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SysNet Tools: The Multiple Goal Linear Programming (MGLP) Model and MapLink

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The multiple goal linear programming (MGLP) model

Introduction

The main purpose of the Systems Research Network for Ecoregional Land Use Planning in Tropical Asia (SysNet) is to develop and evaluate methodologies for exploring land use options at the subnational level. Case study regions include Haryana State (India), Kedah-Perlis Region (Malaysia), Ilocos Norte Province (Philippines), and Can Tho Province (Vietnam).

SysNet provides a mechanism for improving the scientific basis for land use planning in support of natural resource management. Systems methodologies are being operationalized into a land use planning and analysis system (LUPAS), which is a decision support system based on the interactive multiple goal linear programming (IMGLP) method and other analytical tools required for exploratory land use studies (Fig. 1). The three main methodology parts of LUPAS are (i) land evaluation including assessment of resource availability, land suitability, and yield estimation; (ii) scenario construction based on policy views; and (iii) land use optimization in the form of an MGLP model (Roetter et al 1998a).

In optimizing land use under different sets of multiple goals, different scenarios are analyzed based on land evaluation, quantified input-output relationships for current and alternative production activities, and formulation of constraints and policy views as mathematical functions. There

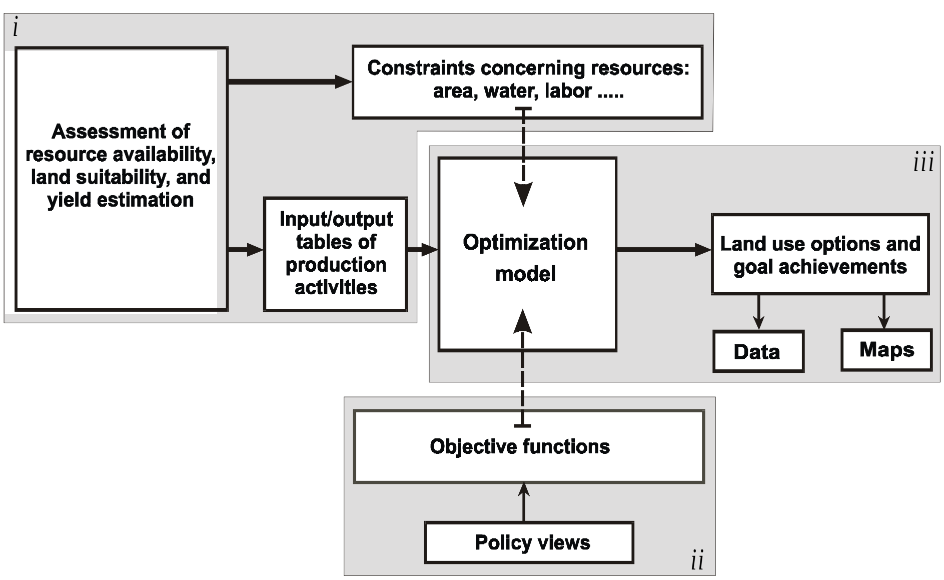


Fig. 1. Structure of the SysNet land use planning and analysis system (LUPAS): (i) land evaluation, (ii) scenario construction, and (iii) land use optimization.

are two types of optimization results: goal achievements and the corresponding land use allocations. (For a detailed diagram of the operational structure of LUPAS, see Annex 1.)

The method of IMGLP (De Wit et al 1988) is the concept underlying LUPAS. This method is currently applied in SysNet to deal with conflicting land use objectives of stakeholders at the regional level (target regions are provinces or states). Results for a given region reveal the extent to which various goals can be met given the technical and physical constraints and provide estimates for analyzing trade-offs between costs and benefits incurred in attaining the various goals.

The technical description of LUPAS will be presented under the MGLP model component. First, the IMGLP method will be characterized briefly. Then the technical details involved in the development of an MGLP model will be discussed for the Can Tho Province case study.

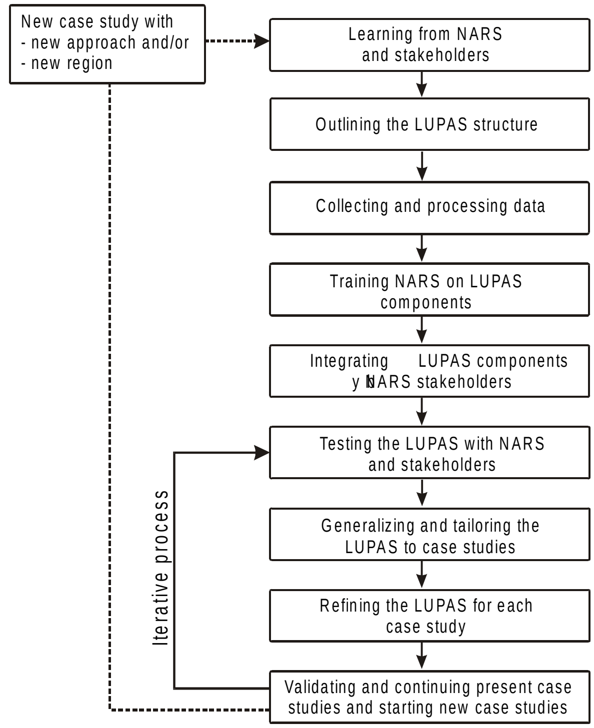


Fig. 2. Steps in developing a land use planning and analysis system (LUPAS).

The IMGLP method

Interactive multiple goal linear programming (IMGLP) can be used to determine optimal options for agricultural development in a region. Land use options under various policy views are explored by using the linear programming technique — i.e., an objective is optimized while taking into account a set of given constraints. The method provides a way by which promising production activities and technologies in a region can be analyzed in view of their contribution to development goals, considering the limited resources available and the diverse and often conflicting objectives of different interest groups (stakeholders) regarding land use and regional development.

The participation and cooperation of stakeholders are important in this integrated approach. To have an impact, the type of questions asked, the type of results obtained, and the data required for analysis need to be discussed with those who have a stake in the development of the region (Van Ittersum et al 1998; Roetter and Hoanh 1999). This interaction with stakeholders will lead to various iterations in model building and formulation (Roetter et al 1998b) (Fig. 2).

The MGLP model consists of three components (Hijmans and Van Ittersum 1996): (i) input-output relations of production activities, (ii) a set of constraints, and (iii) objective functions derived from policy views for the region.

The target-oriented approach is adopted in quantifying input-output relations. In this approach, the combination of inputs (e.g., fertilizer, pesticides) required to achieve a particular output level is identified for a given production situation. Not only production activities currently applied in the region but also promising activities that are not yet applied by local farmers are taken into consideration.

The constraints in the model refer to resource limits, development targets, and other goal restrictions. The last two refer to the minimum and/or maximum values for some of the goals that need to be achieved. These values are derived from policy views in the region. As an example, consider the goal of maximizing income. When this goal is optimized, possible constraints to be included in the model are available land and labor supply in the region and the minimum required rice production to meet the needs of the population. The available land and labor supply are resource limits, and the minimum required rice production is a goal restriction. In addition, the development targets of the region — e.g., production targets for cereals and cash crops — may be included as additional constraints.

Objective functions are formulated by translating the prevailing policy views on agricultural development in the region into mathematical equations. For each optimization run, only one objective is optimized (maximized or minimized) and the others can be used as goal restrictions.

The initial run will be the zero round, where no goal restrictions are set. In successive runs, goal restrictions relating to the land use scenarios being considered are placed. The results of optimization runs are the goal achievements, which are the optimum values of the objective functions, and the corresponding land use allocation. The results of the different land use scenarios are analyzed to show trade-offs between costs and benefits of attaining different goals.

In SysNet, the MGLP model has been developed for each case study region using the mathematical programming software XPRESS-MP (Dash Associates 1997). The MGLP model is linked to the Microsoft Excel spreadsheets, where input data are retrieved and results of optimizations are saved.

The mapping of input and output of the optimization runs and the required data links will be described in Part 2 of this document.

MGLP model description: the Can Tho Province case study

Background

Can Tho Province is located in the central part of the Mekong Delta. It has a total land area of 0.3 million ha, 84% of which is under arable farming with rice-based cropping systems as the predominant land use type. Population in the region (currently 1.9 million) is growing at a rate of 2.1% per year.

There is a need to further intensify rice production in the province to meet the needs of the increasing population not just in the province but also in the whole country. At the same time, farmers in the area are starting to grow other crops to get higher income. To explore agricultural land use options for the region by taking into account the various objectives of the stakeholders, an MGLP model for Can Tho Province was developed.

Two groups of scenarios for the Can Tho case study were considered:

- Scenarios for 2000 (base scenarios): using current data on biophysical and socio-economic resources and development targets for 2000
- Scenarios for 2010 (2010 scenarios): using current data adjusted to changed biophysical conditions (water control according to development plans) and taking into account production targets for 2010

For each group, four scenarios were considered:

1. *Zero round.* Neither goal restrictions nor production and area targets are imposed. This will show values of goal variables that can be achieved when only the resource limits (available land area, labor, and water) are used as constraints.
2. *First round.* In addition to the limits in the previous scenario, lower bounds on the goals

of rice production and total income are imposed.

3. *Second round.* Production targets (lower limit of values for the different products) are imposed in addition to the bounds imposed in the first round.
4. *Third round.* This round imposes the same limits and bounds as in the second round. In addition to production targets, the minimum areas allotted for the different products are also set.

In this publication, only sample results pertaining to the zero round and the third round (optimizations with bounds, and production and area targets) for the base scenarios are presented. Both data and model structure refer to the MGLP version of February 1999 (Hoa and Hien 1999).

The general characteristics of the model for Can Tho are summarized in Table 1.

Objective functions

An objective is expressed by the goal variable and the associated optimization (e.g., maximize rice production, minimize fertilizer use). The 10 objectives (Table 2) were formulated based on land use plans provided by the provincial planning agency and in consultation with policymakers in the region.

An objective function is the term used for a linear equation formulated by specifying the decision variable(s) for achieving the goal (Dash Associates 1997). Table 3 shows the equations relating to the objective functions given in Table 2.

Input and output data

Land unit delineation. The seven districts (administrative units) in Can Tho Province are Chau Thanh (Ch), Long My (Lo), O Mon (OM), Phung Hiep (Ph), Thot Not (Th), Tp Can Tho (Tp), and Vi Thanh (Vi). Socioeconomic data are available at the district level, so administrative unit boundaries were used to reflect socio-economic variations within the province.

Table 1. Codes and sizes of MGLP model variables for Can Tho Province.

No.	Item	Code	Size
1	District	NDist	7
2	Agroecological units (AEU)	NAEU	18
3	Land use type (LUT)	NLUT	19
4	Product type	NProduct	28
5	Product group	NPGroup	11
6	Goal	NGoal	10
7	Technology level	NTech	2
8	Month	NMonth	12
9	Constraint	NConst	14
10	Combination of LUT, AEU, and district	NLUD	608
11	Promising LUTs in each AEU, district, and technology level	NLpUDT	352
12	Land units (combination of AEU and district)	NUD	100

Table 2. Objectives incorporated in the model.

No.	Goal variable	Optimization	Code
1	Total rice production (t)	Maximize	PRice
2	Total nonrice production (t)[a]	Maximize	PNonRice
3	Total net regional farm income (10^6 VN dong)	Maximize	TIncome
4	Equity income (10^6 VN dong)	Maximize	TEquity
5	Total employment (labor-day)	Maximize	TEmploy
6	Total labor productivity (labor-day)	Minimize	TLaborPro
7	Total water use (m^3)	Minimize	TWater
8	Total fertilizer use (t)	Minimize	TFertilizer
9	Total pesticide use (t)	Minimize	TPesticide
10	Total N loss (t)	Minimize	TNLoss

[a]Although this objective was proposed by stakeholders, it was recognized in the post-optimal and scenario analysis that this goal variable does not reflect properly their objective, since it will lead to a large area of heavy products such as sugarcane. In the new version of the MGLP model, this goal will be replaced by total income from nonrice production to reflect the objective of improving diversification in agriculture.

