THESIS

A SPATIAL DECISION SUPPORT SYSTEM (SDSS) FOR HIGHLAND BASIN CONSERVATION AND REHABILITATION, UPPER NAN BASIN NORTHERN THAILAND

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GRADUATE SCHOOL, KASETSART UNIVERSITY

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THESIS

A SPATIAL DECISION SUPPORT SYSTEM (SDSS) FOR HIGHLAND BASIN CONSERVATION AND REHABILITATION, UPPER NAN BASIN NORTHERN THAILAND

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Watershed deterioration is the common phenomena in most parts of the world which is more serious in most of mountainous country like northern of Thailand, among several causes for this, improper and unwise utilization of watershed resources without any conservation work is the prime one which is more severe in developing countries. In highland or mountainous area, the deterioration occured generally in terms of forest loss and land degradation by soil erosion. Among several factors, the major one is deforestation (forest loss) followed by unsuitable agricultural practices(soil loss). Therefore, it was necessary to develop a sustainable land management system for protect the degradation of such valuable resources. In this study Upper Nan Basin Northern Thailand, effectively monitoring of land-use/land cover change(forest loss) was undertaken as the basic and essential step by using GIS. Further analysis, land degradation(soil loss) by using USLE and GIS, sub-watershed prioritization based on its present condition, extent of degradation and sensitivity, optimal land-use planning by integrated of GIS and Multiple Criteria Evaluation(MCE) in each of prioritized sub-watershed, has been done. The tools employed for deriving in this study were Statgraphics Plus 5.0, LINDO 6.0 software, and GIS system of ArcView program. The developed system was also designed to geographically relocate different land-uses obtained from GP model based on the given criteria for highland basin conservation and rehabilitation.

The results showed that the rate of forest degradation of the study area was 1.48 per cent per year, which was too high while considering the sustainability, along with 0.09 ton/hec./yr was increased in soil erosion rate between 1977 to 2000, the 1 in 9 sub-watershed degraded prioritization in Upper Nan Basin namely ; B0902 Upper Nan River were found to be first priority for conservation activities as slope stabilization, slope failure protection, gully control by check dam, reforestation, growing of horticultural crop along with some other intensive soil conservation activities were required. The results as showed that the optimum land-use derived from GP model in B0902 consists of 48.51% for natural forest (X1) or 107,811 ha; 21.76% for plantation forest (X2) or 48,354 ha; 6.42% for upland crops (X3) or 14,265 ha; 17.44% for tree (X4) or 38,776 ha; 3.37% for paddy field (X5) or 7,488 ha; 1.11 % for grassland (X6) or 2,479 ha; 1.10% for urban (X7) or 2,446 ha; and 0.27% for water body or 601 ha. The overall final results by GIS techniques and the criterias in optimization and conservation prioritization provided SDSS involves to help decision maker or stakeholder to plan for new spatial location of land-use in each sub-watershed of Upper Nan Basin, Northern Thailand.

Suthep Tangsup | S. Tantanasarit 24/03/2006

Student's signature | Thesis Advisor's signature

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LIST OF ABBREVIATION

AHP	=	Analytic Hierarchy Process
AML	=	Arc Macro Language
B0902	=	Upper Part of Mae Nam Nan (0902)
B0903	=	Nam Yao 1 (0903)
B0904	=	Second Part of Mae Nam Nan(0904)
B0905	=	Nam Yao 2 (0905)
B0906	=	Nam Samun (0906)
B0907	=	Third Part of Mae Nam Nan (0907)
B0908	=	Nam Sa (0908)
B0909	=	Nam Wa (0909)
B0910	=	Nam Haeng (0910)
DBMS	=	Data Base Management System
DEM	=	Digital Elevation Model
DGMS	=	Dialog Generation and Management System
DLD	=	Department of Land Development
DSI	=	Degradation Speed Index
DSS	=	Decision Support Systems
DWR	=	Department of Water Resources
GAMS	=	General Algebraic Modeling System
GIS	=	Geographical Information System
GP	=	Goal Programming
GUI	=	Graphical User Interfaces
LP	=	Linear Programming
LUCC	=	Land-use and Land Cover Change
MBMS	=	Model Base Management System
MCE	=	Multi Criteria Evaluation
MSEC	=	Management of Soil Erosion Consortium
ONEP	=	Office of National Resources and Environmental Policy
OUNLP-DSS	=	Overall Upper Nan Land-use Planning DSS

LIST OF ABBREVIATION (Con't)

P	=	Patch
PEI	=	Present Environment Impact Index
PSD-SDSS	=	Priority of Sub-watershed Degradation SDSS
RFD	=	Royal Forest Department
RS	=	Remote Sensing
SDSS	=	Spatial Decision Support Systems
SEE	=	Standard Error of Estimation
SI	=	Sensitivity Index
USLE	=	Universal Soil Loss Equation
WSC	=	Watershed Classification

A SPATIAL DECISION SUPPORT SYSTEM (SDSS) FOR HIGHLAND BASIN CONSERVATION AND REHABILITATION, UPPER NAN BASIN NORTHERN THAILAND

INTRODUCTION

1.Justification

Watershed deterioration is the common phenomena in most parts of the world among several causes for this, improper and unwise utilization of watershed resources without any conservation work is the prime one which is more severe in developing countries (FAO, 1985). In highland area, the deterioration occurs generally in terms of forest loss and land degradation by soil erosion. Among several factors, the major one is deforestation (forest loss) followed by unsuitable agricultural practices(soil loss). Therefore, it is necessary to develop a sustainable land management system that does not cause the degradation of such valuable resources. As limited in times and budget, considering the watershed conservation work, it is not feasible to take whole area at once. This calls to divide the watershed in small units, that is sub-watershed, by considering its drainage system. As the condition of sub-watersheds may not similar, they can be prioritized for conservation work. This is especially important in a predominantly mountainous area like northern of Thailand.

During the early 1960s, more than 50 percent of Thailand is covered by forest, however, in 1999 this declined to only 25 percent. The Nan river basin is the eastern-most of the major headwaters tributaries and provides over 50 % of the net annual water discharge to the Chao Phraya river system in the central plane. The estimated runoff efficiency of the Nan river basin is 23 percent, the highest of the four major northern tributaries to the Chao Phraya. In the Upper Nan Basin, above the Sirikit Reservoir, more than 85 percent of Upper Nan Basin are mountainous area, the rate of Upper Nan Basin soil erosion by average was higher than 0.2 mm/yr which being highest among watersheds in the north.(Jirasuktaveekul et al,1997). Upland erosion not only leads to long-term losses of upland productivity, but also to losses of storage capacity in reservoirs which in turn leads to lost hydropower production, increased flooding, or loss of irrigation capacity downstream. Soil loss creates adverse downstream impacts even when reservoirs are not present. More frequent over bank flows and flood damages will likely result. In addition, lack of adequate water to dilute wastes and general water quality deterioration from uplands results in more serious pollution, including public health problems.

A DSS is a computer-based information system that assists a decision-maker at the moment of taking a decision. A SDSS is a DSS applied to spatial problems. Because of the spatial nature of the decisions, a GIS Geographical Information System must be the centerpiece of any SDSS. Land-use planning is the allocation of land-use to land according to land capability and land suitability. The goals are to optimize production of food, raw materials, and maintain environmental services including supply of water and disposal of wastes which depend upon the stability and resilience of the land system. In reality, however, land-use decisions are made locally by the actual landowners and managers according to their own knowledge and priorities. So in this study, SDSS is intended to draw together the natural resources and land-use data of sectoral agencies (topography, satellite imagery, income, land-use, soil loss, census reports and thematic maps), process them to computer-compatible format, and build up a watershed database (land capability and land suitability to reduces soil loss) for making decision in highland basin conservation and rehabilitation.

From above cause and effect, therefore, it is necessary to study :A Spatial Decision Support System for Highland Basin Conservation and Rehabilitation especially Upper Nan Basin. For this, effective monitoring of land cover/land-use change(forest loss) is the basic and essential step by using GIS. Further analysis, like land degradation(soil loss) by using USLE and GIS, sub-watershed prioritization, optimal land-use planning by integrating GIS and Multiple Criteria Evaluation in each of prioritized sub-watershed, has to be done. And the last step, using GIS as a DSS generator to create Spatial Decision Support Systems (SDSS) for conservation and rehabilitation, and also protective measures in basin system. The result of the integration of these techniques will present two main advantages where conflictive goals must be satisfied. Firstly, it provides easier access to spatial data management, design of land-use allocation scenarios, and graphic visualization. Secondly, it enables different parties with the same interests (scientists, stakeholders, environmentalists and decision makers) work together for minimize soil loss and pursuing sustainable development in Upper Nan Basin.

