DECISION SUPPORT SYSTEM (DSS) FOR SUSTAINABLE WATERSHED MANAGEMENT IN DONG NAI WATERSHED – VIETNAM : APPLYING GIS AND DSS TECHNIQUES FOR RELOCATING LAND USE MAP

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ABSTRACT

Decision makers today need to be able to rapidly find good solutions to increasingly complex problems. Optimization based on decision support system (DSS) can help decision makers to meet this challenge. Building such systems, however, is expensive and time consuming. In this study, DSS was developed using linear programming (LP), goal programming (GP), and geographic information system (GIS) for sustainable watershed management in Dong Nai watershed (589,078 ha), Southern Vietnam. A case study approach is undertaken using 'what-if' planning scenarios. The multi-objective linear programming (MOLP) techniques and GIS have been applied to display the optimum land resource allocation in different scenario, in order to evaluate the sustainable strategy of land development in a watershed. The information incorporated into the optimization objectives include economic benefits characterized by net income, sediment yield, and water discharge. The constraint set thereby consists of the limitations of carrying capacity of various land-use programs and assimilative capacity corresponding to different impacts on water quantity, sediment yield. The type of spatial planning problems described in this paper allocates different land uses across a geographical region, subject to a variety of constraints and conflicting management objectives. This complex land use planning decisions were made not only on what to do (selection of activities) but also on where to do it (i.e., relocate a new set of suitable land use for different scenarios), adding a whole extra class of decision variables to the problem. The new location of suitable land use has been manipulated using the given criteria in term of slope, soil depth, and rainfall. The algorithm was developed in ArcView GIS software to relocate land use map in Dong Nai watershed. The developed DSS performed very well in Dong Nai watershed.

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INTRODUCTION

Justification

Degradation of watershed is a common phenomenon around the world. There are several reasons for such degradation, but most important is improper utilization of watershed resources, among which land use allocation is the most important. Land use allocation has affected watershed and land degradation. The most important consequence of land degradation in Vietnam is the loss of productivity, depletion of fauna and flora and reduction of agricultural land per capita. In terms of the estimated monetary loss on account of land degradation, water erosion and leaching accounted for more than half, salinisation, acidification, drought and water logging for about one third and decline in soil fertility for the rest. (Buckton. *et. al*., 1999). The consequences of flood inundation and water logging are very serious on humans and precious natural resources. For example, two floods in 1999 occurred in the southern central coast claimed 711 lives and caused economic loss estimated at more than US$ 235 million. Besides, millions of tons of soil from the hilly and mountainous regions was eroded and flowed into rivers, streams, plains and the sea.

In Dong Nai watershed, large forest area has been replaced by the expansion of agricultural area, for food subsistence and then, for cash crop production, especially since the beginning of the "open economy" in 1980s. Traditional management systems for forest, land and water have been replaced by subsidiary state-run enterprises and agencies, which were not well motivated to enforce formal regulations and to stop the trend of becoming an open-access situation.

In practice, the resource utilization in the watershed involves multiple objectives, many of which are incompatible or conflicting. Watershed management mechanisms therefore need to be analyzed in depth by taking into account the economic, social, and the environmental goals. Under the constraints of watershed resources and permissible ecological impacts, the effective and harmonious watershed management policies are needed and must endeavors to satisfy both local communities and the national – regional governments. Development to such multi-objectives plans requires the formulation of a mathematical programming technique or quantitative management approach, capable of quantifying the degree to which any proposed management meets objectives such as: (1) satisfactory net incomes, (2) desirable agricultural products, and (3) permissible soil loss and runoff.

Hence, this research attempts to solve the selected Dong Nai watershed in context of watershed management through the Linear Programming and GIS criteria-DSS (Decision Support Systems) approach.

OBJECTIVES

In order to formulate watershed management plan in Dong Nai watershed, the main aim in this investigation is how to apply LP and GIS criteria-DSS for optimizing land use allocation and relocating the solution in Dong Nai watershed. The specific objectives of this study are as follows:

1. to determine the decision variable coefficients for LP and GIS;

2. to apply LP technique for optimizing land use allocation in Dong Nai watershed under the criteria of multiple objectives, limited resources, and permissible impacts to the water yield;

3. to apply GIS and DSS techniques for relocating the optimal land use maps allocated by LP.

METHODOLOGY

The Decision Support System (DSS) techniques namely Mathematical programming, Linear Programming (LP), Goal Programming (GP), MINMAX formulations, Geographic information system (GIS), and multi-criteria decision analysis were employed to ranking the desirable priorities, their potential outcomes, and quantifying their achievement level respectively. Mathematical programming makes it possible to obtain the optimal solution of the problem in order to make the objective function maximum or minimum while fulfilling all other requirements at the same time. Mathematical programming is able to give a synthetic approach to complex situations. The results and problem structure are discussed in the next section, before that an out look of the necessity for integrating the GIS along with analytical model has been elaborated in the following section. The methodology employed herein can be described as follows:

Study Area Description

Dong Nai watershed locates in the Southern of Vietnam which is one of three province at East – Southern, Vietnam. It is situated between $10^\circ\ 31' - 11^\circ\ 35'$ latitude and $106^\circ\ 42' - 107^\circ\ 35'$ longitude. The region occupies an area of approximately 586,427 ha as shown in Figure 1.

The Scenario planning methodology

The scenario planning approach applied to the case study area of Dong Nai watershed is shown in Figure 2. The principal planning task is to bring about the efficient planning of future in Dong Nai watershed. The objectives from each of these plans assist in deciding upon the socio-economic, physical and environmental data required to formulate the different planning scenarios. The objectives are also used later in the methodology to evaluate the efficiency of each proposed planning scenario.