The province was delineated into agroecological units (AEU) by overlaying information on soil and hydrology. The overlay resulted in 18 unique combinations. The different AEUs and associated characteristics are given in Table 4.

Table 3. Equations of the objectives in the Can Tho model.

	Objective	Code	Formula
1	Rice production (Maximize)	PRice	SUM(lut=byLUT,u=byLU,d=byDist,p=byProduct,t=byTech | AvaiArea(u,d,1)>0 .AND. LUPromising(lut,u,d)=1) Yield(lut,u,d,t,p) * ProductType("Rice",p) * LUA(t,u,lut,d)
2	Nonrice production (Maximize)	PNonRice	SUM(lut=byLUT,u=byLU,d=byDist,p=byProduct,t=byTech | AvaiArea(u,d,1)>0 .AND. LUPromising(lut,u,d)=1) Yield(lut,u,d,t,p) * ProductType("NonRice",p) * LUA(t,u,lut,d)
3	Total income (Maximize)	TIncome	SUM(lut=byLUT,u=byLU,d=byDist,t=byTech | AvaiArea(u,d,1)>0 .AND. LUPromising(lut,u,d)=1) NetIncome(lut,u,d,t) * LUA(t,u,lut,d)
4	Income equity (Maximize)	TEquity	MaxDistIncome > 0 DistIncome(d=byDist): SUM(lut=byLUT,u=byLU,d,t=byTech | AvaiArea(u,d,1)>0 .AND. LUPromising(lut,u,d)=1) NetIncome(lut,u,d,t) * LUA(t,u,lut,d) < MaxDistIncome
5	Total employment (Maximize)	TEmploy	SUM(lut=byLUT,u=byLU,d=byDist,t=byTech,m=byMonth | AvaiArea(u,d,1)>0 .AND. LUPromising(lut,u,d)=1) LaborNeed(lut,u,d,t,m)* LUA(t,u,lut,d)
6	Labor productivity (Maximize) = minimize employment with targets	TLaborPro	SUM(lut=byLUT,u=byLU,d=byDist,t=byTech,m=byMonth | AvaiArea(u,d,1)>0 .AND. LUPromising(lut,u,d)=1) LaborNeed(lut,u,d,t,m)* LUA(t,u,lut,d)
7	Total water need (Minimize)	TWater	SUM(lut=byLUT,u=byLU,d=byDist,t=byTech,m=byMonth | AvaiArea(u,d,1)>0 .AND. LUPromising(lut,u,d)=1) WaterNeed(lut,u,d,t,m)* LUA(t,u,lut,d)
8	Total fertilizer (Minimize)	TFertilizer	SUM(lut=byLUT,u=byLU,d=byDist,t=byTech | AvaiArea(u,d,1)>0 .AND. LUPromising(lut,u,d)=1) Fertilizer(lut,u,d,t) * LUA(t,u,lut,d)
9	Total pesticide (Minimize)	TPesticide	SUM(lut=byLUT,u=byLU,d=byDist,t=byTech | AvaiArea(u,d,1)>0 .AND. LUPromising(lut,u,d)=1) Pesticide(lut,u,d,t) * LUA(t,u,lut,d) > 0
10	Total N loss (Minimize)	TNLoss	SUM(lut=byLUT,u=byLU,d=byDist,t=byTech | AvaiArea(u,d,1)>0 .AND. LUPromising(lut,u,d)=1) NLoss(lut,u,d,t) * LUA(t,u,lut,d)

Table 4. Agroecological units in Can Tho Province.

Unit	Soil: Vietnamese classification – Code	Soil: Vietnamese classification – Description	Soil: Equivalent USDA classification	Water conditions: Flooding – Depth (cm)	Water conditions: Flooding – Duration	Water conditions: Irrigation condition	Area (ha): Current	Area (ha): Future
AEU01	Pb	Alluvial with new sediment	*Typic Tropaquents*	<30	None	Irrigated	1,605	1,605
AEU02	P	Alluvial without new sediment	*Aeric Tropic Fluvaquents*	<30	Oct	Irrigated	15,078	15,078
AEU03	Pf_b	Alluvial with yellow-reddish layer and new sediment	*Fluventic Aeric Tropaquepts*	30-60	Oct	Irrigated	35,010	76,952
AEU04	Pf_b	Alluvial with yellow-reddish layer and new sediment	*Fluventic Aeric Tropaquepts*	30-60	Sep-Nov	Irrigated	17,759	0
AEU05	Pf	Alluvial with yellow-reddish layer but no new sediment	*Aeric Tropaquepts*	<30	Oct	Irrigated	17,663	16,684
AEU06	Pf	Alluvial with yellow-reddish layer but no new sediment	*Aeric Tropaquepts*	30-60	Oct	Irrigated	6,609	43,371
AEU07	Pf	Alluvial with yellow-reddish layer but no new sediment	*Aeric Tropaquepts*	60-100	Sep-Nov	Irrigated	36,762	0
AEU08	Sp1	Strongly potential acid sulfate soils	*Sulfaquepts*	30-60	Oct	Irrigated	13,359	12,683
AEU09	Sj2M	Moderately active saline-acid sulfate soils	*Sulfic Tropaquepts, Salic*	30-60	Aug-Oct	Irrigated	28,799	28,799
AEU10	Sj3	Slightly active acid sulfate soils	*Sulfic Tropaquepts*	30-60	Aug-Oct	Rainfed	12,323	12,323
AEU11	Sp2	Moderately potential acid sulfate soils	*Sulfic Fluvaquents*	60-100	Sep-Nov	Irrigated	20,193	20,193
AEU12	Sj2	Moderately active acid sulfate soils	*Pale Sulfic Tropaquepts*	>100	Aug-Dec	Irrigated	5,510	5,510
AEU13	Sj1M	Strongly active saline-acid sulfate soils	*Sulfaquents*	30-60	Aug-Oct	Irrigated	3,790	3,790
AEU14	Sp2M	Moderately potential saline-acid sulfate soils	*Sulfic Tropaquents, Salic*	30-60	Aug-Oct	Rainfed	5,431	5,431
AEU15	Sp1M	Strongly potential saline-acid sulfate soils	*Sulfaquents, Salic*	60-100	Aug-Oct	Irrigated	4,766	4,766
AEU16	Sj1	Strongly active acid sulfate soils	*Sulfaquepts*	60-100	Aug-Oct	Rainfed	2,141	2,141
AEU17	Mi	Slightly saline soils	*Tropaquepts, Salic*	30-60	Aug-Oct	Irrigated	5,304	5,304
AEU18	Sj3M	Slightly active saline-acid sulfate soils	*Tropaquepts, Salic*	30-60	Aug-Oct	Rainfed	4,163	4,163

Source: Lai et al (1998b).

The total available area for agriculture was determined by excluding areas such as built-up and protected areas. The overlay of the administrative units (districts) and the AEUs resulted in 100 land units (LU) that can be assumed to be homogeneous in both biophysical and socioeconomic characteristics.

Production activities. The agricultural production systems considered contain the following products: rice, corn, bean, soybean, mungbean, sugarcane, watermelon, cucumber, petchay, bittergourd, gourd, sweet potato, cabbage, pineapple, fruit, and fish.

The combination of these products in cropping/production systems resulted in 19 land use types (LUTs). The selection of promising LUTs is based on current inventory, development plans, and LUTs existing in other regions with similar agroecological conditions (Lai et al 1998b). These LUTs and the associated codes used are given in Table 5.

Two technology levels were considered: high (H) and low (L). These two technology levels refer to two levels of yield: the current level and an estimated farmer's maximum yield. Data for the current yield level were derived from surveys, whereas data for the latter were derived from expert knowledge (Lai et al 1998a).

With 19 LUTs, 100 LUs, and 2 technology levels, the total number of combinations was 3,800. However, not all LUTs combine with each of the LUs and technology levels. Some characteristics of the LUs at a given technology level will make them unsuitable for a particular LUT. For example, triple rice is considered unsuitable for strongly acid sulfate soils (AEU 8, 13, 15, and 16). When considering only the promising combinations, the number is reduced to just 352 combinations.

Table 6 shows the different cropping system elements and the corresponding codes used in the model.

Table 5. Land use types used in the MGLP model.

No.	Land use type[a]	Code
1	Rice WS – rice SA	RR
2	Rice WS – rice SS – rice SA	RRR
3	Rice WS – soybean SS – rice SA	RSR
4	Rice WS – mungbean SS – rice SA	RMR
5	Sugarcane – bean	SB
6	Rice SA – transplanted rice – soybean SS	RTS
7	Rice WS – watermelon SS – rice SA	RWR
8	Rice WS – rice SA – fish	RRF
9	Cucumber WS – cucumber SA	CC
10	Petchay WS – cucumber SS – cucumber SA	PCC
11	Bitter gourd WS – gourd SA	BG
12	Rice WS – sweet potato SS – rice AW	ROR
13	Rice WS – corn SS – rice SA	RCR
14	Cabbage SS – petchay SA	CP
15	Rice WS – petchay SS – rice SA	RPR
16	Sugarcane	S
17	Sugarcane – rice WS	SR
18	Pineapple	P
19	Fruit	F

[a]WS = winter-spring, SA = summer-autumn, SS = spring-summer.

Table 6. Cropping system elements used in the MGLP model.

No.	Item	Code
1	Rice WS	Rws
2	Rice SA	Rsa
3	Rice SS	Rss
4	Soybean SS	Sss
5	Mungbean SS	Mss
6	Sugarcane 05[a]	S05
7	Bean 05[a]	B05
8	Transplanted rice	TrR
9	Watermelon SS	Wss
10	Fish 08[b]	Fis
11	Cucumber WS	Cws
12	Cucumber SA	Csa
13	Petchay WS	Pws
14	Cucumber SS	Css
15	Bitter gourd WS	Bws
16	Gourd SA	Gsa
17	Sweet potato SS	Oss
18	Rice AW	Raw
19	Corn SS	COR
20	Cabage SS	CAB
21	Petchay SA	Psa
22	Petchay SS	Pss
23	Sugarcane	S16
24	Sugarcane 17[c]	S17
25	Pineapple	PIN
26	Rice WS 08[b]	Rw8
27	Rice SA 08[b]	Rs8
28	Fruit	FRU

[a]For LUT 05. [b]For LUT 08. [c]For LUT 17.

Based on the main agricultural objectives, 11 product groups were formed: rice, nonrice, sugarcane, vegetable, beans, corn, fish, fruit, pineapple, export rice, and upland crops.

Input, intermediate, and output items. The various input-output relations for each production activity as well as the available resources (e.g., area and labor) are stored as a Microsoft Excel file with several worksheets. To simplify referencing of items, the Lookup functions of Excel are used (see Annex 2).

Each item is identified by a range name. Figure 3 shows the Excel file Ctda2010.xls, which contains the input data needed to run the model. The highlighted cells correspond to the *Yield* range. Other named ranges, such as *InputOutput* and *LaborNeed*, can be seen in the drop-down list located at the top left corner of the sheet.

The various inputs stored in the Excel file and the corresponding dimensions and codes are shown in Table 7.