2. Objecttives

In order to formulate watershed management plan in Upper Nan Basin, the main aim in this investigation is how to apply GIS and Multiple Criteria Evaluation for optimizing land-use allocation and relocating the solution in Upper Nan Basin. The specific objectives of this study are as follows:

1. to estimate the forest and soil loss of the Upper Nan Basin;
2. to prioritize degradation in the Upper Nan Basin sub-watershed based on its present condition, extent of degradation and sensitivity, using GIS and USLE model;
3. to optimize soil loss, land-use income, using integrated of GIS and Multiple Criteria Evaluation;
4. to use GIS as a DSS generator to create spatial decision support systems (SDSS) for Upper Nan Basin conservation and rehabilitation.

3. Expected Outcomes

Based on the above-mentioned objectives, the following are the expected outcomes of this study:

1. Upper Nan Basin land-use is forecasted;
2. Prediction of the forest loss and soil loss of the Upper Nan Basin;
3. Optimal soil loss, land-use income under the resources constraint;
4. Spatial optimal new land allocation under the resources constraint.

LITERATURE REVIEW

The watershed is a logical unit for planning; because it explicitly forces one to recognize that sustained land or resource based development depends on the interaction of all the activities that take place throughout the watershed. Uplands and lowlands are physically linked in a watershed via the hydrologic cycle. Upstream activities affect downstream opportunities and problems by influencing the flow of water, sediment and other waterborne materials through the system. To recognize this fact, one has merely to look at the numerous examples where poor upstream land-use practices result in disaster downstream.

Therefore, a broad understanding of various topics in watershed science and modeling technology was required to complete the studies presented in this dissertation, and it is important to thoroughly review each of these. The first part covers some definition and background watershed management approach, sustainable watershed management and decision support system. The later will focus on how to integrate mathematical modeling, GIS and DSS techniques. The second part involves with soil erosion science and modeling using the most popular erosion prediction model, that is USLE. As the other objective of this research deals with topography, a large portion of the review of erosion models is focused on slope and length factors. Subsequently, the subject of watershed modeling together with hill slope definition and grid based hydrological modeling are reviewed and discussed. The third part concerns with the GIS and Decision Support System (DSS) model focusing on the framework for planning and decision making, computer-based system for supporting spatial decisions, the mathematical programming have been reviewed focusing on optimization algorithms that include linear programming (LP), goal programming (GP). Finally, previous investigation using GIS-DSS and mathematical modeling aforementioned are also included in this part of literature review.

1.Watershed and Watershed Management

Essential to the success of watershed management is a clear understanding of some of its basic underlying concepts. This part endeavors to define key terms and principles that are relevant to watershed management.

1.1 Watershed Definitions

Brooks et. al.(1992) described that watershed is a topographically delineated area of land from which rainwater can drain as surface runoff through a river system with a common outlet, which could be a dam, irrigation or domestic water supply off-take point or where the river discharges into a larger river, lake or sea . A watershed is part of a larger system stretched across the Earth's surface, with adjacent watershed separated by boundaries or divides.

The term "Watershed" is synonymous with "river basin", "drainage area" and "catchments". The term "river basin" is often used in reference to large watersheds (usually over 100,000 ha). In contrast, "catchments" usually refers to smaller watersheds (ranging from less than 1,000 ha to 100,000 ha).

A watershed is a self-contained system consisting of intricately interacting biotic and abiotic components and often of several linked ecosystems or portions of a number of ecosystems.

A watershed is not necessarily an upland or mountainous landform; it may occur in a lowland setting, and the land surface may be a major site for residential, commercial, industrial, agricultural, educational, experimental, environmental and forestland uses. Many of these uses are often conflicting and competing with each other for limited watershed land resources. Watersheds are a major source of nutrients and pollutants, which are deposited in lakes, coastal areas, and rivers.

1.2 Watershed Management Approach

Brooks et. al (1992) defined watershed management as the process of guiding and organizing land and other resource uses in a watershed to provide desired goods and services without adversely affecting soil and water resource. It is also defined as the application of business methods and technical principles to the manipulation and control of watershed resources to achieve a desired set of objectives such as maximum supply of usable water, minimization of soil erosion and sedimentation problems, and reduction of flood and drought occurrences. Planning and implementation of both technical and policy initiatives is necessary to enable the natural and human resources of individual watersheds to contribute to one or more of the following development aims:

- Improved rainwater management within individual watersheds so as providing quality water from both surface and groundwater sources on a sustainable basis to meet the needs of different water users (human settlement, lowland farmland / irrigation systems, power and transport infrastructure, fish ponds and coral reefs/ coastal resources) within and downstream of the watershed, and increased protection from flood and sedimentation damage for the downstream area of the watershed;
- Improved standard of living, through the maintenance, enhancement and development of existing and new sustainable livelihood opportunities for those individuals, households and communities whose welfare needs are met wholly, or in part, by the utilization of watershed resources;
- Improved maintenance, enhancement and protection of those areas that are important for bio-diversity conservation;
- Improved care and management of the natural resources within watersheds, thereby enabling them to be used for economically productive purposes (water, forestry, agriculture, tourism, power generation, etc.) on a sustainable basis while maintaining and enhancing their social and environmental service functions.

In the context of limited natural resources and rapid population growth the concepts of multiple use and sustainable management have been established to cope with the need for long term social stability of future generations. Watershed management involves the integrated management of all the natural resources of a drainage basin in order to protect, maintain, or improve water yields. It requires s synthetic approach, integrating the various aspects of hydrology, ecology, soils, physical climate and other sciences to provide the scientific basis of management. Then to develop from this basis, rational procedures of applying this information to achieve desired results and to derive guidelines for choosing acceptable management alternatives within the scope of social wants and needs (Satterlund and Adams, 1992).

Watershed management is a term mainly used by foresters and soil conservationists. The holistic approach which includes all facets of complex interactions among bio-technical, social, economic, institutional and political factors is taken into consideration to ensure that all resources development activities are implemented in concert with one another to achieve a variety of objectives successfully. It can be summarized as a part of natural resources which composed of three main principles: (1) Land-use planning in terms of land capability and suitability, (2) Resource utilization and conservation which depend on natural resources characteristics, and (3) Pollution control in terms of erosion, floods, protection of aesthetic values and others mitigation impact planning (Hewlett and Nutter, 1969; Jermar, 1987; and Chunkao, 1992).

1.3 Watershed Functions and Hydrologic Processes

The interaction between the structures: biotic and abiotic which function mainly in terms of hydrological process, nutrient and food chains in the watershed ecosystem are extremely close. The over exploitation of some resources will impact their natural relationships and always contribute the undesirable outcomes through human being. However, human are inextricably bound to their ecosystem and function only as consumers.

The hydrologic balance or water budget is both a fundamental concept of hydrology and a useful method for the study of the hydrologic cycle. The hydrologic cycle represents the processes and pathways involved in the circulation of water from land and water bodies, to the atmosphere and back again. The cycle is complex and dynamic but can be simplified if we categorize components into input, output or storages.

The hydrologic processes of the biosphere and the effects of vegetation and soils on these processes such as precipitation, infiltration, percolation, evaporation, transpiration, surface runoff, subsurface flow, and groundwater flow can all be affected by land management activities. Likewise, man can alter the magnitude of various storage components including soil water, snow packs, lakes, reservoirs, and rivers. With a water budget we can examine existing watershed systems, quantify the effects of management impacts on the hydrologic cycle and in some cases predict or estimate the hydrologic consequences of proposed or future activities.

1.4 Brief History of Watershed Management

1.4.1 The Ancient History

The history of man's study of water and his use of it is as interesting and ancient as any other branch of the earth science (Hewlett and Newtter, 1969). The ancient Chinese had a proverb "to rule the mountain is to rule the river". A concept of the hydrologic cycle arose there as early as 900 B.C., but had no influence on Western thought at that early time (Nace, 1974).