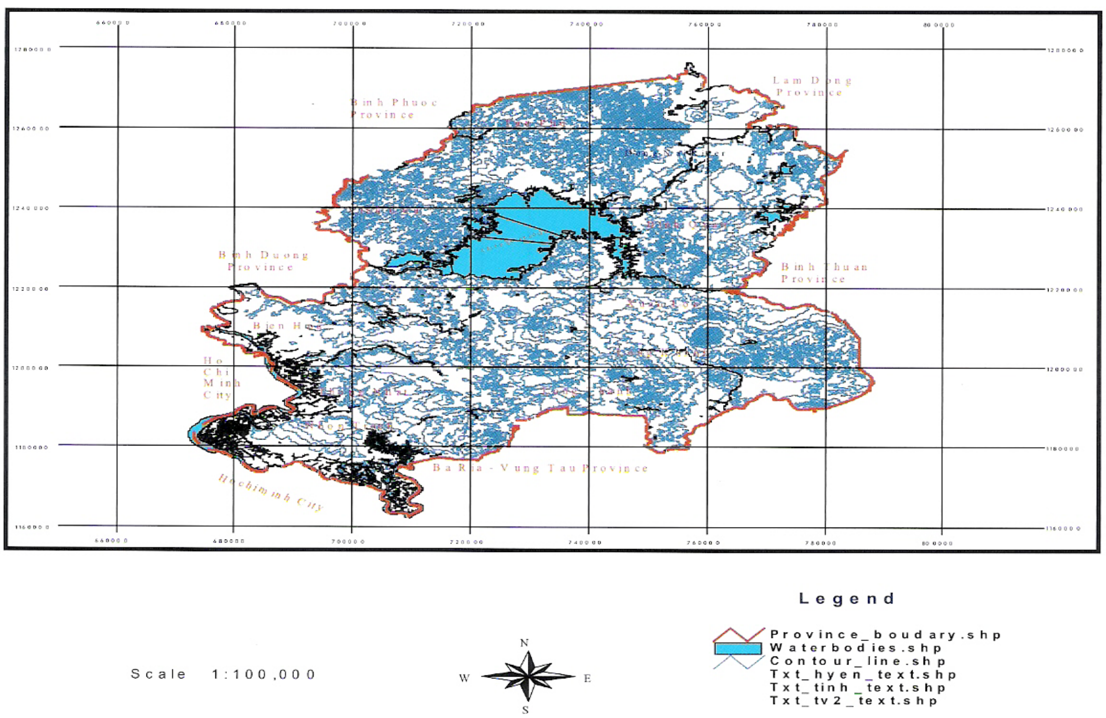

Figure 1. Dong Nai Watershed Topography, Vietnam

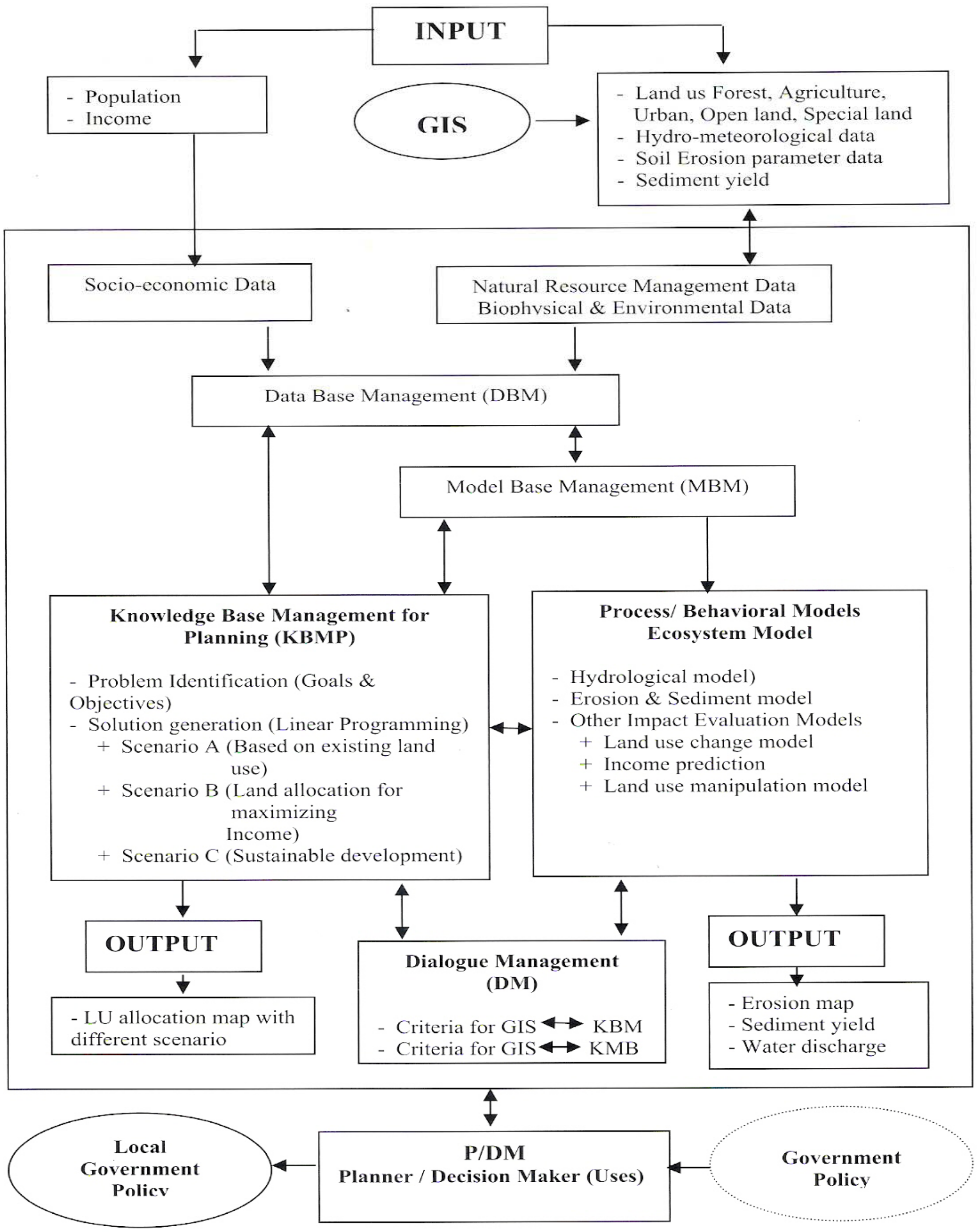

Figure 2. General Methodology in development DSS for sustainable land allocation

The next step of the planning methodology is to formulate possible land-use scenarios. Three land-use planning scenarios are formulated for Dong Nai watershed. Scenario A -'future trends' is based on existing socioeconomic trends. Scenario B – 'Land allocation for maximizing economic' will be derived using optimization modelling of land valuation data. Scenario C – 'sustainable development' will be derived using a number of environmental layers and assigning weightings of importance to each layer using a multiple criteria analysis (MCA) approach.

Relocating Land use allocation mapping

Based on results from linear programming, and goal programming of three scenarios (Scenario A "Future Trends" scenario, scenario B "Land Allocation for Maximizing Economic Scenario", scenario C "Sustainable Development" scenario), the final step of this research is to mapping the location of land uses allocated by different scenarios using GIS techniques with the given criteria.

Since the linear programming (LP), and goal programming (GP) does not provide a spatial representation for the suggested land use allocations only how many hectares of each land use should be changed, but have no indication which specific hectares should be altered. Two approaches will be followed to map the results. First, linear programming will be considered just as a tool to optimize land use allocation; the results will be mapped out of the linear programming environment using criteria of spatial suitability in GIS environment. In order to obtain the information necessary for setting up the criteria constraints, some of the land use type needed to be further analyzed and combined many parameters. This situation is well suited to the use of a GIS-technique. The GIS-ArcView program provides a