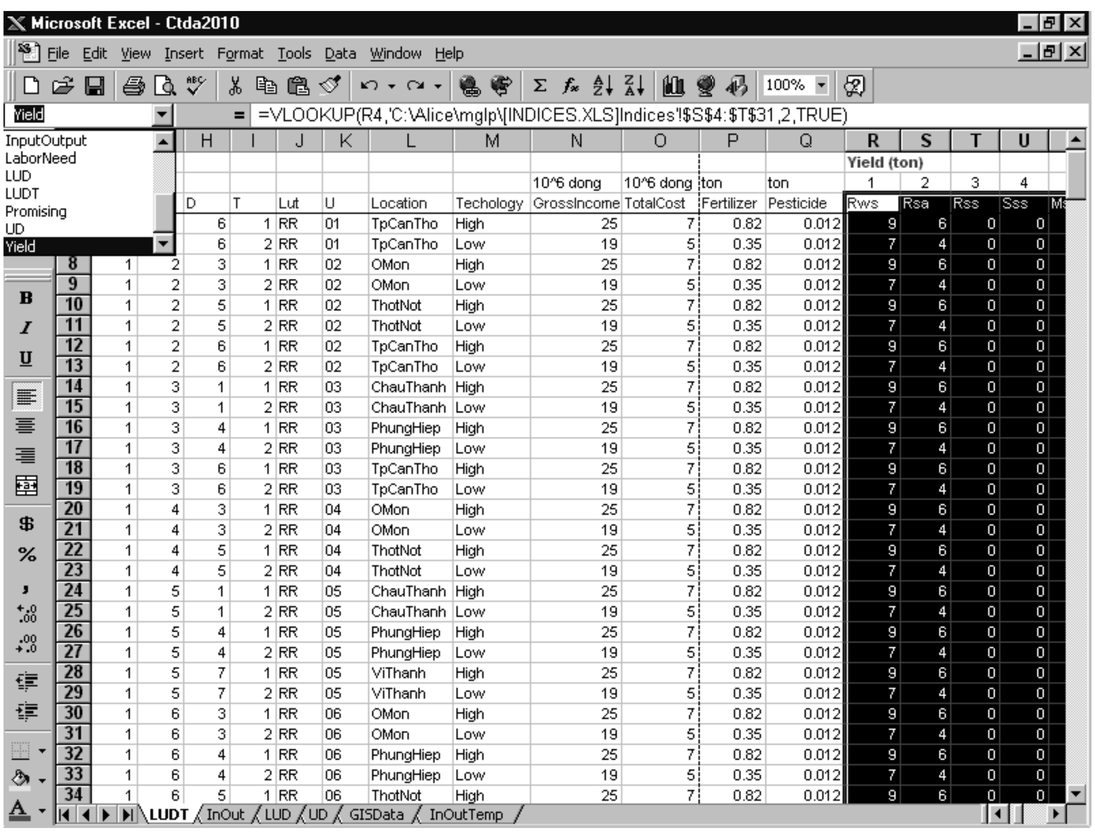
XPRESS-MP retrieves the data corresponding to each item with the use of the ODBC statement and SQL select statements. Below is the program excerpt that retrieves data on resource limits from the CtData2010.xls Excel file:

```
CONNECT ODBC, 'DSN=Excel Files;
DBQ=c:\ct\CtDa2010.xls'

DISKDATA -c

AvaiArea  = 'SELECT * FROM AvaiArea'
AvaiLabor = 'SELECT * FROM
AvaiLabor'
AvaiWater = 'SELECT * FROM
AvaiWater'

DISCONNECT
```



			H	I	J	K	L	M	N	O	P	Q	R	S	T	U
													Yield (ton)			
									10^6 dong	10^6 dong	ton	ton	1	2	3	4
			D	T	Lut	U	Location	Techology	GrossIncome	TotalCost	Fertilizer	Pesticide	Rws	Rsa	Rss	Sss
			6	1	RR	01	TpCanTho	High	25	7	0.82	0.012	9	6	0	0
			6	2	RR	01	TpCanTho	Low	19	5	0.35	0.012	7	4	0	0
8	1	2	3	1	RR	02	OMon	High	25	7	0.82	0.012	9	6	0	0
9	1	2	3	2	RR	02	OMon	Low	19	5	0.35	0.012	7	4	0	0
10	1	2	5	1	RR	02	ThotNot	High	25	7	0.82	0.012	9	6	0	0
11	1	2	5	2	RR	02	ThotNot	Low	19	5	0.35	0.012	7	4	0	0
12	1	2	6	1	RR	02	TpCanTho	High	25	7	0.82	0.012	9	6	0	0
13	1	2	6	2	RR	02	TpCanTho	Low	19	5	0.35	0.012	7	4	0	0
14	1	3	1	1	RR	03	ChauThanh	High	25	7	0.82	0.012	9	6	0	0
15	1	3	1	2	RR	03	ChauThanh	Low	19	5	0.35	0.012	7	4	0	0
16	1	3	4	1	RR	03	PhungHiep	High	25	7	0.82	0.012	9	6	0	0
17	1	3	4	2	RR	03	PhungHiep	Low	19	5	0.35	0.012	7	4	0	0
18	1	3	6	1	RR	03	TpCanTho	High	25	7	0.82	0.012	9	6	0	0
19	1	3	6	2	RR	03	TpCanTho	Low	19	5	0.35	0.012	7	4	0	0
20	1	4	3	1	RR	04	OMon	High	25	7	0.82	0.012	9	6	0	0
21	1	4	3	2	RR	04	OMon	Low	19	5	0.35	0.012	7	4	0	0
22	1	4	5	1	RR	04	ThotNot	High	25	7	0.82	0.012	9	6	0	0
23	1	4	5	2	RR	04	ThotNot	Low	19	5	0.35	0.012	7	4	0	0
24	1	5	1	1	RR	05	ChauThanh	High	25	7	0.82	0.012	9	6	0	0
25	1	5	1	2	RR	05	ChauThanh	Low	19	5	0.35	0.012	7	4	0	0
26	1	5	4	1	RR	05	PhungHiep	High	25	7	0.82	0.012	9	6	0	0
27	1	5	4	2	RR	05	PhungHiep	Low	19	5	0.35	0.012	7	4	0	0
28	1	5	7	1	RR	05	ViThanh	High	25	7	0.82	0.012	9	6	0	0
29	1	5	7	2	RR	05	ViThanh	Low	19	5	0.35	0.012	7	4	0	0
30	1	6	3	1	RR	06	OMon	High	25	7	0.82	0.012	9	6	0	0
31	1	6	3	2	RR	06	OMon	Low	19	5	0.35	0.012	7	4	0	0
32	1	6	4	1	RR	06	PhungHiep	High	25	7	0.82	0.012	9	6	0	0
33	1	6	4	2	RR	06	PhungHiep	Low	19	5	0.35	0.012	7	4	0	0
34	1	6	5	1	RR	06	ThotNot	High	25	7	0.82	0.012	9	6	0	0

Fig. 3. An excerpt of the input file.

Table 7. Various inputs stored in the Excel file.

No.	Item	Code	Dimension
1	Available area of each AEU in each district	AvaiArea	byAEU, byDist
2	Available labor in each AEU and district	AvaiLabor	byAEU, byDist
3	Gross income in each LUT, AEU, district, and technology level	GrossIncome	byLUT, byAEU, byDist, byTech
4	Total cost in each LUT, AEU, district, and technology level	TotalCost	byLUT, byAEU, byDist, byTech
5	Fertilizer need in each LUT, AEU, district, and technology level	Fertilizer	byLUT, byAEU, byDist, byTech
6	Pesticide need in each LUT, AEU, district, and technology level	Pesticide	byLUT, byAEU, byDist, byTech
7	Nitrogen loss in each LUT, AEU, district, and technology level	NLoss	byLUT, byAEU, byDist, byTech
8	Labor need in each LUT, AEU, district, technology level, and month	LaborNeed	byLUT, byAEU, byDist, byTech, byMonth
9	Water need in each LUT, AEU, district, technology level, and month	WaterNeed	byLUT, byAEU, byDist, byTech, byMonth
10	Yield of each product in each LUT, AEU, district, and technology level	Yield	byLUT, byAEU, byDist, byTech, byProduct

From within XPRESS-MP, several intermediate calculations such as yield per product group are performed. Table 8 lists the intermediate variables and their dimensions and formulae.

Outputs are selected during the post-optimal analysis in XPRESS-MP and saved in an Excel file (i.e., CtOutput.xls). The formulae for grouping the outputs are given in Table 9.

Constraints

A constraint refers to

(i) resource limits such as insufficient supply of land, labor, and/or water to meet the requirements for achieving goals, e.g., target yields of rice at a given technology

(ii) development targets for nongoal variables, e.g., production and area targets for corn and fruits

(iii) a goal restriction imposed by other objectives, e.g., goal to increase income in the region restricted by required minimum production of rice

The first three constraints (Table 10) refer to resource limits on available area, labor, and water, respectively. Goal restrictions were imposed to specify requirements identified from the prevailing policy views in the region. This includes target minimum income for the region (constraint 4) and rice production (constraint 5).

Constraints 6 to 18 are the development targets, which include production targets for corn, vegetables, bean, sugarcane, fruits, and pineapple and area to be allotted for export rice, sugarcane, pineapple, fruit trees, upland crops, and fishery.

Different sets of targets and resource limits are applied for the base and the 2010 scenarios (Table 11).

Table 12 shows the equation applied for each constraint.

Results from the MGLP model

The zero round refers to the optimization run where no targets or restrictions other than those pertaining to resource limits (such as available area, labor, and water) are imposed.

Table 13 shows the results of the zero round for the current scenario. Each column under “Objective” refers to an optimization run. The

Table 8. Intermediate variables.

No.	Variable	Code	Dimension	Formula
1	Yield of rice	YieldRice	byLUT, byLU, byDist, byTech	SUM(p=byProduct) Yield (byLUT, byLU, byDist, byTech, p) * ProductType("Rice",p)
2	Yield of nonrice	YieldNonRice	byLUT, byLU, byDist, byTech	SUM(p=byProduct) Yield (byLUT, byLU, byDist, byTech, p) * ProductType("NonRice",p)
3	Yield of corn	YieldCorn	byLUT, byLU, byDist, byTech	SUM(p=byProduct) Yield (byLUT, byLU, byDist, byTech, p) * ProductType("Corn",p)
4	Yield of vegetable	YieldVegetable	byLUT, byLU, byDist, byTech	SUM(p=byProduct) Yield (byLUT, byLU, byDist, byTech, p) * ProductType("Vegetable",p)
5	Yield of beans	YieldBeans	byLUT, byLU, byDist, byTech	SUM(p=byProduct) Yield (byLUT, byLU, byDist, byTech, p) * ProductType("Beans",p)
6	Yield of sugarcane	YieldSugarcane	byLUT, byLU, byDist, byTech	SUM(p=byProduct) Yield (byLUT, byLU, byDist, byTech, p) * ProductType("Sugarcane",p)
7	Yield of pineapple	YieldPineppple	byLUT, byLU, byDist, byTech	SUM(p=byProduct) Yield (byLUT, byLU, byDist, byTech, p) * ProductType("Pineapple",p)
8	Yield of export rice	YieldExportRice	byLUT, byLU, byDist, byTech	SUM(p=byProduct) Yield (byLUT, byLU, byDist, byTech, p) * ProductType("ExportRice",p)
9	Yield of upland	YieldUpland	byLUT, byLU, byDist, byTech	SUM(p=byProduct) Yield (byLUT, byLU, byDist, byTech, p) * ProductType("Upland",p)
10	Yield of fishery	YieldFish	byLUT, byLU, byDist, byTech	SUM(p=byProduct) Yield (byLUT, byLU, byDist, byTech, p) * ProductType("Fish",p)

No.	Variable	Code	Dimension	Formula
11	Yield of fruit	YieldFruit	byLUT, byLU, byDist, byTech	SUM(p=byProduct) Yield (byLUT, byLU, byDist, byTech, p) * ProductType("Fruit",p)
12	Total labor cost in each month	LaborCostMonth	byLUT, byLU, byDist, byTech, byMonth	If(LaborNeedMonth(byLUT,byLU,byDist,byTech,byMonth) - AvaiLabor(byLU,byDist,1)>0, LaborNeedMonth(byLUT, byLU,byDist,byTech,byMonth) * HiredLaborCost - AvaiLabor(byLU,byDist,1) * HiredLaborCost, LaborNeedMonth(byLUT, byLU,byDist,byTech,byMonth) * FamilyLaborCost)
13	Total labor cost in all year	LaborCost	byLUT, byLU, byDist, byTech	SUM(m=1:Nmonth) LaborCost(byLUT, byLU, byDist, byTech , m)
14	Total net regional farm income	NetIncome	byLUT, byLU, byDist, byTech	GrossIncome (byLUT, byLU, byDist, byTech) - TotalCost (byLUT, byLU, byDist, byTech) - LaborCost (byLUT, byLU, byDist, byTech)

Table 9. Selected outputs.