Both China and the Mediterranean region before the birth of Christ seemed to have all the requirements to be the birthplace of watershed management for instance, water scarcity, high demand for irrigation and municipal use. Furthermore, the rules, the laws and the customs developed by western civilization were applied to the distribution and use of water, but not to the lands that were its sources. The record fell silent through the Dark Ages until 1215, when Louis VI of France issued a decree on waters and forests. In 1342, a community in Switzerland reserved the first "ban" or protection forest, and the sixteenth century onward, many such forests were proclaimed (Satterlund and Adams, 1992).

1.4.2 Watershed Management in Thailand

According to the TFSMP Core Team (1993), the Royal Forest Department (RFD) initiated watershed management in Thailand early in the 1950s. A number of RFD stations rehabilitated denuded watershed areas particularly in the Northern and Northeastern part.

In the 1970s, the RFD realized that the project would be more fruitful if the interests of all watershed inhabitants were taken into consideration when formulating management plans. That is why, the new strategic planning, of the Mae Sa Integrated Watershed and Forest Land Use Project was established in 1972. The management objectives were promotion of economic growth and improving of living conditions; market - oriented agriculture; and reforestation. Unfortunately, the project was not reached its targets due to excessively bureaucratic procedure and failed to give the inhabitants security of land tenure (TFSMP Core Team, 1993).

Experience from previous watershed management projects led to revision of planning and implementation procedures in the 1980s, with a new focus on sustainability and replicability of the projects, including local government concern for the process of planning and problem solving. The recommendations from those experiences can be summarized as:

◦ Tropical, semi - tropical and temperate fruit trees are promising upland crops, but more promotion is needed.

◦ Bench terracing can reduce soil erosion, but is rather costly and not practical for the farmers.

◦ Marketing cooperatives are quite rather effective for the local Thai, but not for the hill tribes.

◦ Small – scale water resources development is beneficial for water supply, but the larger ones need more intricate distribution systems.

◦ Fire control, range management and reforestation are essential for mountainous watersheds.

◦ The area of 2.4 ha per household (STK program: Thai initials for “national forest land usufructuary certificts”) is inadequate for food production.

◦ The community leaseholds of 320 to 480 ha close to the forest should be provided for the landless villagers to diversity their local economy.

◦ The research and monitoring components need to be amplified and continued.

◦ The executive authority of RFD should be decentralized.

In the Sixth National Economic and Social Development Plan (during 1985 - 1990) the office of Environmental Policy and Planning promulgated the Cabinet Resolution, “Watershed Classification Regulation” since 1985, which aims to achieve sustainable managed forest land, water and other natural resources in the Ping and Wang river basins of the North. The watershed classification criteria with the agreement among agencies concerned are based on five stable parameters i.e., slope ; elevation ; landform ; soil ; and geology (TFSMP Core Team, 1993).

Five classes of watershed have been classified, the erosion prone land being identified as classes 1 to 3, with classes 4 to 5 being suitable for upland and lowland farming. The definition and land-use recommendations for each class are briefly described below:

WSC 1: Protected of conservation forest and headwater source: Normally these zones are in the high elevation and very steep slopes, there are two subclasses: WSC 1A–the overall area is undisturbed and WSC 1B–some part has been cleared for cultivation. The areas are supposed to be a permanent forest covered.

WSC 2: Commercial forest: These areas may be at high elevations and some steep slopes, but their physical form result in less erosion than WSC 1. If appropriate conservation measures are taken, there is a possibility for utilization in terms of logging, grazing, or cultivation.

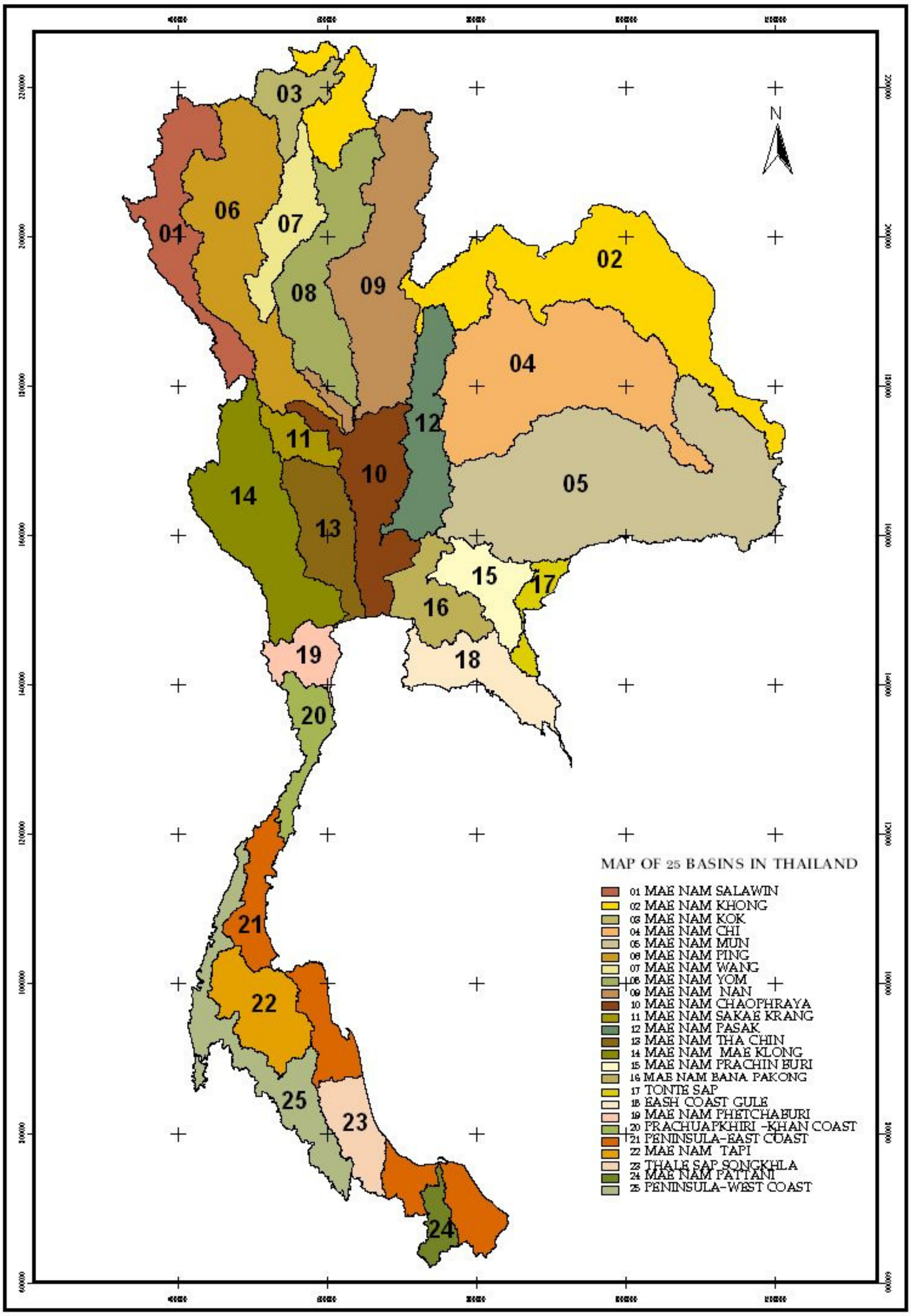
WSC 3: Fruit tree plantation: It is the upland areas with requiring soil conservation measures, slope and less erosive landforms. These areas are usually used for fruit tree plantation or certain agricultural crops and may be used for commercial forest, agro-forestry, grazing or other permanent uses.

WSC 4 : Upland farming :The areas of gently sloping for row crops, fruit trees, and grazing with moderate soil conservation measures.

WSC 5 : Lowland farming : The areas of gently sloping to flat, used for paddy field or other agricultural purpose with few restriction.

It should be realized that the WSC 1, 2 and 3 together account for 53.14% of the northern land area (TFSMP Core Team,1993), while only 25 % of the land is under good forest cover (RFD, 1999).

In 1990, the National Committee on Hydrology approved the 25 main river basins (Figure1) as the planning units for integrated development in terms of watershed and water resource development for social quality of life and environmental protection throughout the country (TFSMP Core Team, 1993 and Tangtham, 1984, 1997). The recognition of this integrated approach is a crucial point for achieving sustainable management. To move towards this policy, harmonious land-use planning procedures are needed in which it is possible to choose optimum scenario by means of quantitative modeling and optimization, particularly in the northern region which is the most important headwater area for the central part of the country.