board set of functions to fulfill the requirements of this problem. After the analysis is performed, the program provide a value for the area which meets all the criteria requirements stated before based on algorithms. For instance, about 5% watershed area that should be changed from any land use to new forest land can be located by selecting auxiliary variables. The same can be done with all the land use changes. Auxiliary variables are used to locate each land use change. According to linear programming, and goal programming we know exactly how many hectares of each land use changes should be relocated. In other word, from all the grid cells of land use (excepted forest existing), which grid cell should be selected for transformation to forest land. The selection of these cells is performed using four criteria variables: slope, soil depth, soil type, and rainfall. Besides four criteria variables, we can set up one that is distance from existing forest land to new forest land, if above four variables could not meet new forest land area we need. The selection of transition cells from any land use to a new land use is performed in a similar way. For example, in the case of forest land developments three criteria limitations are established: (i) minimization percent slope is 15%; (ii) soil depth should in level 1 or level 2; (iii) rainfall should less than 1500 mm/yrs. The conceptual framework for algorithm development to relocate land use map in Dong Nai watershed is presented in Figure 3.

RESULTS AND DISSCUSION

The Derived Variable Coefficients for Linear Programming, Goal Programming Model

Since a few of decision variable coefficients related to income, water discharge, sediment yield, according to the land use complex on the Dong Nai watershed, had been made available. The derived input data applied as decision variable coefficients in this study were thus based on the previous research finding, theoretical background, and surveying study particularly income.