<table>
<tr><th>No.</th><th>Item</th><th>Code</th><th>Dimension</th><th>Formula</th></tr>
<tr><td>1</td><td>Area of each LUT in each district</td><td>AreaLD</td><td>byDist, byLUT</td><td>SUM(u=byLU,t= byTech | AvaiArea(u,d,1)>0.AND.LUPromising(lut,u,d)=1)
LUA (t, u, lut, d)</td></tr>
<tr><td>2</td><td>Production of each product type in each district</td><td>ProductionPD</td><td>byDist, byProduct</td><td>SUM (lut =byLUT, u =byLU, t =byTech | AvaiArea (u, d,1) > 0)
Yield (lut, u, d, t, p) * LUA (t, u, lut, d)</td></tr>
<tr><td>3</td><td>Income from land use type in each district</td><td>IncomeLD</td><td>byDist, byLUT</td><td>SUM (u = byLU, t = byTech, m = byMonth | AvaiArea (u, d, 1) > 0 .AND. LUPromising (lut, u, d) = 1) NetIncome (lut, u, d, t) * LUA (t, u, lut, d)</td></tr>
<tr><td>4</td><td>Area of each land use type in each land unit in each district to GIS</td><td>AreaLUD</td><td>NUD, byLUT</td><td>SUM (u =1:NLU, d =1:Ndist, t =byTech | AvaiArea (u, d, 1) > 0 .AND. LUPromising (lut, u, d) = 1 .AND. u = UD (ud, 1) .AND. d =UD(ud, 2))
UD(ud, 3) * LUA (t, u, lut, d)</td></tr>
<tr><td>5</td><td>Total net farm income in each district</td><td>DistIncome</td><td>byDist</td><td>SUM (lut = byLUT, u = byLU, d, t = byTech | AvaiArea (u, d, 1) > 0 .AND. LUPromising (lut, u, d) = 1) NetIncome (lut, u, d, t) * LUA (t, u, lut, d)</td></tr>
<tr><td>6</td><td>Average of total net farm income in each district</td><td>AvgIncome</td><td></td><td>SUM (lut = byLUT, u = byLU, d = byDist, t = byTech | AvaiArea (u, d, 1) > 0 .AND. LUPromising (lut, u, d) = 1)
NetIncome (lut, u, d, t) / NDist* LUA (t, u, lut, d)</td></tr>
<tr><td>7</td><td>Average of the absolute deviation of net farm income between districts (10^6 VN dong)</td><td>DevIncome</td><td></td><td>EquityIncome = SUM(d=byDist) ABS(EdistIncome(d) - AvgIncome)/NDist
!(EdistIncome(d) - AvgIncome)</td></tr>
</table>

Table 10. Constraints in the model.

No.	Item	Code
Resource limits		
1	Total of all crop areas (ha) ≤ total area available	Area
2	Total of labor needs (ha) ≤ total labor available	Labor
3	Total of water needs (1000 m^3) ≤ water available	Water
Goal restrictions		
4	Total net regional farm income (10^6 VN dong) ≥ target	T_Income
5	Total rice production (t) ≥ target	P_Rice
Development targets		
6	Total corn production (t) ≥ target	PCorn
7	Total vegetable production (t) ≥ target	PVegetable
8	Total bean production (t) ≥ target	PBeans
9	Total sugarcane production (t) ≥ target	PSugarcane
10	Total fruit production (t) ≥ target	PFruit
11	Total pineapple production (t) ≥ target	PPineapple
12	Total area of export rice (ha) ≥ target	AExportRice
13	Total area of sugarcane (ha) ≥ target	ASugarcane
14	Total area of pineapple (ha) ≥ target	APineapple
15	Total area of fruit special (ha) ≥ target	AFruitSpecial
16	Total area of upland (ha) ≥ target	AUpland
17	Total area of fishery (ha) ≥ target	AFishery
18	Fruit area in each district (ha) ≥ target	AFruitArea

Table 11. Targets and resource limits for the base and 2010 scenarios.

No.	Code	Unit	Relation	Values	
				Base	2010
Resource limits					
1	Area	ha	≤	244,884	239,513
2	Labor	10^3 manday mo^{-1}	≤	929,008	951,558
3	Water	10^3 m^3 mo^{-1}	≤	10,634,000	10,634,000
Goal restrictions					
4	T_Income	10^6 VN dong	≥	3,500,000	4,429,000
5	P_Rice	t	≥	1,800,000	2,200,000
Development targets					
6	PCorn	t	≥	68,000	68,000
7	PVegetable	t	≥	120,000	120,000
8	PBeans	t	≥	15,000	15,000
9	PSugarcane	t	≥	2,000,000	2,000,000
10	PPineapple	t	≥	22,500	22,500
11	PFruit	t	≥	700,000	700,000
12	ASugarcane	ha	≥	30,000	30,000
13	APineapple	ha	≥	5,000	5,000
14	AExportRice	ha	≥	50,000	50,000
15	AUpland	ha	≥	30,000	30,000
16	AFishery	ha	≥	15,000	30,000
17	AFruitSpecial	ha	≥	30,000	40,000
18	AFruitArea	ha	≥	31,100	31,100

Table 12. Equations applied to constraints.

<table>
<tr><th>No.</th><th>Constraint</th><th>Code</th><th>Equation</th></tr>
<tr><td>1</td><td>Corn production</td><td>PCorn</td><td>SUM(lut=byLUT,u=byLU,d=byDist,p=byProduct,t=byTech |
AvaiArea(u,d,1)>0 .AND. LUPromising(lut,u,d)=1 .AND. ProductType("Corn",p)=1)
Yield(lut,u,d,t,p) * LUA(t,u,lut,d) > TargetValue("PCorn") * PCornTarget</td></tr>
<tr><td>2</td><td>Vegetable production</td><td>PVegetable</td><td>SUM(lut=byLUT,u=byLU,d=byDist,p=byProduct,t=byTech |
AvaiArea(u,d,1)>0 .AND. LUPromising(lut,u,d)=1 .AND. ProductType("Vegetable",p)=1)
Yield(lut,u,d,t,p) * LUA(t,u,lut,d) > TargetValue("PVegetable") * PVegetableTarget</td></tr>
<tr><td>3</td><td>Bean production</td><td>PBeans</td><td>SUM(lut=byLUT,u=byLU,d=byDist,p=byProduct,t=byTech |
AvaiArea(u,d,1)>0 .AND. LUPromising(lut,u,d)=1 .AND. ProductType("Beans",p)=1)
Yield(lut,u,d,t,p) * LUA(t,u,lut,d) > TargetValue("PBeans") * PBeansTarget</td></tr>
<tr><td>4</td><td>Sugarcane production</td><td>PSugarcane</td><td>SUM(lut=byLUT,u=byLU,d=byDist,p=byProduct,t=byTech |
AvaiArea(u,d,1)>0 .AND. LUPromising(lut,u,d)=1 .AND. ProductType("Sugarcane",p)=1)
Yield(lut,u,d,t,p) * LUA(t,u,lut,d) > TargetValue("PSugarcane") * PSugarcaneTarget</td></tr>
<tr><td>5</td><td>Pineapple production</td><td>PPineapple</td><td>SUM(lut=byLUT,u=byLU,d=byDist,p=byProduct,t=byTech |
AvaiArea(u,d,1)>0 .AND. LUPromising(lut,u,d)=1 .AND. ProductType("Pinneapple",p)=1)
Yield(lut,u,d,t,p) * LUA(t,u,lut,d) > TargetValue("PPineapple") * PPineappleTarget</td></tr>
<tr><td>6</td><td>Exported rice production</td><td>PExportRice</td><td>SUM(lut=byLUT,u=byLU,d=byDist,p=byProduct,t=byTech |
AvaiArea(u,d,1)>0 .AND. LuPromising(lut,u,d)=1 .AND. ProductType("ExportRice",p)=1)
Yield(lut,u,d,t,p) * LUA(t,u,lut,d) > TargetValue("PExportRice ") * PExportRiceTarget</td></tr>
<tr><td>7</td><td>Upland production</td><td>PUpland</td><td>SUM(lut=byLUT,u=byLU,d=byDist,p=byProduct,t=byTech |
AvaiArea(u,d,1)>0 .AND. LUPromising(lut,u,d)=1 .AND. ProductType("Upland",p)=1)
Yield(lut,u,d,t,p) * LUA(t,u,lut,d) > TargetValue("PUpland") * PUplandTarget</td></tr>
<tr><td>8</td><td>Fish production</td><td>PFish</td><td>SUM(lut=byLUT,u=byLU,d=byDist,p=byProduct,t=byTech |
AvaiArea(u,d,1)>0 .AND. LUPromising(lut,u,d)=1 .AND. ProductType("Fish",p)=1)
Yield(lut,u,d,t,p) * LUA(t,u,lut,d) > TargetValue("PFish") * PFishTarget</td></tr>
</table>

Table 12. Equations applied to constraints (continued).

<table>
<tr><th>No.</th><th>Constraint</th><th>Code</th><th>Equation</th></tr>
<tr><td>9</td><td>Fruit production</td><td>PFruit</td><td>SUM(lut=byLUT,u=byLU,d=byDist,p=byProduct,t=byTech |
AvaiArea(u,d,1)>0 .AND. LUPromising(lut,u,d)=1 .AND. ProductType("Fruit",p)=1)
Yield(lut,u,d,t,p) * LUA(t,u,lut,d) > TargetValue("PFruit")* PfruitTarget</td></tr>
<tr><td>10</td><td>Area of corn</td><td>ACorn</td><td>SUM(lut=byLUT, u=byLU ,d=byDist,t=byTech |
AvaiArea(u,d,1)>0 .AND. LUPromising(lut,u,d)=1 .AND. ProductLUT("Corn",lut)=1)
LUA(t,u,lut,d) > TargetValue("ACorn")* ACornTarget</td></tr>
<tr><td>11</td><td>Area of vegetables</td><td>AVegetable</td><td>SUM(lut=byLUT, u=byLU ,d=byDist,t=byTech |
AvaiArea(u,d,1)>0 .AND. LUPromising(lut,u,d)=1 .AND. ProductLUT("Vegetable",lut)=1)
LUA(t,u,lut,d) > TargetValue("AVegetable")* AvegetableTarget</td></tr>
<tr><td>12</td><td>Area of beans</td><td>ABeans</td><td>SUM(lut=byLUT, u=byLU ,d=byDist,t=byTech |
AvaiArea(u,d,1)>0 .AND. LUPromising(lut,u,d)=1 .AND. ProductLUT("Corn",lut)=1)
LUA(t,u,lut,d) > TargetValue("ABeans")* ABeansTarget</td></tr>
<tr><td>13</td><td>Area of sugarcane</td><td>ASugarcane</td><td>SUM(lut=byLUT,u=byLU,d=byDist,t=byTech |
AvaiArea(u,d,1)>0 .AND. LUPromising(lut,u,d)=1 .AND. ProductLUT("Sugarcane",lut)=1)
LUA(t,u,lut,d) > TargetValue("ASugarcane")* ASugarcaneTarget</td></tr>
<tr><td>14</td><td>Area of pineapple</td><td>APineapple</td><td>SUM(lut=byLUT,u=byLU,d=byDist,t=byTech |
AvaiArea(u,d,1)>0 .AND. LUPromising(lut,u,d)=1 .AND. ProductLUT("Pinneapple",lut)=1)
LUA(t,u,lut,d) > TargetValue("APinneapple")* ApineappleTarget</td></tr>
<tr><td>15</td><td>Area of exported rice</td><td>AExportRice</td><td>SUM(lut=byLUT, u=byLU ,d=byDist,t=byTech |
AvaiArea(u,d,1)>0 .AND. LUPromising(lut,u,d)=1 .AND. ProductLUT("ExportRice",lut)=1)
LUA(t,u,lut,d) > TargetValue("AExportRice")* AExportRiceTarget</td></tr>
<tr><td>16</td><td>Area of upland crops</td><td>AUpland</td><td>SUM(lut=byLUT,u=byLU,d=byDist,t=byTech |
AvaiArea(u,d,1)>0 .AND. LUPromising(lut,u,d)=1 .AND. ProductLUT("Upland",lut)=1)
LUA(t,u,lut,d) > TargetValue("AUpland")* AUplandTarget</td></tr>
</table>

Table 12. Equations applied to constraints (continued).