Source : Department of Water Resources(2005)

Figure 1 Map of 25 main river basins in Thailand

1.5 Sustainable Watershed Management

Sustainability involves ensuring a long term supply of water of adequate quality for all designated purposes for which an area is intrinsically suitable while minimizing adverse economic, social and ecological impacts and maintaining the structure and function of the natural system (Diane, 2002). Raul (2002) described that sustainable watershed management involves informed decision-making in a complex array of biophysical, social and economic environments made up of processes and interactions between ecosystems, their components and between human groups intervening in such ecosystems. Decisions involve the allocation of resources, formulation of policies, interventions in, and manipulations of natural resources present in the naturally-defined area confined by a watershed or hydrological basin. Due to the complexity of issues involved in watershed management, this requires a multi-disciplinary, holistic and integrated approach. An ecological approach to managing watersheds recognizes the interconnectedness and relationships of mutual dependence between the ecosystems present and the degree in which manipulations of the structure and functions of one ecosystem may result in inputs and changes to the structure and functions of other related ecosystems.

1.6 Policy for Sustainable Watershed Management in Thailand

Primarily, the resources have been misused which caused drought, flood and siltation. The government policies need to be transparent that can be easily examined. Both conservation and utilization of natural resources (soil, water, forest and mineral) need to go side by side. Human resources could express idea and use the local wisdom to solve the problems of water resource in order to maintain sustainable development for upstream and downstream. The priority of critical watershed ranging from 1-25 needs to be done in order to draw the plan and develop in the right direction.

2.Forest Loss and Soil Loss In Thailand

2.1 Briefs Impact of Soil Loss and Forest Loss in Thailand

The results of environmental impact monitoring based on information reported by the Office of National Resources and Environmental Policy (ONEP) during 2002-2003 can be summarized as follows:

• Soil erosion covers an area of 100 million rai (16 million hectares). The most severe areas of erosion are in the northern region;

• In 2002, forest reserve and recreation areas totaled around 57.78 million rai (9.2 million hectare) or 18 percent of the total land area. After logging concession were banned in 1989, the annual deforestation rate declined from 2.9 million rai to 1 million rai per year;

• In 2002, 62 provinces were reported to have encountered water shortages. The problem affected 1.3 million households and around 5.7 million people. In the same year, there were 12 floods reported during the rainy season.

2.2 Forest Loss and National Forest Policy in Thailand

2.2.1 Status of Forest Area in Thailand

Thailand had approximately 37 % of forest area about a decade. This forest area has been destroyed continuously and was reduced to 25.02 % in 1999. The causes of forest deterioration are unsustainable cutting of forests for financial gains, development of forest land for human settlements and agricultural.(Table 1.)

Table 1 Status of forest area in Thailand

Year	Remaining Forest	
	Rai	Percent
1961	171,017,812	53.33
1973	138,578,125	43.21
1975	128,278,755	40.00
1976	124,010,625	38.67
1978	109,515,000	34.15
1982	97,875,000	30.52
1985	94,291,349	29.40
1988	89,877,182	28.03
1989	89,635,625	27.95
1991	85,436,284	26.64
1993	83,470,967	26.03
1995	82,178,161	25.62
1998	81,076,428	25.28
1999	80,242,572	25.02

Source: Charuppat(1998) ; 1 hectare(ha) equals 6.25 rai

2.2.2 National Forest Policy in Thailand

To solve the problem of forest destruction, the Cabinet set up the National Forest Policy in 1985 which has set the goals for better management of forestry and the other natural resources. In addition, to achieve a long term and coordinated national forest administration and development and for better understanding between state and private sectors, it is hereby declared as a national forestry policy that

1. Long term guidelines for forest management and development shall be established to maximize national social and economic benefits and national security,

with sufficient measures provided for environmental protection. Emphasis shall be placed and harmonized utilization of forest resources and other natural resources.

2. Role and responsibility sharing among various government agencies and the private sector in forest management and development shall be promoted.

3. National forest administration shall be reorganized in line with the changing quality and quantity of forest resources and environment.

4. Forty percent of the country area shall be kept under forests. The forest area shall be divided as follows :

4.1 Protected forest : 25% of the country area shall be kept as protection forests for nature conservation, recreation and environmental quality protection.

4.2 Production forest : 15% of the country are shall be designate as production forest of produce timber and other forest products.

5. Public and private sectors together shall develop and manage the forest are to achieve the objective of providing perpetual direct and indirect benefits to the country.

6. Science and technology to increase the efficiency of agricultural production shall be enhanced to reduce to risk of the forest being destroyed to increase agricultural land.

7. The State shall establish a forest development plan as part of the natural resources development plan in the National Social and Economic Development plan to harmonize a mutual utilization action between forest resources and other natural resources.

8. Efficiency in timber production shall be increased through appropriate forest

management techniques using both selection and clear cutting system. In the clear cutting system, the cleared area shall be replanted immediately.

9. To conserve and protect natural environment, the State shall accelerate the city planning process and designate specific area for forest, residential, rural and agricultural areas in each province to prevent forest land encroachment.

10. National Forest Policy Committee shall be established under the Forest Acts for policy formulation, supervision and management of national forest resources.

11. The State shall undertake extension programs to create public awareness, instill positive attitude, and proper skills on the wise use, as apposite to the negative effects of forest destruction and wasteful use, of forest resources.

12. The State shall promote reforestation by the public and private sectors for domestic industrial consumption. Export of wood and wood products shall be encouraged. Community forestry such as reforestation on public land by private sector, tree planting on marginal agricultural land and establishment of forest woodlot for household consumption shall also be promoted.

13. The State shall encourage integrated wood using and pulp and paper industries to realize the whole-tree utilization concept.

14. Amendment of forest acts shall be made to support efficient forest resources conservation and utilization.

15. Wood energy as a substitute of fossil energy shall be promoted through energy plantations.

16. Any land with the slope of 35% or more on an average shall be designated as forest land. No title deed, or land-use certificate under the Land Acts shall be issued for the land of this category.

17. Explicit guidelines shall be established to deal with various forest degradation problems e.g. shifting agriculture, forest fires, forest clearing by the hill tribe minorities, etc. Measures on enforcement of law and penalty codes shall be specified and respective due processes shall be established . Regional Forestry Law Enforcement Center shall be established. Measures shall also be devised to penalize corrupted government official and influential person.

18. Incentive systems shall be established to promote reforestation by the private sector.

19. Human resources and rural settlement planning must be in conformity with national natural resources management and conservation plans.

The main objectives of these policies in brief are:

1.Thailand should have the forest land not less than 40% of the country area or about 128 million rais, approximately 20.5 million hectares (1 rai = 0.16 hectare).

2. Dividing forest land into 2 parts as Conservation Zone at least 15% (19.2 million rais, about 3.1 million hectare) and 25% for Economic Zone (32 million rais, about 5.1 million hectare).

2.5 The Problem of Soil Loss in Thailand

In Thailand, soil erosion has been identified as a major problem in sustaining agriculture on steeplands. It causes severe on- and off-site environmental and socioeconomic impacts. To address these concerns, the Royal Forest Department (RFD) and the Land Development Department (LDD) entered into an agreement with the International Board for Soil Research and Management (IBSRAM) in Bangkok to implement the collaborative project entitled, ‘Catchment approach to combating soil erosion in Thailand’ in 1999 under the umbrella of the Management of Soil Erosion Consortium (MSEC).

MSEC employs a new research paradigm based on a participatory, interdisciplinary catchment approach in mid- to long-term experiments (5–15 years) to assess the significance of sustainability factors on steeplands. Catchment studies will also be useful in quantifying the processes occurring within and the interactions among the different compartments of the ecosystems. The three key elements of this approach are: the focus on on- and off-site impacts, the provision of scientifically of sound information for decision-makers, and the involvement of the whole range of stakeholders from land-users to policy-makers.

3. Soil Erosion Prediction Method

Soil erosion has been studied for more than 60 years. Many empirical and theoretical formulas have been developed to predict or estimate soil erosion. Although many researchers have pointed out the limitations they inherited, USLE and its modifications are still the most important soil erosion prediction tools in soil erosion prediction.

3.1 Soil Erosion Prediction Methods prior to USLE

Zingg (1940) first began to use empirical equations to estimate soil erosion by water. He recommended an equation as:

$$A = C\ S1.4\ L0.6$$

where

A = average soil loss per unit area from a land slope of unit width (lb/ft2),

C = a constant of variation,

S = degree of land slope (%),

L = horizontal length of land slope (ft).