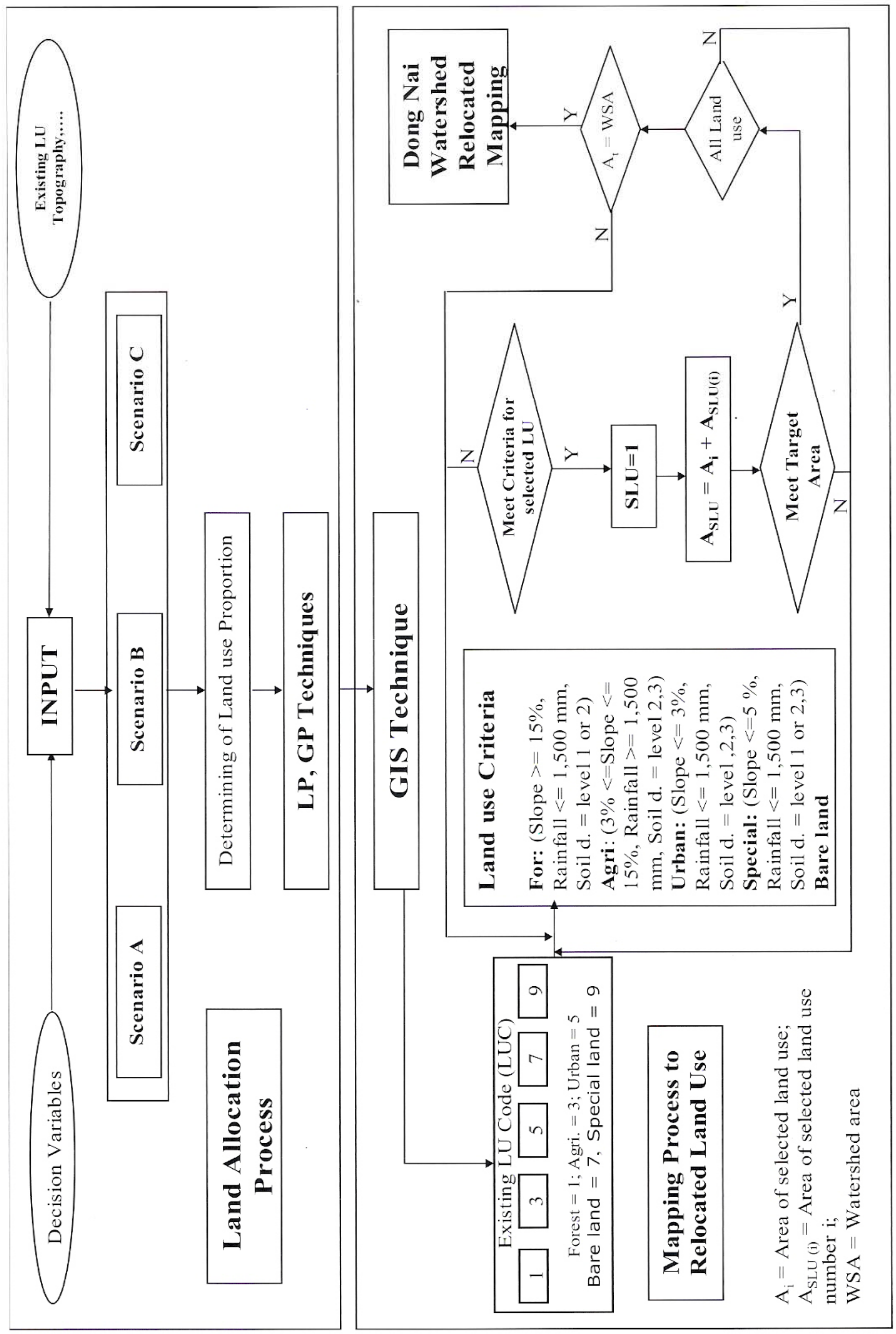

Figure 3. Conceptual framework for algorithm development to relocate land use map in Dong Nai watershed

The decision variable coefficients derived for applying in LP model, and GP in this study are presented for the watershed scale. These quantitative coefficients and their application in solving the land use allocation for sustainability is shown in Table 1.

Soil Erosion and Sedimentation in Dong Nai watershed based on Scenario A

Estimation of on-site erosion used the USLE based on GIS technique. The result are shown in Figure 4. On – site soil erosion of the most in Dong Nai watershed is ranging from 0.90 – 20.99 ton $ha^{-1}yr^{-1}$. The on-site erosion in Dong Nai watershed based on land use at year 2000 was 9,181,005 ton/yr, and the average on-site soil erosion was 15.58 to ton $ha^{-1}yr^{-1}$.

Based on observed sediment yield data from Tri An hydro-electric power plant and Institute of Water Resources in Ho Chi Minh City in Tri An reservoir, Dong Nai watershed at the year 2000 was 1,299,450 m^3 or 3,248,625 ton. In terms of the definition of sediment delivery ratio (SDR), the SDR in Dong Nai watershed was 0.35.

Solution of Quantitative Planning Management Scenarios of Dong Nai Watershed

1. MINMAX formulation

<u>The Present Watershed Scenario (Scenario A)</u>

Based on existing socio-economic trend in Dong Nai watershed, and relationship between gross income, water discharge, sediment yield, and land use change in Dong Nai watershed, the multiple objectives achievement levels of present watershed management scenario on watershed net income, water discharge, and sediment yield were approximately 10,093,650,805 thousands VND/yr, 509 m^3/s and 1,291,011 m^3 with the proportion of land allocation of Natural Forest (X_1 = 22.216 % or 131,089 ha), Forest Plantation (X_2 = 8.325% or 49,120), Industrial Crops (X_3 = 28.520% or 168,284 ha), Paddy Field (X_4 = 22.805% or 134,561 ha), Residential / Urban (X_5 = 1.822% or 10,751 ha), Open land (X_6 = 4.787% or 28,245 ha), and Special land (X_7 = 11.546 % or 68,013 ha).

<u>The Land Allocation for Maximizing Economic Scenario (Scenario B)</u>

Much physical, environmental, and economic data for land resource and watershed management has to be compiled to build up the objective function. The maximizing economic scenario that means the economic objective (net income) is the first priority to optimize decision variables as shown in the first row in Table 2.

<u>The Sustainable Development Scenario (Scenario C)</u>

The types of environmental impacts in this research for control as part of land use planning have to reflect directly the needs in the current watershed, which consist of sediment yield from soil erosion, and water discharge. The scenario is thus set the sustainable development on the environmental impact as the first priority. The environmental objectives function are then included sediment yield and water discharge. Firstly, sediment yield will be put as the first priority to optimize decision variables as shown as Scenario C1 in Table 2, Then water discharge will be put as the first priority to optimize decision variables as shown as Scenario C2 in Table 2. The resalts of land allocation based on Scenario A, B, and C are presented in Table 2.