No.	Constraint	Code	Equation
17	Area of fisheries	AFish	SUM(lut=byLUT,u=byLU,d=byDist,t=byTech | AvaiArea(u,d,1)>0 .AND. LUPromising(lut,u,d)=1 .AND. ProductLUT("Fish",lut)=1) FishPondRatio * LUA(t,u,lut,d) > TargetValue("AFish") * AFishTarget
18	Area of fruit tree	AFruit	SUM(lut=byLUT,u=byLU,d=byDist,t=byTech | AvaiArea(u,d,1)>0 .AND. LUPromising(lut,u,d)=1 .AND. ProductLUT("Fruit",lut)=1) FishPondRatio * LUA(t,u,lut,d) > TargetValue("AFruit") * AFruitTarget
19	Area of fruit tree by district	DAreaFruit (d=byDist)	SUM(lut=byLUT,u=byLU,t=byTech | AvaiArea(u,d,1)>0 .AND. LUPromising(lut,u,d)=1 .AND. ProductLUT("Fruit",lut)=1) LUA(t,u,lut,d) > DAFruit(d) * DAFruitTarget
20	Area by land unit by district	Area (u=byLU,d=byDist)	SUM(lut=byLUT,t=byTech | AvaiArea(u,d,1)>0 .AND. LUPromising(lut,u,d)=1) LUA(t,u,lut,d) < AvaiArea(u,d,1)
21	Labor by month	Labor (m=byMonth)	SUM(lut=byLUT,u=byLU,d=byDist,t=byTech | AvaiArea(u,d,1)>0 .AND. LUPromising(lut,u,d)=1) LaborNeedMonht(lut,u,d,t,m) * LUA(t,u,lut,d) < SUM(u=byLU,d=byDist) AvaiLabor(u,d,1)
22	Water by month	Water (m=byMonth)	SUM(lut=byLUT,u=byLU,d=byDist,t=byTech | AvaiArea(u,d,1)>0 .AND. LUPromising(lut,u,d)=1) WaterNeedMonth(lut,u,d,t,m) * LUA(t,u,lut,d) < SUM(u=byLU,d=byDist) AvaiWater(u,d,1)

Table 13. Results of the zero round for the base scenario.

No.	Objective function	Unit	Objective			
			Max PRice	Max PNonRice	Max TIncome	Max TEmploy
1	PRice	t	<u>3,372,710</u>	0	629,009	1,486,742
2	PNonRice	t	0	<u>10,096,794</u>	2,774,505	7,576,250
3	TIncome	10^6 VN dong	3,215,742	2,527,369	<u>6,337,484</u>	1,468,130
4	TEquity	10^6 VN dong	126,579	306,336	196,616	184,262
5	TEmploy	10^3 labor-day	42,853,993	78,270,681	34,712,905	<u>107,138,677</u>
6	TLaborPro	10^3 labor-day	42,853,993	78,270,681	34,712,905	107,138,677
7	TWater	10^3 m^3	28,351,800	23,904,000	28,351,800	28,351,800
8	TFertilizer	t	238,129	266,778	233,957	371,891
9	TPesticide	t	4,252	5,630	3,263	6,156
10	TNLoss	t	4,252	5,630	3,263	6,156
11	Equity by deviation/average[a]	%	0.6	1.7	0.4	1.8

[a]This additional value is calculated to reflect the equity in income by district.

column header identifies the objective and the associated optimization (maximize or minimize). Underlined figures refer to the optimal value of the corresponding objective function.

Results of the zero round show that the maximum achievable rice production with the current resource base is 3.4 million t. This is almost twice the level of rice production in 1996 (1.8 million t). To achieve this production level, 28.35 billion m^3 of water and 42.85 billion labor days are needed. Producing this much rice will result in a total income of 3.22 billion VN dong for the entire province.

When a goal is minimized (e.g., minimize fertilizer use) in the zero round, the resulting goal values will all be zero. Because no other goal restrictions are imposed (such as minimum production level), the model will just opt for a solution of not allocating any land to any LUT. Running an objective function that is being minimized will only have nonzero results when lower bounds on goals or constraints are imposed.

Tables 14 shows the land use allocation by district for the model run of maximizing rice production. Available land in the province would be allocated to three LUTs: 58% to triple rice crop, 38% to double rice crop, and 4% to double rice crop with fish.

In the third round, bounds of goals, production, and area targets are imposed (refer to Table 11 for target values). The optimizations in this round resulted in lower optimal values (Table 15 a, b) compared with those in the zero round. For instance, the value for rice production decreased by 29%; for nonrice production, the decrease was 68%; and total income declined by 45% compared with the zero round.

Conclusions and recommendations

The MGLP component of LUPAS is described in this technical document with the Can Tho Province model as an example.

Table 14. Land use allocation (in ha) for each district when rice production is maximized.

No.	District	Land use type			Total
		Rice-rice	Rice-rice-rice	Rice-rice-fish	
1	Chau Thanh	8,172	16,515	0	24,687
2	Long My	33,925	0	0	33,925
3	O Mon	0	34,294	9,672	43,966
4	Phung Hiep	19,304	16,692	0	35,996
5	Thot Not	10,521	34,199	0	44,720
6	Tp Can Tho	0	26,671	0	26,671
7	Vi Thanh	18,675	7,625	0	26,300
	Province	90,597	135,996	9,672	236,265

Table 15a. Results of optimizations (maximizations) when area and production targets are considered.

No.	Objective function	Unit	Max PRice	Max PNonRice	Max TIncome	Max TEquity	Max TEmploy
1	PRice	t	2,406,205	2,389,003	2,398,822	2,377,546	2,339,472
2	PNonRice	t	3,109,500	3,200,836	3,109,500	3,112,669	3,144,005
3	TIncome	10^6 VN dong	3,500,000	3,500,000	3,515,636	3,500,000	3,500,000
4	TEquity	10^6 VN dong	170,104	171,932	174,485	145,468	174,238
5	TEmploy	10^3 labor-day	50,430,728	50,874,803	50,435,843	50,497,495	51,878,821
6	TLaborPro	10^3 labor-day	50,430,728	50,874,803	50,435,843	50,497,495	51,878,821
7	TWater	10^3 m^3	28,351,800	28,351,800	28,351,800	28,351,800	28,351,800
8	TFertilizer	t	249,301	250,885	250,478	250,927	252,210
9	TPesticide	t	4,631	4,682	4,661	4,662	4,632
10	TNLoss	t	4,631	4,682	4,661	4,662	4,632
11	Equity by deviation/average[a]	%	0.7	0.7	0.7	0.6	0.7

[a]This additional value is calculated to reflect the equity in income by district.

Table 15b. Results of optimizations (minimizations) when area and production targets are considered.

No.	Objective function	Unit	Min TLaborPro	Min TWater	Min TFertilizer	Min TPesticide	Min TNLoss
1	PRice	t	2,345,896	2,379,841	2,378,481	2,345,896	2,379,841
2	PNonRice	t	3,109,500	3,109,500	3,109,500	3,109,500	3,109,500
3	TIncome	10^6 VN dong	3,500,000	3,500,000	3,500,000	3,500,000	3,500,000
4	TEquity	10^6 VN dong	162,910	171,932	160,106	162,910	171,932
5	TEmploy	10^3 labor-day	48,718,281	50,121,291	50,540,883	48,718,281	50,121,291
6	TLaborPro	10^3 labor-day	48,718,281	50,121,291	50,540,883	48,718,281	50,121,291
7	TWater	10^3 m^3	28,351,800	28,158,775	28,351,800	28,351,800	28,158,775
8	TFertilizer	t	246,714	249,140	243,111	246,714	249,140
9	TPesticide	t	4,533	4,641	4,666	4,533	4,641
10	TNLoss	t	4,533	4,641	4,666	4,533	4,641
11	Equity by deviation/average[a]	%	0.7	0.7	0.7	0.7	0.7

[a]This additional value is calculated to reflect the equity in income by district.

In addition to presenting results of optimizations in tabular form, goal values can also be presented graphically and land use allocations can also be shown in map form. This will facilitate comparison of goal values and land use allocations for the different scenarios considered. For purposes of interpretation, it is also useful to illustrate the trade-off between two objectives.

Part 2 of this technical document will describe the operational procedure for mapping results of optimizations.

Different land use allocations can result in similar objective values. In addition to analyzing optimal solutions, nearly optimal solutions can be examined to analyze land use allocations that will result in nonoptimal but only slightly different objective values. Makowski et al (1998) present a framework for studying nearly optimal solutions of linear programming models developed for exploring land use options for the agricultural sector.

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MapLink: a tool for linking data in Excel file to GIS

Introduction

A geographic information system (GIS) is a computer-based system that enables the capture, modeling, manipulation, retrieval, analysis, and presentation of geographically referenced data (Worboys 1995). GIS has wide applications covering various fields.

In SysNet, GIS is used as a supporting tool for resource assessment, delineation of land units, and mapping of land use options and goal achievements (Fig. 1).

What has been lacking in LUPAS is an interface that can link the data in the input-output tables for the various agricultural production activities and the optimization results to GIS. During the SysNet Technical Review Workshop held in Bangkok, Thailand, in November 1998, it was pointed out that the mapping of key variables, such as crop yields at defined technology levels, fertilizer, or irrigation water requirements, will facilitate the examination of the spatial distribution of the input-output data, provide another way to cross-check the correctness of the data being used, and analyze spatially the results of optimization runs for the different scenarios. In response to these needs, a first interface, linking input-output data in Excel files to Idrisi maps, was developed in January 1999.

Various data are stored in Microsoft Excel files (see Part 1). Before these can be mapped, they need to be converted to a format that the GIS software can recognize — e.g., mdb or dbf format. Then, the file needs to be imported into the GIS and mapped following certain procedures. A solution to this problem was found in *MapLink*, a tool created for linking data in Excel files to a GIS.

The GIS software Idrisi (Eastman 1997) is used by various SysNet teams, but it can read data from xbase files and mdb files (Microsoft Access) only. Since the SysNet project uses Microsoft Excel to store input-output data and results of optimization runs, the data to be mapped need to be converted to either dbf or mdb format first. In Idrisi, the file is then opened using the “database workshop.” The variable required is mapped by linking the database file to a base map and assigning field values to the image. After completing these steps, the resulting map is displayed. This procedure, though not too complicated, requires some steps and knowledge in the use of Idrisi. Because of the volume of data to be mapped resulting from the large number of variables being used in the different scenarios and optimization runs, a routine to facilitate this procedure becomes necessary.