More than 7,500 plot-years and 500 watershed-years of erosion research data were compiled from 21 states by the year of 1956. D. D. Smith and W. H. Wischmeier developed a series of empirical equations about soil erosion based on these data. The Universal Soil Loss Equation was the compressive result of these researches. Smith and Wischmeier (1957) indicated that the principal factors in addition to rainfall that could also affect the soil erosion are percentage slope, length of slope, cover or cropping system, soil and the management. An empirical equation for estimating field soil loss is as follows: (which was the best approach then available)

$$A = C\ S\ L\ K\ P\ M \qquad (1)$$

where

A = average annual field soil loss (ton/acre),

C = average annual plot soil loss (ton/acre) for a selected rotation with farming up and down slope,

S and L = relative factors for percent (S) and length (L) of slope adjusted to give unity loss on a three per cent slope 90 ft long,

K = soil factor whose values must be relative to a unity value for the soil of the plots from which C values are secured,

P = factor for conservation practices in relation to a unity value for up-and- down- hill farming,

M = management factor.

Wischmeier and Smith (1958) combined raindrop diameter and velocity data to determine the kinetic energy of rainfall. They suggested:

$$EI = 916 + 331 \log10I \qquad (2)$$

Where E = the kinetic energy (ft-ton/acre-in),

I = the rainfall intensity (in/hr).

Multiplication of E and the total amount of rainfall (inches) give the total kinetic energy. Also, they found that, EI30, the product of kinetic energy (E) and the maximum 30-minute intensity (I30), was the best single rainfall parameter for prediction of soil loss.

3.2 Universal Soil Loss Equation (USLE)

The most widely used method of predicting soil erosion is the Universal Soil Loss Equation. In 1965, Agriculture Handbook 282 was published, which served as the main reference manual for USLE until it was revised in 1978 as Agriculture Handbook 537, Wischmeier and Smith (1978). The USLE was derived from statistical analysis of 10,000 plot-years of natural runoff plots data and the equivalent of 1000 to 2000 plot-years of rainfall simulators' data. The authors emphasized that the USLE is an erosion model designed to predict the longtime average soil losses from sheet and rill erosion, and from specific field areas in specified cropping and management systems. Many variables and interactions influence sheet and rill erosion. The USLE groups these variables under six major erosion factors, the product of which, for a particular set of conditions, represents the average annual soil loss (Wischmeier, 1976). The equation of USLE (Wischmeier and Smith, 1978) is as follows:

$$A = R\ K\ L\ S\ C\ P \tag{3}$$

where

A = the estimated soil loss (ton/acre-year),

R = the rainfall and runoff factor (hundreds of ft-ton-in/acre-yr),

K = the soil erodibility factor (ton-acre-h/hundreds of acre-ft-ton-in),

L = the slope length factor,

S = the slope steepness factor,

C = the cover and management factor,

P = the supporting practice factor.

With appropriate selection of its factor values, the equation computes the average soil loss for a multi-crop system, for a particular crop year in a rotation, or for a particular crop-stage period within a crop year. It computes the soil loss for a given site as the product of five major factors whose most likely values at a particular location can be expressed numerically. Erosion variables reflected by these factors vary considerably about their means from storm to storm, but effects of the random fluctuations tend to average out over extended periods.

1) Rainfall Erosivity Indices (R-factor)

The most suitable expression of the erosivity of rainfall is an index based on the kinetic energy of the rain. The relationship between median rain drop size and rainfall intensity is highly variable, due to many factors, such as, the coalescence of smaller drops, instability of larger drops and its origin (convectional rain or frontal rain).

In 1958, Wischmeier and Smith found that soil loss by splash, overland flow and rill erosion is related to a compound index of kinetic energy and the maximum 30-minute intensity (I_{30}). Kinetic energy is calculated as:

$$KE = 11.87 + 8.73 \log_{10} I \qquad (4)$$

Where I is the rainfall intensity (mm/h) and KE is the kinetic energy ($J \cdot m^{-2} \cdot mm^{-1}$).

This index, known as EI_{30}, is open to criticism. Firstly, being based on the estimates of kinetic energy as calculated above, it is of suspect validity for tropical rains of high intensity as well as for high altitudes and areas where rainfall energy are rather low. Secondly, it assumes that erosion occurs even with light intensity rains while it was shown later that erosion is almost entirely caused by rain falling at intensities greater than 25 mm/h (Hudson, 1965). The inclusion of I_{30} is an attempt to correct for overestimating the importance of light intensity rain but it is not entirely successful because the ratio of intensive erosive rain to non-erosive rain is not well correlated with I_{30}. In fact, there is no obvious reason why the maximum 30-minute intensity is the most appropriate parameter to choose.

To overcome the likelihood of overestimating soil loss from high intensity rainfall, the recommended practice with the EI_{30} index is to use a maximum value of 28.3 $J \cdot m^{-2} \cdot mm^{-1}$ for the E component for all rains above 76.2 mm/h and a maximum value of 63.5 mm/h for I_{30} term (Wischmeier and Smith, 1978). The method used to compute rainfall erosivity indices are shown below with the estimating equations in Table 2.

Table 2. Methods used to compute erodsivity index (R).

From Roose (1975)		
Mean annual rainfall erosion index (R) in metric units	= 0.5 x P x 1.73	(5)
From Morgan (1974)		
Mean annual erosivity (MAE1) (KE>25) (j/m^2)	= 9.28 x P - 8,838	
Multiply by I_{30} (75 mm/h; max. value recommended By Wischmeier, 1977)	= MAE1 x I_{30}	(6)
From Foster el. al. (1981),		
Mean annual EI30 (MAE2) ($kg.m.mm)/(m^2.h$)	= 0.276 x P x I_{30}	
With these units, divide by 100 to give R value in Metric units	= MAE2/100	(7)
From Renard and Freimund,		
Rainfall erosion index (R) in metric units	= 0.0048 x P1.61	(8)
From El-Swaify and others 1985,		
Rainfall erosion index (R) in metric units	= 38.5 + 0.35 (P)	(9)
From Wanapiryarat et. al. 1986,		
Daily erosivity factor in (y)	= -3.2353 + 1.789 ln (x)	
Rainfall erosivity (index (R)	= Σy	(10)

Where, P=Mean annual precipitation and x=Daily rainfall data. Results from equation 8 and 9 were found to be about average of all, the first one found to be the highest, and the second and third showed up the lowest. The results from the equation 10 were discarded and the average of the results from first three equations was taken as R-value in order to minimize the error. Since the rainfall data were not evenly distributed and not may measuring stations were situated in the study area, the calculated values in vector were converted to raster to provide polygon around a set of points

2) The soil erodibility factor, K.

K is a quantitative value determined experimentally. Experiments should be carried under the “standard condition”, which is a 22.13 m (72.6 ft) long unit plot with a uniform length-wise slope of 9%. The plot should be in continuous fallow, tilled up and down the slope, free of vegetation for more than 2 years. Soil loss data from plots that meet all the specified conditions except the 9% slope should be adjusted to this standard by S. Actually, measuring K value is very tedious and costly on time, so that a nomograph method has been suggested. To use the nomograph method to find K value of a certain soil, soil textural data such as, particle size distribution, organic matter concentration, soil structure and permeability, are required. K value could be found after those data had been plotted to the nomograph as shown in Figure 2. However, Wischmeier (1977) pointed out that soil erodibility is the inherent susceptibility of a particular soil to erosion. It is a function of soil properties and profile characteristics. Site erodibility is the susceptibility of a particular site or land area to erosion, and it is a function of many interrelated variables in addition to soil properties.

3) The topographic factor, L and S.

LS is the expected ratio of soil loss per unit area from a field slope to that from a 72.6 ft length of uniform 9% slope under otherwise identical conditions. The numerical values could be obtained directly from the slope effect chart or data table from Wischmeier and Smith (1978). The calculation equation of LS is shown in Table 3.