2. Mapping the LP results

The final step of this model involves with the geographical distribution of the land allocation proportion of different land obtained in Table 2. LP does not provide a spatial representation for the resulted land use allocation. From Table 2, we know how many hectares of each land use should be changed, but have no indication which specific hectares of land use should be altered. Two approaches can be applied to map the results. First, if LP is considered just as the tool to optimize land use allocation, the results can be mapped out of the LP environment using criteria of spatial suitability. For instance, the 25,967 ha that should be changed from other land use to new forest land can be located by selecting auxiliary variables, such as slope, rainfall, soil depth. For soil depth, we divided to three level, level 1 representative soil depth less than or equal 50 mm, level 2 representative soil depth more than 50 and less or equal 100 mm, level 3 representative soil depth more than 100 mm. Slope and rainfall are also employed in land use relocation process.

In this study, slope, rainfall and soil depth were selected as auxiliary variables for setting the criteria for land use relocation. The new relocated areas must be closed to the existing targeted land use type. All auxiliary variables (slope, rainfall, and soil depth) are used to locate each land use change. According to Table 2, the following changes would be manipulated: (i) from other land use types (industrial crops, paddy field, bareland/openland, special land) to forest land, (ii) from bareland/openland and special land, industrial crops, paddy field to urban, (iii) from bareland/openland and special land to agricultural land (industrial crops, paddy field), (iv) from bareland/openland to special land. For scenario B, a figure of 15,964 grid cells of non-forest land or 399,103ha consisting of industrial crops, paddy field, bareland/ openland, and special land, 1,038 grid cells should selectively transform to forest land by the setting criteria.

The selection of these cells is performed using three auxiliary variables: slope, rainfall, soil depth as previously mentioned. In the case of other land use types (industrial crops, paddy field, bareland/ openland, special land) to forest land, the higher slopes (>= 15 %), and shallow soil depth (level 1) are considered most suitable for change. A cross tabulation file is created from land use map, slope map (DEM), soil depth level map, and interpolate rainfall map, in order to identify the slope, soil depth level, rainfall distribution required for non-forest. A cumulative histogram is used to detect the slope level, soil depth level, rainfall level at which the number of required cells (1,038) is reached. In this case, it is at 6.5 percent, so that all the cells with higher slope are candidates for transformation from non-forest (industrial crops, paddy field, bareland/openland, special land) to forest land. The selection of transitioned cells in the second step, i.e., (ii) from bareland/openland and special land, industrial crops, paddy field to urban, (iii) from bareland/openland and special land to agricultural land (industrial crops, paddy field), (iv) from bareland/openland to special land, was performed in a similar process. The criteria finally used are as follows: (i) grid cells with less than 1 per cent slope and closest with existing urban/residential would be transformed to urban/residential; and (ii) grid cells with slope less than 10 percent, and soil depth in level 2 or 3 and high rainfall for transformation to agricultural land. The final land use allocation maps in different scenario are presented in Figure 5, 6, 7, 8 .

Table 1. Determination of decision variable coefficients in individual objective

	Constant/ Intercept	Forest land		Agricultural land		Residential (X_5)	Open land (X_6)	Special land (X_7)
		Natural Forest (X_1)	Plantation forest (X_2)	Industrial crops (X_3)	Paddy flied (X_4)			
Z_1	-	2094724	212422.7	65638608	34447878	3894415800	0	25300836
Z_2	5,322,520	-42902.8	-44648.2	-43294.8	-43286.8	-326300	-52347.7	-80560.8
Z_3	484,190,000	-4,105,530	-4326230	-4074280	-4052680	-22992500	-4792260	-7121250

Where the three objectives considered in this analysis:

Z_1 = the objective function of income (thousand VND)
Z_2 = the objective function of water discharge (m^3/s)
Z_3 = the objective function of sediment yield (m^3)

and the seven decision variables are defined as:
X_1 (%) = the optimal percent prepared for natural forest conservation;
X_2 (%) = the optimal percent allowed for plantation forest;
X_3 (%) = the optimal percent for industrial crops;
X_4 (%) = the optimal percent for paddy flied;
X_5 (%) = the optimal percent for residential/ urban;
X_6 (%) = the optimal percent for open land/ bare land;
X_7 (%) = the optimal percent for special land.

Table 2. The optimal solution in the case of the inclusion of each individual objective independently

		Objective function value Z_k	Forest land		Agricultural land		Residential (X_5)	Open land (X_6)	Special land (X_7)
			Natural Forest (X_1)	Plantation forest (X_2)	Industrial crops (X_3)	Paddy flied (X_4)			
Scenario A	Z_1	10,093,650,805	22.216% (131089)	8.324% (49120)	28.519% (168284)	22.805 (134561)	1.822% (10751)	4.786% (28245)	11.524 (68013)
	Z_2	509							
	Z_3	1,291,011							
Scenario B	Z_1	10,899,260,000	26.600% (156,694)	8.400% (49,482)	26.600% (156,694)	23.250% (136,960)	2.063% (12,152)	2.830% (16,665)	10.260% (60,439)
	Z_2	398.5							
	Z_3	1,987,056							
Scenario C 1	Z_1	10,590,623,950	27.550% (162291)	11.880% (69982)	23.630% (139199)	21.790% (128419)	2.049% (12070)	2.829% (16665)	10.260% (60439)
	Z_2	184.8							
	Z_3	1,222,000							
Scenario C 2	Z_1	10,562,626,711	31.032% (182803)	8.400% (49483)	23.299% (137255)	22.130% (130357)	2.049% (12070)	2.829% (16671)	10.260% (60439)
	Z_2	6,174							
	Z_3	2,200,960							

Note: Z_1 = Net Income (thousands VND); Z_2 = Water discharge (m^3/s); Z_3 = Sediment yield (m^3)