MapLink creates a new map using a defined set of values and a base map. This system was developed using Excel and inovaGIS, which is a component-based program that was developed at the New University of Lisbon in Portugal. It consists of a library of routines for accessing existing Idrisi raster images and creating new images from within Windows-based applications, such as Excel (Goncalves 1998). *MapLink* makes use of this library to automate the mapping of data stored in Excel. The resulting files created by *MapLink* are in standard Idrisi format and can be accessed in Idrisi for further analysis.

This part of the technical document describes *MapLink* and how it can be used to create Idrisi maps.

The file system, structure, and use of *MapLink*

MapLink consists of one Excel file with two types of worksheets: the map sheet (*Maps)* and the data sheets *(ByDistrict*, *ByAEU*, *ByLU)*. There can be any number of data sheets and the name of the data sheets can be changed to suit specific needs. The name of the map sheet, however, should not be changed. Otherwise, an error message, "Subscript out of range", will be displayed because the program cannot locate the *Maps* sheet.

To activate *MapLink*, press Ctrl+M. This will activate the program that opens the user menu. The routines to automate the mapping of the base map and the creation of new maps are stored as macros in MAPLINK.XLS. The base map can be an administrative map (showing district, municipal, or regional boundaries), a map of agroecological units, or a map of land units (combination of the two) in a region.

The user will be prompted to enter information, such as the filename of the base map, which is required to create maps (Fig. 4). A detailed description of the user interface is given in the next section.

The *ByLU*, *ByAEU*, and *ByDistrict* sheets are the data sheets from where the program will get the variables to map. Of current interest to SysNet are maps by administrative units, agroecological units, and land units (combination of administrative and agroecological units). The values in these sheets will be mapped by matching the codes with the identifiers (ids) in the base

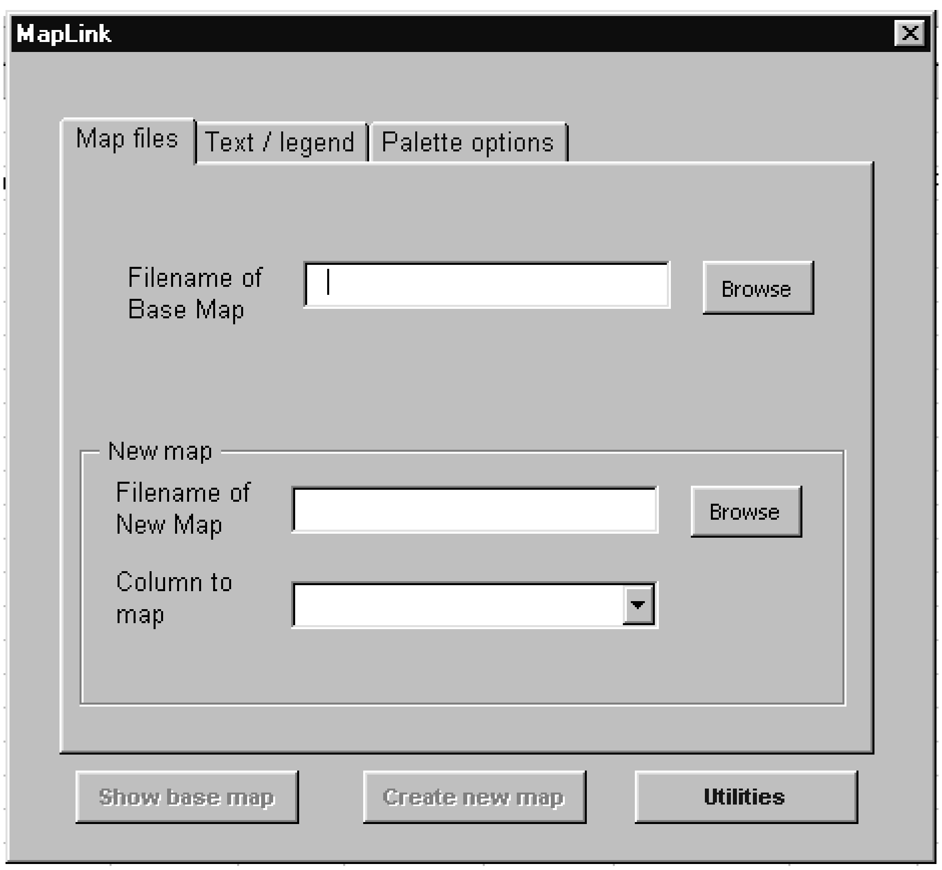


Fig. 4. The *MapLink* interface.

map, so care must be taken to ensure that the codes in the base map and in the data sheet refer to the same geographical area. New data sheets can be added as required and the names of these sheets can be changed without affecting the execution of the program.

Figure 5 shows a set of sample data by district, which is a preliminary output of the optimization runs for the Haryana model.

MapLink gets data from the *Values* and *ValuesHeader* ranges. To define a range in Excel, select *Insert* in the menu bar, then click on *Name*, then *Define.* This will open up a dialog box to identify the name to be created and the cell location of the values.

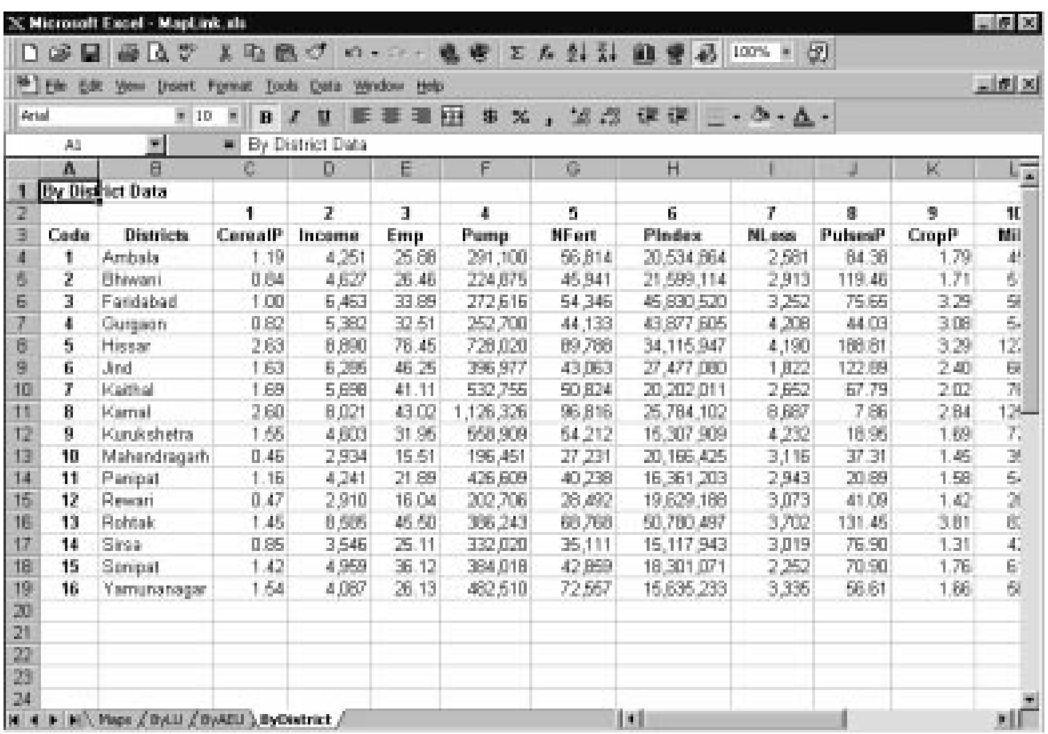
The *ValuesHeader* range contains the variable names to be mapped. It has one row and can have any number of columns, depending on the number of variables you need to map. Figure 6 shows the *ValuesHeader* range for the sample data shown in Figure 5.

The first column of the *Values* range contains the code to be mapped and should match with the code in the Idrisi file. This will ensure that the data will be mapped to the correct map polygon. The second column contains a description of the first column. The remaining columns are the values to be mapped. Figure 7 shows the *Values* range for the sample data shown in Figure 6.

When a new map is created, aside from creating the actual Idrisi file, the resulting map will be dumped into the *Maps* worksheet as a picture (Fig. 8). Similarly, the base map will be pasted to this worksheet. These pictures can be copied and pasted to Word documents for inclusion in reports and/or visual aids.

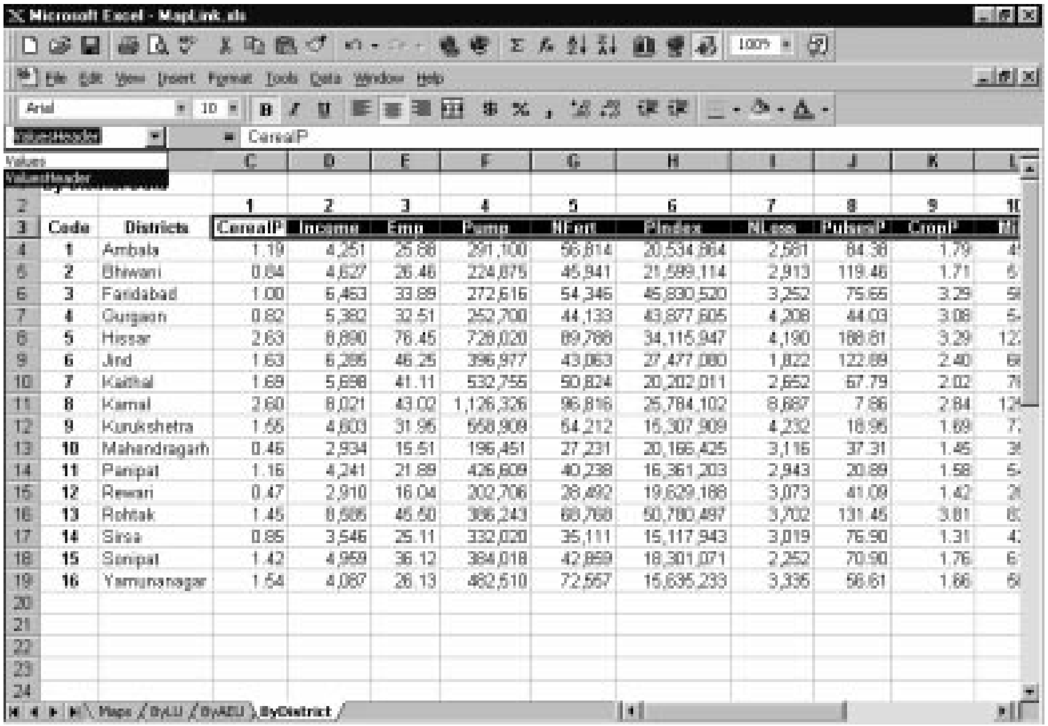
The user interface

MapLink's user interface consists of a pop-up screen. It has three tabs to group similar