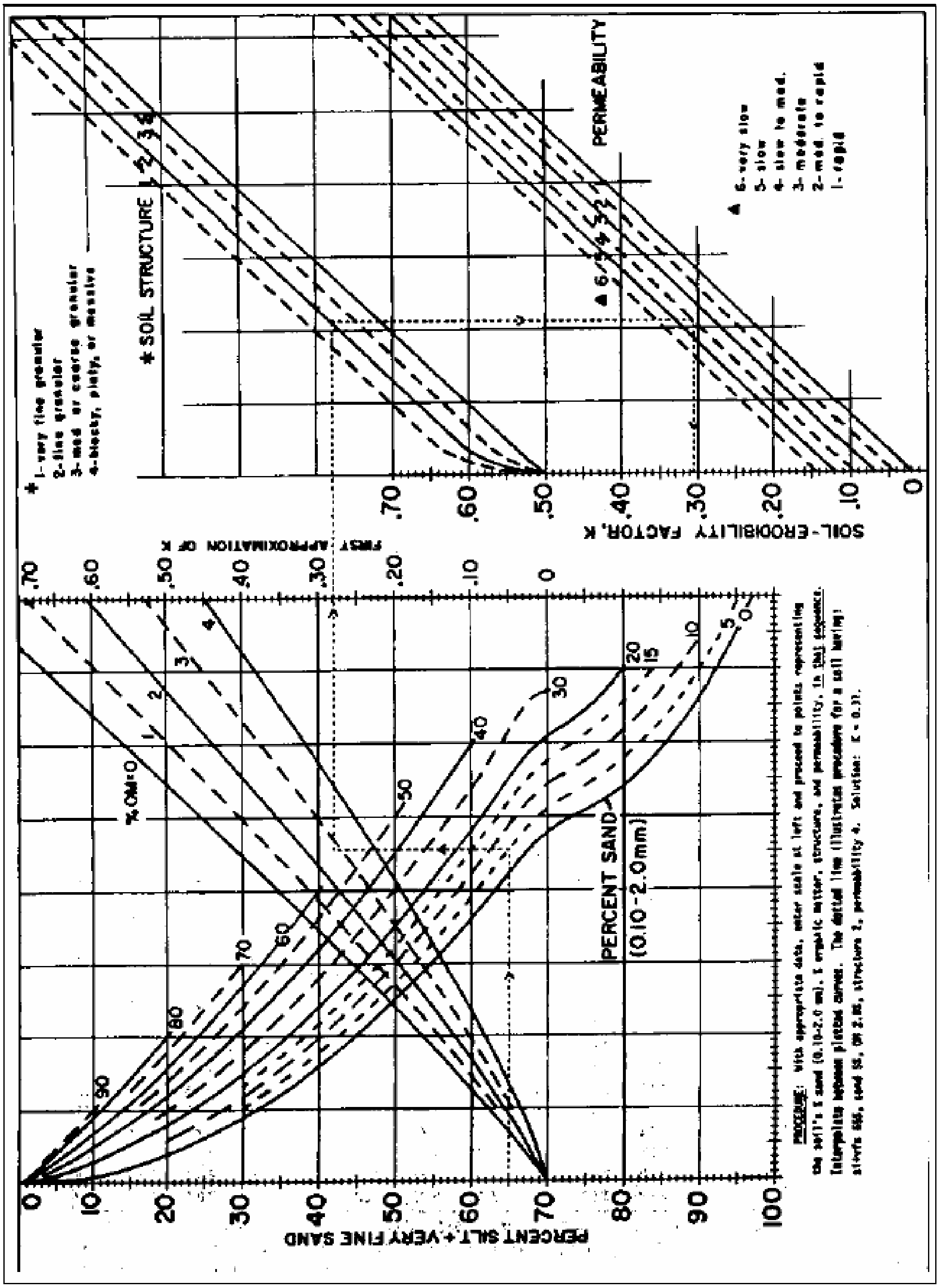


Figure 2. The Soil erodibility nomograph of Wischmeier and Smith (1978)

Table 3. Mathematic equations used for calculating LS factors

Wischeier and Smith (1978)

$$LS = \left(\frac{x}{22.13}\right)^{n}(0.065 + 0.045s + 0.065s^{2}) \qquad (11)$$

where x is the slope length (m) and s is the slope gradient in percent.

n = 0.5 for slope > 5%, =0.4 for slope 3.5 to 4.5%, =0.3 fro slope l to 3.5%, and =0.2 for slope less than 1%.

McCool, et. al. (1987)

$$LS = \left(\frac{x}{22.13}\right)^{0.5}(\frac{0.1}{2s} - 0.55) \qquad (12)$$

McCool, et. al. (1989), Moore and Wilson (1992) → gives the best result (Myint,1997)

$$\text{For slope <9\%, } LS = \left(\frac{x}{22}\right)^{n}(10.8\sin\beta + 0.03) \qquad (13)$$

$$\text{For slope } \geq 9.0\%, \; LS = \left(\frac{x}{22}\right)^{n}(16.8\sin\beta + 0.5) \qquad (14)$$

where β = slope gradient in degrees, n = F / (l + F), and

$$F = (\sin\beta / 0.0896) / (3\sin^{0.8}\beta + 0.56) \qquad (15)$$

4) Cover and management factor, C.

C is the ratio of soil loss from land cropped under specified conditions to the corresponding loss from clean-tilled, continuous fallow. For construction areas, the site preparations that remove all vegetation and also the root zone of the soil not only leave the surface completely without protection but also remove the residual effects of prior vegetation. Therefore, this condition is comparable to the previously defined continuous fallow condition, i.e., C equals to 1.0.

5) Support practice factor, P.

P is the ratio of soil loss with a specific support practice to the corresponding loss with up-and-down-slope culture. For construction sites, P equals to 1.0.

3.3 Limitations of USLE

Generally, the USLE applies only to sheet, rill, and inter-rill erosion (it cannot be used to predict gully or stream bed erosion), and it applies to large areas of loose soil, bare and exposed for 2 or more years. Also, USLE uses a yearly rainfall erosion index and yearly distribution curves based on long-term averages. Designed to predict long term average annual soil loss, USLE would produce misleading soil loss values if it were applied to a seasonal or single storm situation (Wischmeier 1976).

Loch (1984) suggested that the nomograph method for estimating K factor is only valid for certain ranges of soil properties. It cannot be used with confidence for soils which have higher clay contents and more active clay minerals than the soils for which nomographs are available.

4. Model-GIS Integration for Soil Erosion

GIS, when integrated with a model, is a powerful tool in analyzing soil erosion since the process has a spatially distributed character. In integrated model-GIS applications, the cell sizes should be properly selected to reflect the spatial variation of the erosion process. The advantages of using GIS are described by De Roo (1996) as:

(a) the possibility of rapidly producing input maps (soil maps, land-use maps, etc.) for assessment of alternative land management scenarios;

(b) the possibility of displaying model results as maps;

(c) the ability to analyze large catchments with many pixels so that the catchment can be investigated in more detail.

Modern technology has provided efficient tools such as advanced models, remote sensing and satellite imaging, GIS, and expert systems to facilitate decision making for environmental management. These tools are currently integrated to establish an environmental information system, which permits testing and evaluating of alternative management scenarios. Thus, current decision making procedures are realized within a multimedia framework, which is easily accessible by users at local or even global levels.

The majority of these developments are experienced in developed countries. The management problems of the developing countries are at least as severe as those of the developed ones. Thus, advanced tools to support decision making are definitely needed. However, the development and implementation of an integrated system of tools are often hindered by such problems as lack of adequate and reliable data, planners' attitudes towards sophisticated tools, lack of communication between decision makers and scientists/engineers who develop the tools, lack of training and education, lack of agreement among different organizations who are responsible for various stages of the management process, etc.

The study presented herein constitutes an example where two tools, a soil erosion model and GIS, are integrated to infer on the sensitivity of a basin to soil erosion and to estimate gross erosion along with associated nonpoint source pollution loads. In this study, however, the model selected (Universal Soil Loss Equation – USLE) and the case itself is kept as simple as possible due to significant limitations in data on land processes, as the case is with most developing countries.

The main focus of the presented paper is that, although GIS permits more effective and accurate application of the USLE model for small watersheds, most model-GIS applications are subject to data limitations. In modeling, the current trend is more towards the development and the use of sophisticated (physically based, distributed) models; however, the integration of such complex models with GIS still needs caution and improvement due to data constraints. The paper shows that the situation is worse in developing countries even with the use of such simple models like USLE. An effective investigation of soil loss within a watershed by using GIS – USLE integration requires spatially distributed data on several parameters describing the basin. Such parameters include topography, rainfall characteristics, soil types, vegetation, land-use, and the similar. In Thailand, like in most developing countries, data on most of these parameters are often collected on a local basis, and therefore, a well-organized regional or basin-wide database is not available.