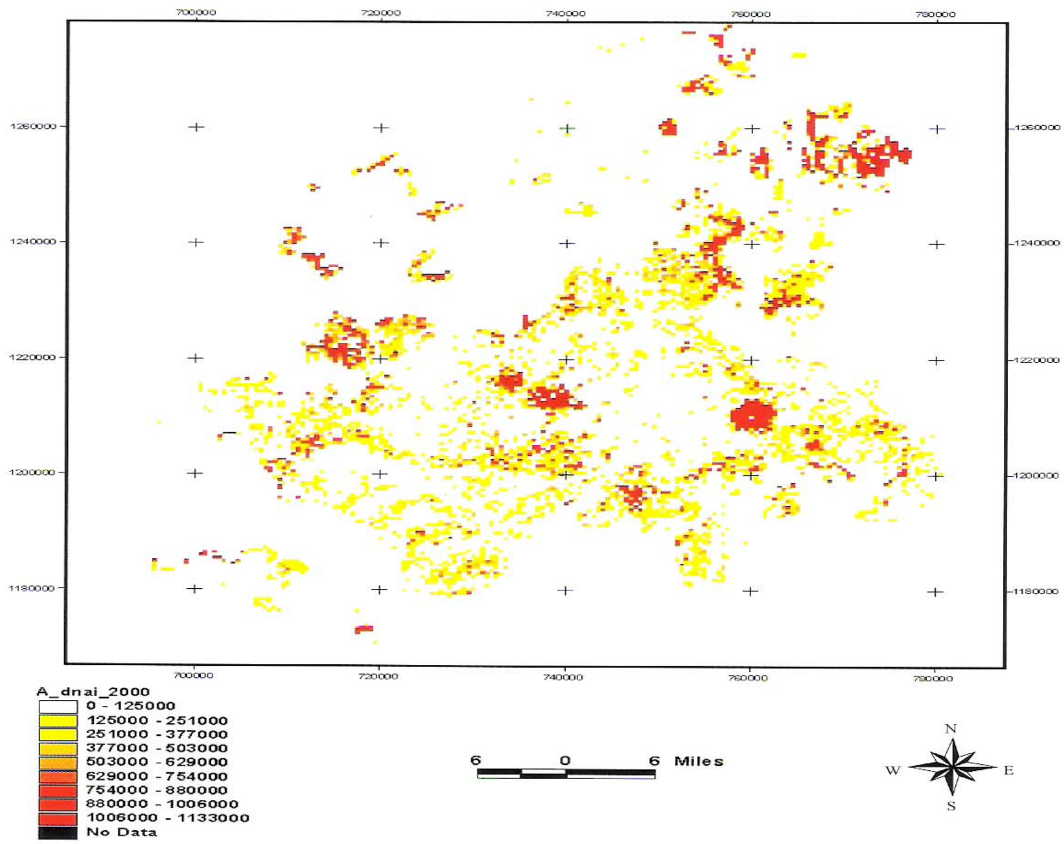

Figure 4. Soil Erosion Map in Dong Nai Watershed at year 2000

CONCLUSION

Several alternative planning scenarios in the above analysis have provided necessary information for the decision maker in selecting the most desirable management plan for the Dong Nai watershed. Overall, final linear programming solutions suggest that increasing the urban area is feasible if sediment yield can be controlled by Dong Nai watershed communities. A more practical approach can be gained through an interactive procedure in this analysis, in which the decision maker may proceed from one non-inferior solution to another by comparing each land management alternative and evaluating trade-offs between individual goals. But, the inherent complexity in comparing the environmental impacts of very different natures to the technico-economic values in this analysis may decrease the confidence in applying its optimal solutions. However, such an analysis is significant specifically for those developing countries with a highly populated community and limited land space, although the decision makers usually tend to ignore such a dilemma. A more complex analytical system is needed in the future because Vietnam is also evolving from a development of land-use in watershed and conservation of reservoir water quantity to a water economy (water right trade-off) and river basin