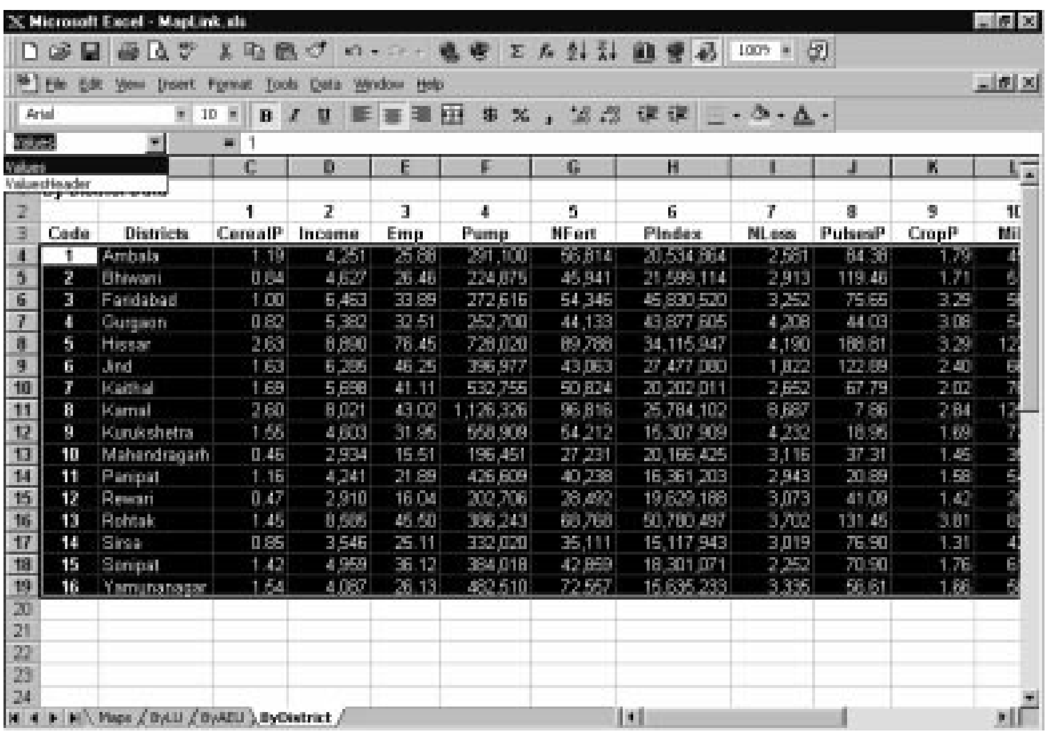
		1	2	3	4	5	6	7	8	9
Code	Districts	CerealP	Income	Emp	Pump	NFert	PIndex	NLoss	PulsesP	CropP
1	Ambala	1.19	4,251	25.88	291,100	56,814	20,534,864	2,581	84.38	1.79
2	Bhiwani	0.84	4,627	26.46	224,875	45,941	21,599,114	2,913	119.46	1.71
3	Faridabad	1.00	6,463	33.89	272,616	54,346	45,830,520	3,252	75.65	3.29
4	Gurgaon	0.82	5,382	32.51	252,700	44,133	43,877,605	4,208	44.03	3.08
5	Hissar	2.63	8,890	76.45	728,020	89,788	34,115,947	4,190	188.81	3.29
6	Jind	1.63	6,286	46.25	396,977	43,063	27,477,080	1,822	122.89	2.40
7	Kaithal	1.69	5,698	41.11	532,755	50,824	20,202,011	2,652	67.79	2.02
8	Karnal	2.60	8,021	43.02	1,126,326	96,816	25,784,102	8,687	7.86	2.84
9	Kurukshetra	1.56	4,603	31.95	558,909	54,212	16,307,909	4,232	18.95	1.69
10	Mahendragarh	0.46	2,934	15.51	196,451	27,231	20,166,425	3,116	37.31	1.45
11	Panipat	1.16	4,241	21.89	426,609	40,238	16,361,203	2,943	20.89	1.58
12	Rewari	0.47	2,910	16.04	202,706	28,492	19,629,188	3,073	41.09	1.42
13	Rohtak	1.45	8,506	45.50	386,243	68,768	50,780,497	3,702	131.45	3.81
14	Sirsa	0.85	3,546	25.11	332,020	35,111	15,117,943	3,019	76.90	1.31
15	Sonipat	1.42	4,959	36.12	384,018	42,859	18,301,071	2,252	70.90	1.76
16	Yamunanagar	1.54	4,087	26.13	482,510	72,567	15,635,233	3,336	56.61	1.66

Fig. 5. A sample data sheet: data by district.



Code	Districts	CerealP	Income	Emp	Pump	NFert	PIndex	NLoss	PulsesP	CropP
		1	2	3	4	5	6	7	8	9
1	Ambala	1.19	4,251	25.88	291,100	56,814	20,534,864	2,581	84.38	1.79
2	Bhiwani	0.84	4,627	26.46	224,875	45,941	21,599,114	2,913	119.46	1.71
3	Faridabad	1.00	6,463	33.89	272,616	54,346	45,830,520	3,252	75.65	3.29
4	Gurgaon	0.82	5,382	32.51	252,700	44,133	43,877,605	4,208	44.03	3.08
5	Hissar	2.63	8,890	76.45	728,020	89,788	34,115,947	4,190	188.61	3.29
6	Jind	1.63	6,286	46.25	396,977	43,063	27,477,080	1,822	122.89	2.40
7	Kaithal	1.69	5,698	41.11	532,755	50,824	20,202,011	2,652	67.79	2.02
8	Karnal	2.60	8,021	43.02	1,126,326	96,816	25,784,102	8,687	7.86	2.84
9	Kurukshetra	1.56	4,603	31.95	558,909	64,212	15,307,909	4,232	18.96	1.69
10	Mahendragarh	0.46	2,934	15.51	196,451	27,231	20,166,425	3,116	37.31	1.45
11	Panipat	1.16	4,241	21.89	426,609	40,238	16,361,203	2,943	20.89	1.58
12	Rewari	0.47	2,910	16.04	202,706	28,492	19,629,188	3,073	41.09	1.42
13	Rohtak	1.45	8,586	45.50	386,243	68,768	50,780,497	3,702	131.45	3.81
14	Sirsa	0.85	3,546	25.11	332,020	35,111	15,117,943	3,019	76.90	1.31
15	Sonipat	1.42	4,959	36.12	384,018	42,859	18,301,071	2,252	70.90	1.76
16	Yamunanagar	1.54	4,087	26.13	482,510	72,557	15,635,233	3,336	56.61	1.66

Fig. 6. The *ValuesHeader* range for the sample data.



Code	Districts	CerealP	Income	Emp	Pump	NFert	PIndex	NLoss	PulsesP	CropP
		1	2	3	4	5	6	7	8	9
1	Ambala	1.19	4,251	25.88	291,100	56,814	20,534,864	2,581	84.38	1.79
2	Bhiwani	0.84	4,627	26.46	224,875	45,941	21,599,114	2,913	119.46	1.71
3	Faridabad	1.00	6,463	33.89	272,616	54,346	45,830,520	3,252	75.65	3.29
4	Gurgaon	0.82	5,382	32.51	252,700	44,133	43,877,605	4,208	44.03	3.08
5	Hissar	2.63	8,890	76.45	728,020	89,788	34,115,947	4,190	188.61	3.29
6	Jind	1.63	6,286	46.25	396,977	43,063	27,477,080	1,822	122.89	2.40
7	Kaithal	1.69	5,698	41.11	532,755	50,824	20,202,011	2,652	67.79	2.02
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9	Kurukshetra	1.56	4,603	31.95	558,909	64,212	15,307,909	4,232	18.96	1.69
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12	Rewari	0.47	2,910	16.04	202,706	28,492	19,629,188	3,073	41.09	1.42
13	Rohtak	1.45	8,586	45.50	386,243	68,768	50,780,497	3,702	131.45	3.81
14	Sirsa	0.85	3,546	25.11	332,020	35,111	15,117,943	3,019	76.90	1.31
15	Sonipat	1.42	4,959	36.12	384,018	42,859	18,301,071	2,252	70.90	1.76
16	Yamunanagar	1.54	4,087	26.13	482,510	72,557	15,635,233	3,336	56.61	1.66

Fig. 7. The *Values* range for the sample data.

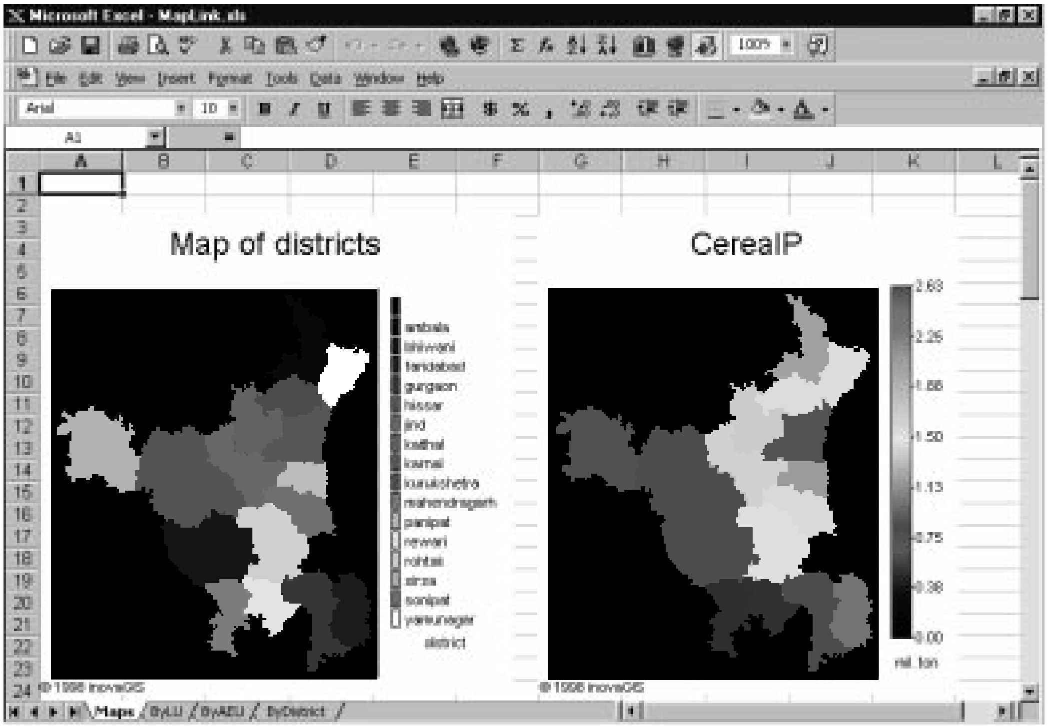

Fig. 8. The base map and the new map will be dumped into the *Maps* worksheet.

information that requires user input: Map files, Text/legend, and Palette options.

Map files

The *Map files* tab (Figs. 4 and 9) prompts the user to enter the following required information:

Filename of base map. *MapLink* will only accept Idrisi raster images as base maps. The filename can be typed directly (include the file path, e.g., c:\haryana\maps\district.img) or the *Browse* button can be used to locate the file. An error message will appear if the file does not exist in the subdirectory you specified.

If you get an error message, "Compiler error: Can't find project or library," this means that you have not yet installed inovaGIS in your machine. Refer to the next section for the procedure for installing inovaGIS.

Filename of new map. The created map will be stored under this name. Be sure to include a logical file path to avoid an error in creating the map. The *Browse* button can also be used to locate the correct subdirectory where you want to save the file. If another file with the same name exists in the subdirectory, the contents of the file will be overwritten.

Column to map. This field should contain the variable to be mapped. The variable can be typed or selected by clicking on the drop-down list. The items in this list are extracted from the *ValuesHeader* range. When a variable name other than those defined in the *ValuesHeader* range is typed, an error will occur.

Text/legend

This tab contains information pertaining to titles and legends of the map to be displayed. Initially, the *Base map* and the *New map* frames are inactive. When the filename for the corresponding map is indicated in the *Map files* tab, the frame will become active.

Stored information about the base map such as title, number of data labels, and unit will be shown in the base map frame. For the new map, default information will be displayed. Figure 9 shows the contents of the *Map files* and the *Text/legend* tabs for the maps shown in Figure 8.

Title of map. The default title for the base map is the title as saved in the actual Idrisi file. For the new map, the default title is the name of the variable. The title for the base map can be modified so that the pasted picture can show a different title. However, the changes will not be saved in the actual Idrisi file.

Categorize the data? Answering “no” will create a map of continuous values. Indicating “yes” will create a map of discrete values, i.e., the values of the new map will be categorized based on the range of values (maximum and minimum values) as well as the number of classes/categories required. The default is “yes.”

Unit. For the new map, this information will be stored in the Idrisi image to be created and will be displayed in the legend of the pasted map. There is no default value so, when no information is indicated, the resulting pasted map will not have a unit in the legend.

Number of classes/data labels. If you answered “no” to the previous question, this refers to the number of data labels in the legend. Otherwise, this refers to the number of discrete classes to be placed in the legend.