5. Spatial Decision Support Systems (SDSS)

5.1 What is GIS, DSS and SDSS?

5.1.1 GIS and Data for GIS

GIS is a general purpose technology for handling geographic data in digital form, with the ability to preprocess data into a form suitable for analysis, to support analysis and modelling directly, and to post-process results (Goodchild, 1993).

Tomlinson (1985) gave the meaning of GIS as the information and filled in the map for decision making. GIS is the hardware and software including the system design and collecting data, analysis, results of data in different positions on earth and helping with the complicated planning and eliminating the problem.

GIS may record and demonstrate in two types: raster or grid format and vector format. Grid format or pixel is referred to the coordinating system, detail of spatial data may record variance in the grid size. The dominant information of spatial is manipulation data, reversible to transform into digital data.

Vector format may be used the continuation of spot and coordination to allocate the objects or interest. The advantage of vector format is the storage data area, which is not large, and symbols of data may be similar to the real data. However, it is difficult to calculate (Ongsomwang, 1995).

Spatial area is the important database, GIS system relates to the database and conjugates data in map and ground check because it is very important to its analysis. Therefore, the structure of the map and coordinating are important to the accuracy of the facts and analysis of data. The relationship of spatial is important to the data value and transfer to digitizer, then to coordinates of the land.

5.1.2 Decision Support System (DSS)

Decision Support Systems (DSS) are defined as computer -based information systems designed to support decision makers interactively in thinking and making decisions about relatively unstructured problems. Traditionally, DSSs have three major components, a database, a model base and a user interface as depicted in Figure 3a.

Little (1970) defines DSS as a “model-based set of procedures for processing data and judgments to assist a manager in his decision making”. He argues that to be successful, such as system must be simple, robust, easy to control, adaptive, complete on important issues, and easy to communicate with.

Moore and Chang (1980) argue that the structured ness concept, so much a part of early DSS definitions (that is, that DSS can handle semi-structured and unstructured situation), is not meaningful in general; a problem can be described as structured or unstructured only with respect to a particular decision maker.

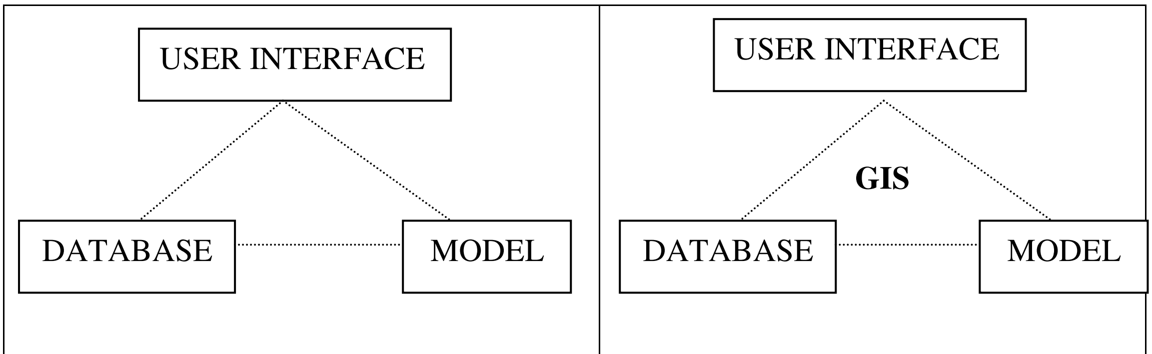
Bonczek et al. (1980) define a DSS as a computer-based system consisting of three interacting components: a language system (a mechanism to provide communication between the user and other components of the DSS), a knowledge system (the repository of problem domain knowledge embodied in DSS, either as data or procedures), and a problem-processing system (the link between the other two components, containing one or more of the general problem manipulation capability required for decision making).

Finally, we have many definitions for DSS. They usually fall into one of two categories: narrow or broad. The narrow definition takes the view that a DSS is an interactive computer program that uses analytical methods and models to help decision makers formulate alternatives for unstructured problems, analyze their impacts, and then select appropriate solutions for implementation (Watkins and Mckinney, 1995). The DSS will essentially solve or give options for solving a given problem. The decision process is structured in a hierarchical manner, the user inputs various parameters, and the DSS essentially evaluates the relative impact. The broader definition incorporates the above narrow definition but also includes other technologies that support decision-making such as knowledge or information discovery systems, database systems, and geographic information systems (GIS) (Power, 1997).

5.1.3 Spatial Decision Support Systems (SDSSs)

An extension of the DSS concept, **Spatial Decision Support Systems (SDSS)**, which are the integration of DSS and GIS (Figure 3b) was initiated by Densham and Goodchild (1988). A significant capability of the SDSS is the ability to use spatial analysis and display tools with the sectoral models and that would form the model base of SDSSs. The modeling capability allows the user of the SDSS to simulate changes in objects and attributes. The database component of the SDSS can supply input data for the models. After the models are run, the resulting output can be written to the database for later display via the user interface, in tabular, chart or map form. For planning purposes, this ability to dynamically change information, forecast and perform sensitivity analysis is essential.

Both GISs and DSSs have been widely used in water resources, and SDSSs, as the conjunctive use of GISs and DSSs, have also been contributed to our understanding of natural resources in recent years. Compared to traditional DSSs, SDSSs have been improved through the incorporation of GIS in the aspects of data base, interface and model connection, etc. For data base, a GIS not only brings spatial dimensions into the traditional natural resource data base, but also, more significantly, has the ability to integrate various social, economic and environmental factors related to natural resources planning and management for use in a decision-making process. Therefore such a system helps to attain an integrated view of the world.(Lam and Swayne,1991; Cowan et al.,1996). For interface, the visual display capacity of GISs and the graphical user interface of DSSs complicates the user interface of a SDSS, which allows the user to take complete control of data input and manipulation. The sophisticated user interfaces can provide user-defined triggers, which allow the user to dictate how features will respond to environmental changes, and to construct rules to control the modeling process (Crosbie,1996). The ease and flexibility in which any natural resource system can be defined, modified and visualized through the designed interface should bring ease and flexibility to the modeling and result analysis (Loucks et al.,1996).



(3a) Decision Support Systems (DSS)

(3b) Spatial Decision Support Systems (SDSS)

Source: Densham and Goodchild (1988)

Figure 3 Decision Support Systems (DSS) and Spatial Decision Support Systems

5.2 Spatial Decision-Making and GIS Systems

5.2.1 Spatial Decision Problems

The main characteristics of spatial decision problems include:

- a large number of decision alternatives,

- the outcomes or consequences of the decision alternatives are spatially variable,

- each alternative is evaluated on the basis of multiple criteria,

- some of the criteria may be qualitative while others may be quantitative,

- there are typically more then one decision maker (or interest group) involved in the decision-making process,

- the decision makers have different preferences with respect to the relative importance of evaluation criteria and decision consequences,

- the decisions are often surrounded by uncertainty.

5.2.2 Decision-Making Process

Simon (1960) suggests that any decision-making process can be structured into three major phases(Figure 4) :

- intelligence - is there a problem or an opportunity for change?
- design - what are the decision alternatives?
- choice - which alternative is best?

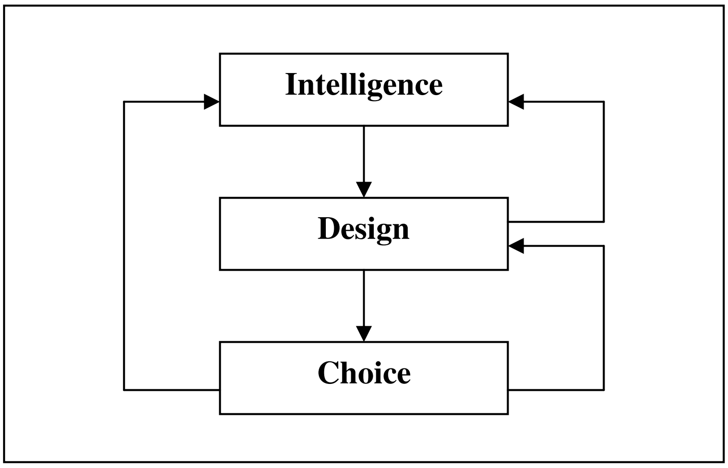


Figure 4 Phases of decision-making

5.2.3 Decision Support

1) Intelligence

- the intelligence phase involves searching or scanning the environment for conditions calling for decisions;
- this phase requires an exploratory analysis of the decision situation;
- GIS can play a vital role at the initial stage of spatial decision-making;
- the system can help in coordinating decision situation analysis through its ability to integrate and explore data and information from a wide range of sources;
- GIS can effectively present information in a comprehensive form to the decision makers.

