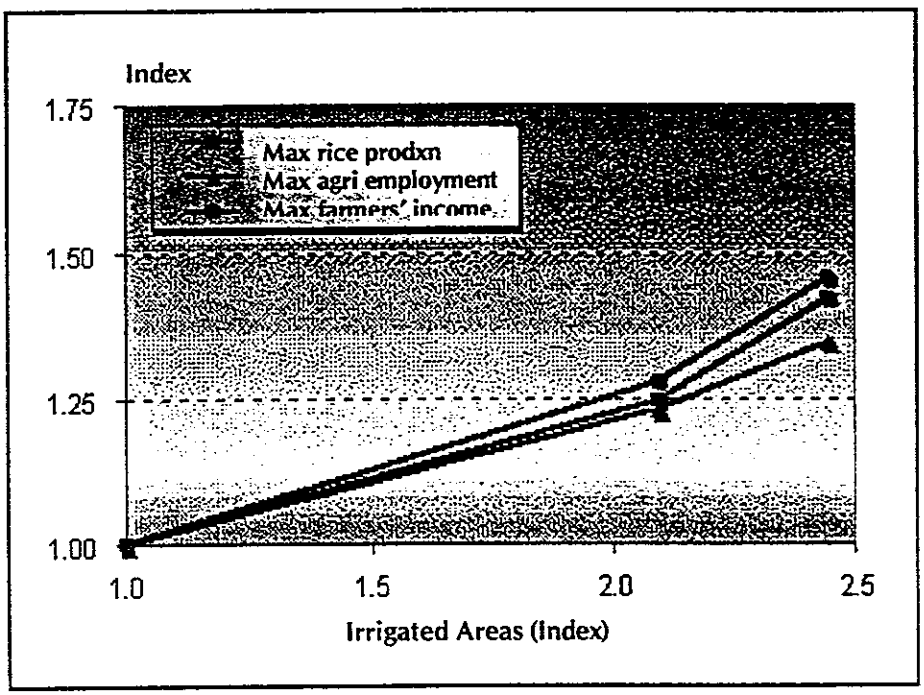
On the average, labor costs account for about 40% of total production cost in rice production and 32% for non-rice (Lucas et al., 1999). For the crops considered in this study, labor requirements range from 20 man-days to 95 man-days per hectare. Optimization results show that an increase/decrease in available labor resulted in increase/decrease in rice production, employment and income (***Figure 2***). A 10% reduction in available labor led to a 1% reduction in all three goals, while a 20% reduction in available labor led to an 2% decrease in rice production and income and 3% reduction in employment. On the other hand a 20% increase in available labor resulted to only 1% increase in rice production, income and employment. This result implies that the current labor supply in the province is more than sufficient, except during months with peak labor requirement, e.g., harvesting period so that a 20% reduction or increase in labor only resulted to marginal change in the value of the different goals considered.

Figure 2
Impact of Change in Available Labor on Goal Achievements



In the province, 36% of the arable land derives its irrigation from surface water. If the irrigated area is expanded, the value of the objective functions increased (***Figure 3***). Doubling the irrigated area resulted to 25% increase in the value of the rice output, employment and farmers' income.

Figure 3
Impact of Change in Irrigated Area on Goal Achievements



4. CONCLUDING REMARKS

As mentioned earlier in most optimization problems, like the case of SIFR, there are several objectives that the stakeholders want to satisfy at the same time, some of which are conflicting with each other. In the case of SIFR, MCA was used to determine the preferred land use option. While MCA is able to prioritize land uses, it cannot and will not be able to quantify the benefits and cost of the different land uses to the society. A more suitable tool for these kind of multiple criteria problems is the Interactive Multiple Goal Linear Programming (IMGLP) is being proposed.