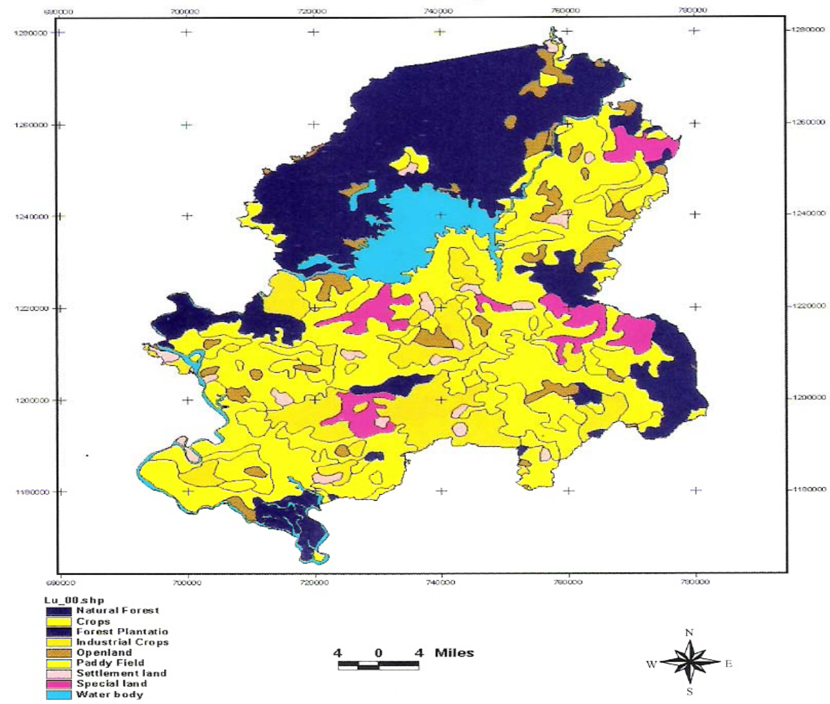

Figure 5. Land use map in Dong Nai Watershed Scenario A

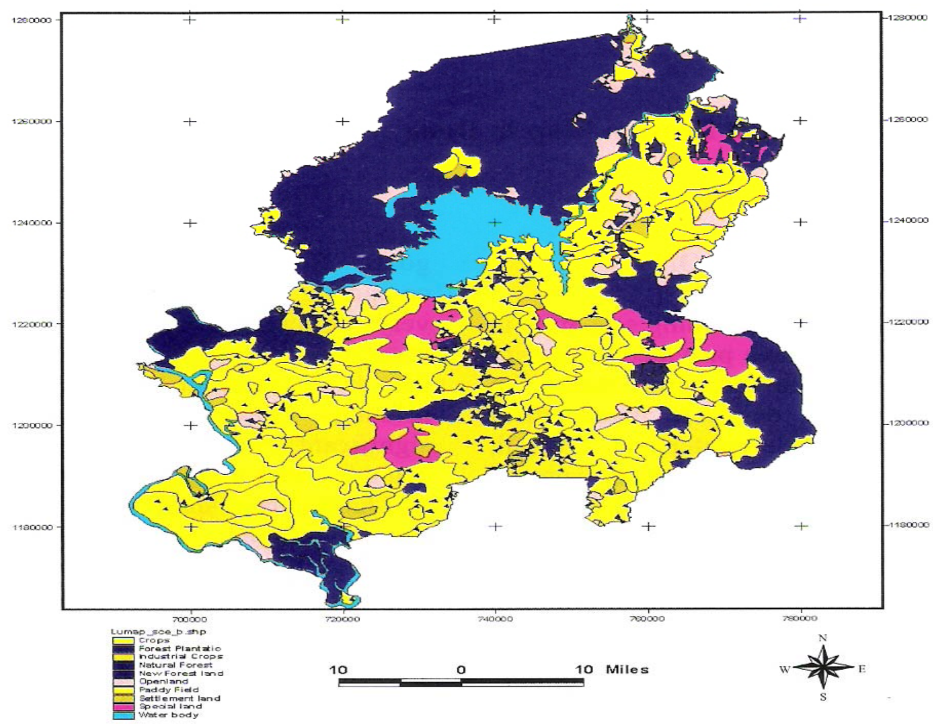

Figure 6. Land use map in Dong Nai Watershed Scenario B

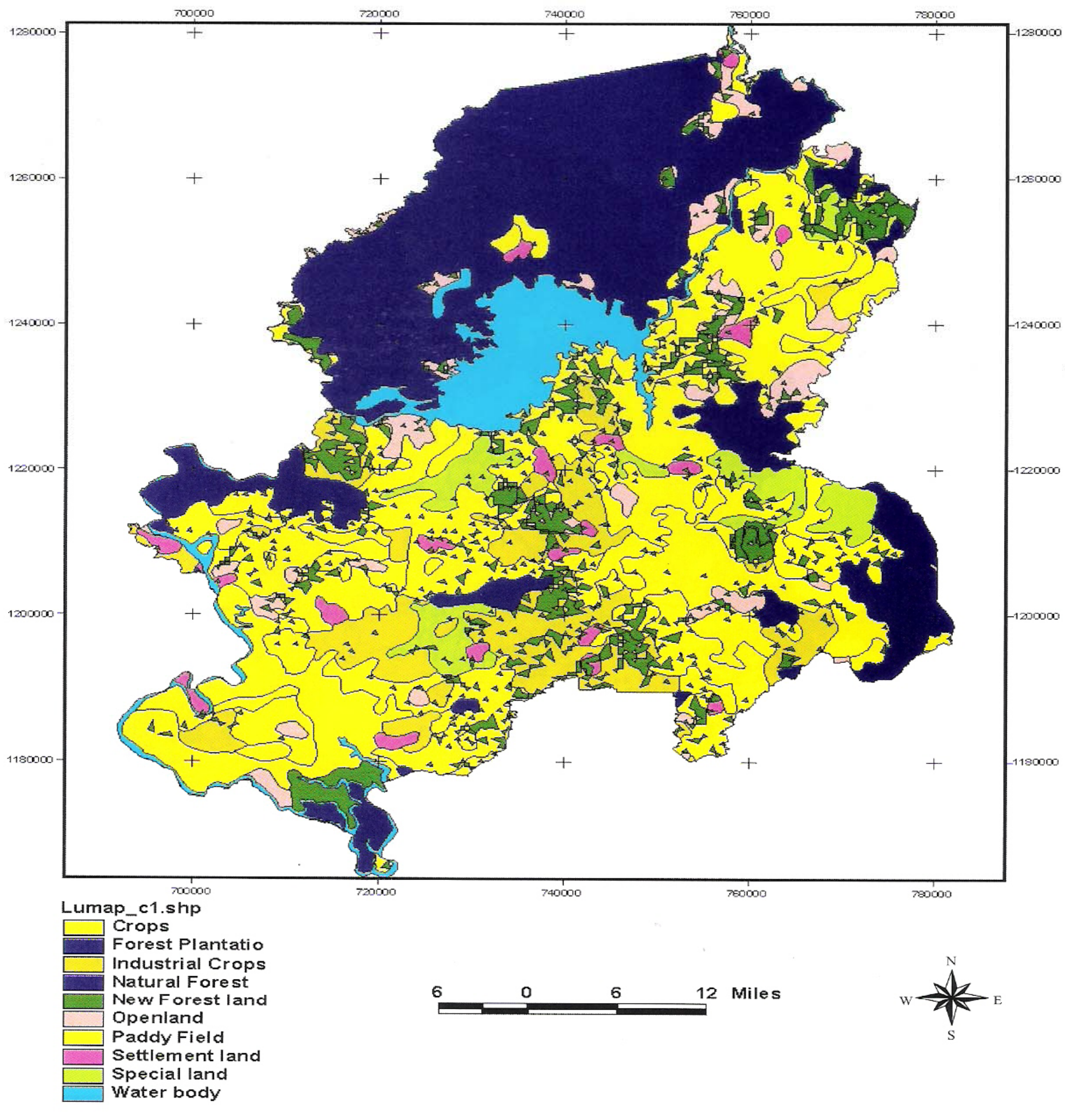

Figure 7. Land use map in Dong Nai Watershed – Scenario C with sediment yield as the first priority (Scenario C 2)

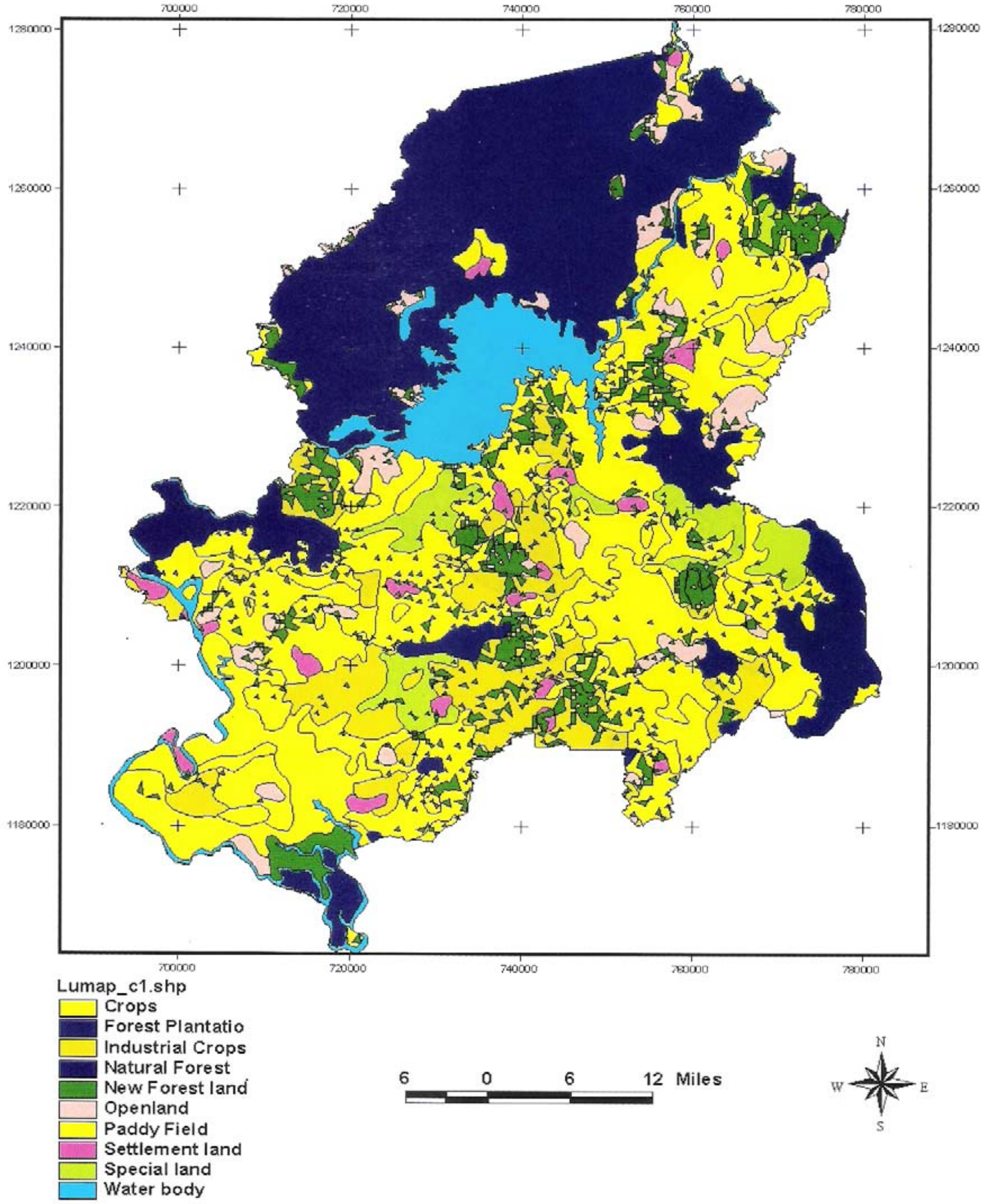

Figure 8. Land use map in Dong Nai Satershed–Scenario C with sediment yield as the first priority (Scenario C 2)

planning by a conjunctive surface-ground water reallocation. Further, the modeling efforts can be combined with a geographical information system (GIS), and computer language (Visual basic, C^+, Pascal to help decision makers evaluate the socio-economic and ecological impacts of various planning scenarios in the framework of a decision support system (DSS).

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