Palette options

The colors to be used in mapping the different units can be specified using this option. Any of the seven predefined palettes can be used (Grey256, Grey16, Alt256, Composit, Idri256, Idri16, IBM16) or the user can specify a different set by selecting colors. A color box will be displayed when you click on a box and you can select from the basic colors or define custom colors. The color scheme can also be inverted and an option for creating gradients is also available. The default palette is Idri16.

At the bottom of the screen are three buttons: *Show base map*, *Create new map*, and *Utilities*.

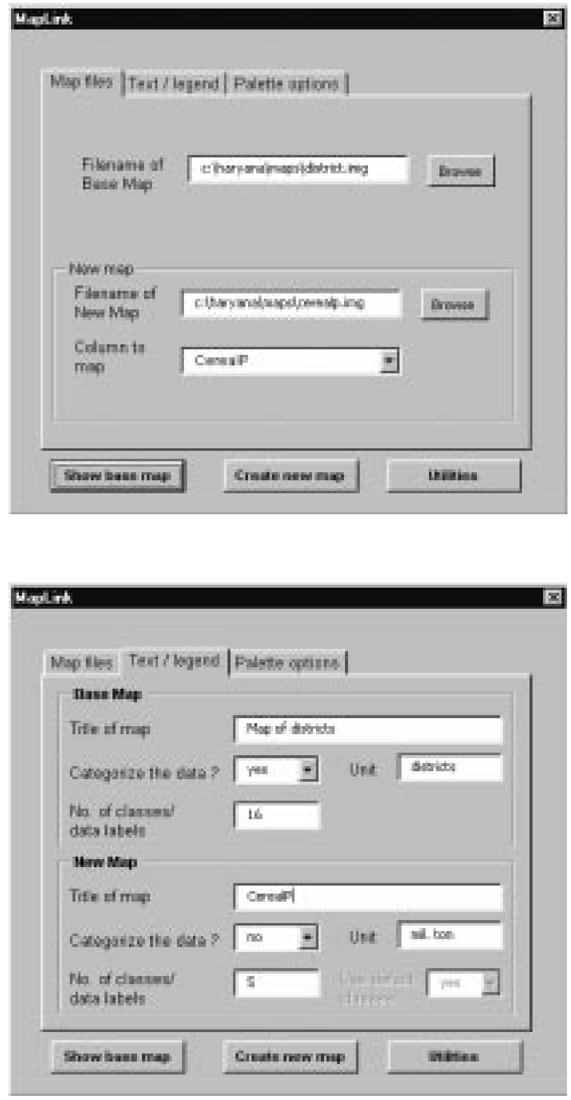

Fig. 9. The *Map files* (top) and *Text/legend* tabs (bottom).

Show base map

Initially, this button is inactive. It will become active when the filename for the base map is specified. Clicking on this button will display the base map in the *Maps* sheet, adopting the map settings indicated on the *Text/legend* and *Palette options* tabs.

Create new map

Like the previous button, this will become active only when the filename for the new map and the column to map field are specified. Clicking on this button will create a new Idrisi file and display the created map in the *Maps* sheet.

Utilities

This button has been added to include other utilities. In the current version of *MapLink*, this includes the point query facility. By pointing the cursor over the map, the cell value, the row and column, and the geo-referenced locations are displayed.

When this button is clicked, a new window appears. By clicking on *File*, then *Open*, and selecting the file, the map will be displayed (Fig. 10). Multiple files can be opened and tiled/ arranged as required.

This routine could not be implemented in Excel. The Visual Basic programming language was used instead and the executable file is called up from within Excel. Other features such as computation of areas and statistical summary of the values of the images will be added in the next version.

Getting started

1. Copy the file MAPLINK.XLS and the base map(s) to the same subdirectory (e.g., C:\MAPLINK).
2. *MapLink* requires that inovaGIS be installed on the computer you are using. To do this, copy inovaGIS.zip from the installation disk to a subdirectory in your computer (e.g., c:\inovaGIS). Extract the files by running WinZIP or PKUnzip. Run setup and

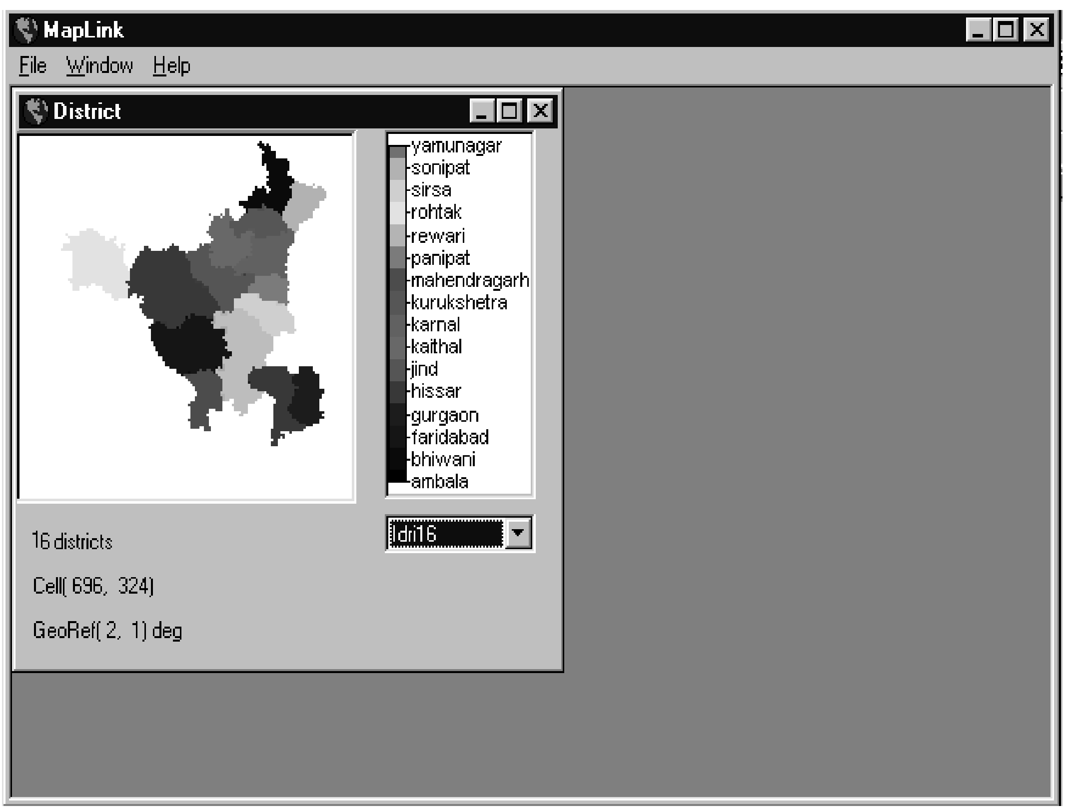

Fig. 10. The Utilities window.

several screens will guide you on the installation process. Be sure to click on "Yes, Launch program file" before ending the installation. Note that you need to install inovaGIS only once on a computer.

3. Open the Excel file MAPLINK.XLS. Put the variables and the data set you need to map on the appropriate data sheet (e.g., *ByDistrict*, *ByLU*, *ByAEU*). Define the *Values* and *ValuesHeader* ranges.
4. Press Ctrl+M to open the menu.
5. To view the base map, type the filename in the space provided. The saved title, number of classes, and unit will be displayed on the *Text/legend* tab. The title can be changed to a more suitable one, if necessary, but the changes will only be shown on the pasted map and will not be saved. The default palette is Idrisi 16. This can be changed to other saved palettes or a user-defined one. When all settings are finished, click on the *Show base map* button. The map will be pasted onto the *Maps* sheet.
6. To create a new map, enter the filename where the new map will be saved and the name of the variable to be mapped. A list of the available variables (which are taken from the *ValuesHeader* range) can be seen by clicking on the drop-down list in the *Column to map* field. The other map settings such as the titles, legend, and palette can be set by selecting the corresponding tab. Click on the *Create new map* button to map the variable you specified. The map will be pasted onto the *Maps* sheet.

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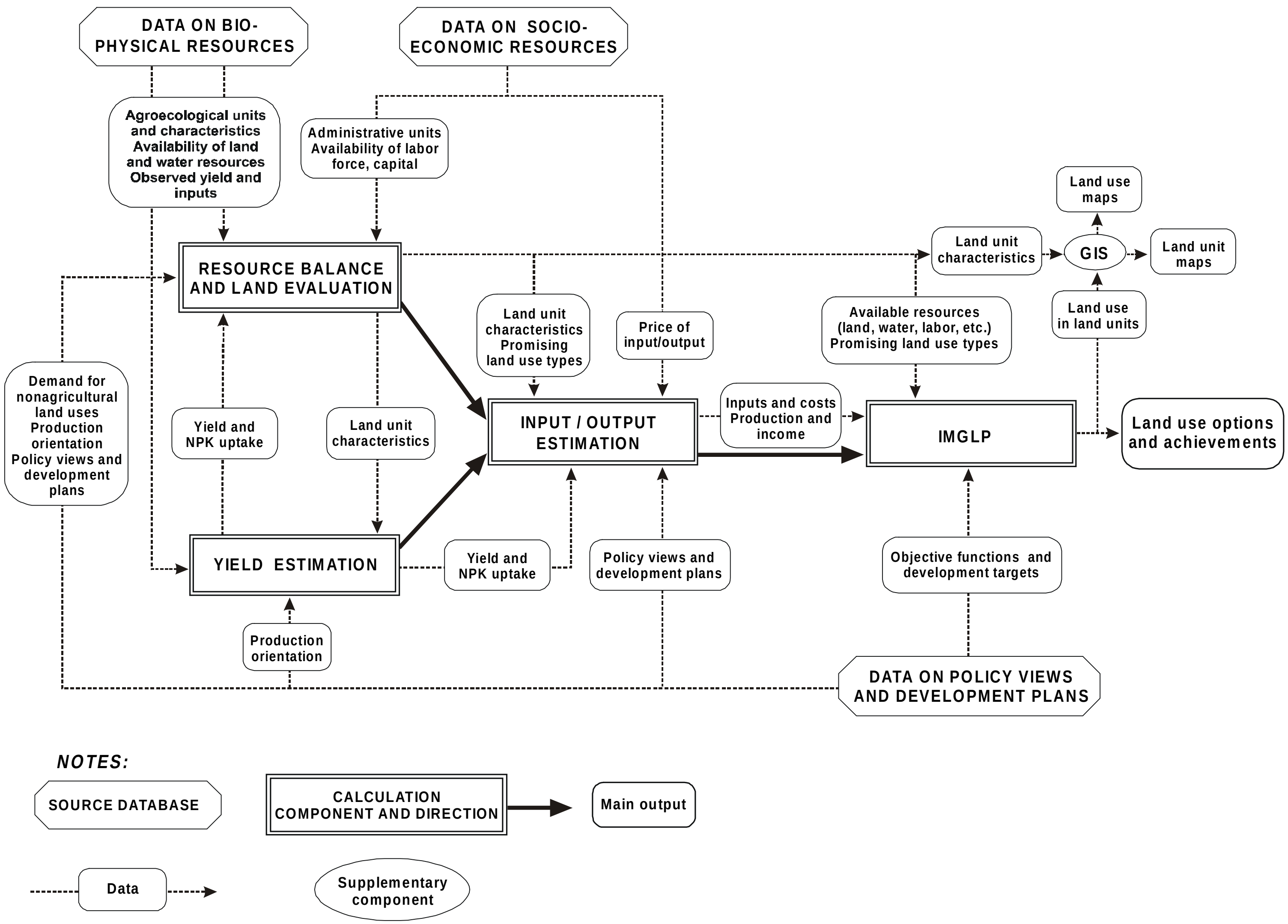

Annex 1. Operational structure of LUPAS (Land Use Planning and Analysis System).