In the case of Samar Islands, the following are the suggested objective functions that can be formulated (***Table 6***):

Table 6
List of Possible Objectives for SIFR

Class of Objectives	Objectives / Goals
Agricultural	1. Max Crop Product Output 2. Max Energy Production 3. Max Protein Production 4. Max Grazing Production
Forestry	5. Max Water Production 6. Max Timber, Pulp Wood, Fuelwood Production 7. Max Recreation
Socio-economic	8. Max Employment 9. Min Emigration 10. Max Income
Environmental	11. Min Uses Detrimental to the Watershed, e.g. Residential and Commercial Areas 12. Min Erosion
Note: the above objective functions will be optimized subject to the following constraints:	
Constraints	1. Capital / Budget 2. Area 3. Other Constraints

Information Needed

In order to build up the IMGLP model the following data need to be assembled:

a. Supply

- Stream flow/water yield from different catchments areas
- Crop Yields (crops planted in the watershed)
- Mining yields
- Production Cost and Returns from different land uses
- Manpower available
- Soil erosion rate by different slopes
- Timber, pulpwood, and fuel wood yields
- Energy and Protein yields

b. Demand

- Stream flow requirement
- Manpower requirement
- Permissible soil erosion rate
- timber, pulpwood, and fuel wood requirement
- Energy and Protein requirement

c. Policy pronouncements

regarding the utilization of the watershed e.g. what should be the limits of the area devoted to other uses in the watershed

REFERENCES

Balangue, T.O. 1979. *A Goal Programming Model for the Integrated-Use Forest Management Problem*. M.S. Thesis. UPLB College of Foresrty. College, Laguna.

Charnes, A. et al. 1968. *A Goal Programming Model for Media Planning.* Management Science. 14: 423-430.

Dash Associates. 1999. *XPRESS-MP Reference Manual Release 11.* Dash Associates Ltd, Bliswort House, Blisworth, Nortants NN73BX, UK, 272pp.

De Wit, C.T., H. Van Kuelen, N.G. Seligman and I. Spharim. 1988. *Application of Interactive Multiple Goal Programming Techniques for Analysis of Regional Agricultural Development.* Agriculture Systems 26(3) 211-230.

Francisco, S.R., N.R. Navarette, L.B. Dimasuay, F.P. Lansigan, C.M. Pascual, M.P Lucas, J.L. Orno, R. Roetter, C.T. Hoanh, A.G. Laborte, T.F. Marcos, C.G. Acosta, E.O Agustin, M.E. Pascua, S.R. Pascua, R.T. Utrera, R.T. Crus and S.R. Obien. 1998. *A Systems Approach to Agricultural Land Use Planning at the Provincial and Municipal Levels of Ilocos Norte Province, Philppines.* Pages 103-109 in Roetter, R., C.T. Hoanh, N.V. Luat, M.K. Van Ittersum and H.H. Van Laar (Eds). Exchange of Methodologies in Land Use Planning. SysNet Research Paper Series No. 1, IRRI, Los Banos, Philippines.

Laborte, A.G., R. Roetter, C.T. Hoanh and S.R. Francisco. 1999. *The Land Use Planning and Analysis System of the Systems Research Network in Asia.* Paper presented at MODSS'99 International Conference on Multiple Objective Decision Support System, 1 – 6 August 1999, Brisbane, Australia.

Lansigan, F.P., J.L. Orno, C.M. Pascual, N.R. Navarette, S.R. Francisco, A.G. Laborte, C.T. Hoanh and R. Roetter. 1998. *Systems Methodology Development for Exploratory Agricultural Land Use Planning for Ilocos Norte Province, Philippines.* Pages 73-80 in Roetter, R., C.T. Hoanh, N.V. Luat, M.K. Van Ittersum and H.H. Van Laar (Eds). Exchange of Methodologies in Land Use Planning. SysNet Research Paper Series No. 1, IRRI, Los Banos, Philippines.

Lee, S.M. and E.R. Clayton. 1972. *Multi-Criteria School Busing Models.* Management Science. 23:395-408.

Lucas, M.P., S. Pandey, R.A. Villano, D.R. Culaanay and S.R. Obien. 1999. *Characterization and Economic Analysis of Intensive Cropping System in Rainfed Lowlands of Ilocos Norte, Philippines.* Expl Agr 53:1-14.

Rosario, E.A. 1987. *Multiple Objective River Basin Land Use Allocation by Goal Programming.* PhD Thesis. UPLB College of Foresrty. College, Laguna.

Van Ittersum, M.K. 1998. *New Concepts and Directions in Exploratory Land Use Studies.* Pages 3-13 in Roetter, R., C.T. Hoanh, N.V. Luat, M.K. Van Ittersum and H.H. Van Laar (Eds). Exchange of Methodologies in Land Use Planning. SysNet Research Paper Series No. 1, IRRI, Los Banos, Philippines.