2) Design

- the design phase involves inventing, developing, and analyzing a set of possible decision alternatives for the problem identified in the intelligence phase;

- a formal model is typically used to support a decision maker in generating the set of alternatives;
- while an increasing number of GIS systems are described as systems for supporting the process of designing and evaluating spatial decision alternatives, most commercially available GIS lack the kinds of spatial analysis and modeling required by decision makers;
- the capabilities of GIS for generating a set of alternative decisions are mainly based on the spatial relationship principles of connectivity, contiguity, proximity and the overlay methods;
- in current GIS environments, models for generating decision alternatives operate in the background, detached from user's insights and qualifications.

3) <u>Choice</u>

- the choice phase involves selecting a particular decision alternative from those available;
- each alternative is valuated and analyzed in relation to others in terms of a pre-specified decision rule;
- the decision rules are used to rank the alternatives under consideration;
- the ranking depends upon the decision maker's preferences with respect to the importance of the evaluation criteria;
- critical for use of GIS in the choice phase is the capability of incorporating the decision maker's preferences into the decision-making process;
- in general, GIS systems do not provide a mechanism for flexible incorporation of the decision maker's preferences into the decision-making process.

5.2.4 Limited of GIS System in Decision-Making Process

- GIS systems have limited capabilities of supporting the design and choice phases of the decision-making process;

- the systems provide a very static modeling environment and thus reduce their scope as decision support tools - especially in the context of problems involving collaborative decision-making.

5.3 Principles, Components and Functions of SDSS

1) Principles of SDSS

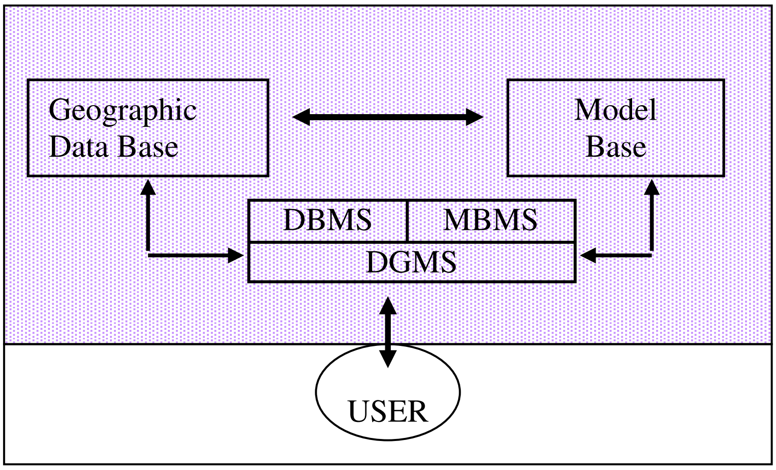
DDM paradigm **-**The technology for a DSS must consist of three sets of capabilities in the areas of dialog, data, and modeling (the DDM paradigm) (Sprague and Watson, 1996), and a well-design SDSS should have balance among the three capabilities.

2) Components and functions of SDSS

There are three components of SDSS; Data Base Management System (DBMS), Model Base Management System (MBMS) and Dialog Generation and Management System (DGMS)

- the Data Base Management System (DBMS) contains the functions to manage the geographic data base;
- the Model Base Management System (MBMS) contains the functions to manage the model base;
- the Dialog Generation and Management System (DGMS) manage the interface between the user and the rest of the system.

(Figure 5 and Table 4)



Source: Sprague and Watson, 1996

Figure 5 The Components of SDSS

5.4 Technologies for Developing SDSS

There are three sets of technologies for building an SDSS: the DSS development tools, the DSS generators, and specific SDSS . The DSS tools facilities the development of specific SDSS or they can be configured into a DSS generator which in turn can be used to build a variety of specific SDSS. Three levels of DSS technology as shown in Figure 6 (Source: Sprague and Watson, 1996) as follows:

1) DSS tools

DSS tools facilitate the development of either a DSS generator or a specific DSS; examples include:

- procedural programming languages and code libraries (e.g., Arc Macro Language (AML) scripting tool of ARC/INFO, Avenue - ArcView GIS software's built-in object-oriented scripting language, TransCAD - Caliper Script macro language, MapInfo - MapBasic);
- visual programming language (e.g. STELLA II, Cantata and Khoros);
- inter-application communication software (e.g. dynamic data exchange (DDE), object linking (OLE), open database connectivity (ODBC));
- simulation languages and software (e.g. SIMULINK, SIMULA);

- application programming interfaces (API) (e.g. the IBM's geoManager API, Java Advanced Imaging API, TransCAD's API);
- applets (e.g. GISApplet, Microsoft Visual J++),
- visual interfaces, graphics and color subroutines (e.g. graphical user interfaces - GUI).

2) DSS generator

DSS generator is a package of related hardware and software which provides a set of capabilities to quickly and easily build a specific SDSS; examples include:

- GIS systems (e.g. ARC/INFO, ArcView, ARCNetwork, Spatial Analyst, MapObjects LT, GRASS, IDRISI, MapInfo, TransCAD);
- database packages (e.g. dBase, Access, Paradox);
- decision analysis and optimization software (e.g. LINDO, EXPERT CHOICE, LOGICAL DECISION);
- statistical and geostatitical software (e.g. S-PLUS, SPSS, StatGraphic);
- simulation (e.g. Spatial Modelling Environment);

3) Specific DSS

Specific DSS are systems devoted to the analysis of a particular set of decision problems and the systems which actually support the decision makers in tackling semi-structured problems; examples include: Active Response Geographic Information System, IDRISI Decision Support; GeoMed, Spatial Group Choice, winR+GIS Spatial Decision Support.

Table 4 The functions of SDSS

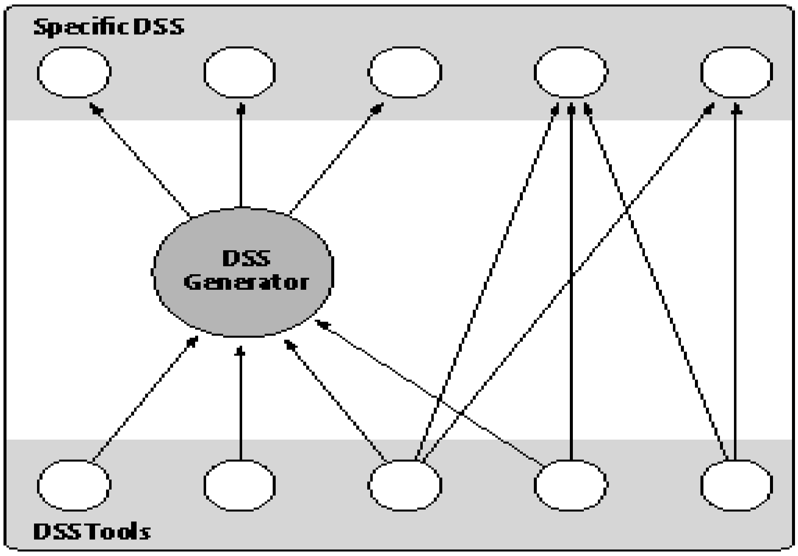
Components	Functions

Data Base and Management	• ***Types of data***
	  o locational (e.g. coordinates)
	  o topological (e.g. points, lines, polygons and relationships between them)
	  o attributes (e.g. geology, elevation, transportation network)
	• ***Logical Data Views*** (relational DBMS, hierarchical DBMS network DBMS, object-oriented DBMS)
	• ***Management of Internal and External Databases*** (acquisition, storage, retrieval, manipulation, directory, queries, integration)

Model Base and Management	• ***Analysis*** (goal seeking, optimization, simulation, what-if)
	• ***Statistics and forecasting***
	  o exploratory spatial data analysis
	  o confirmatory spatial data analysis
	  o time series
	  o geostatistics
	• ***Modeling decision maker's preference***
	  o value structure
	  o hierarchical structure of goals, evaluation criteria, objectives and attributes
	  o pairwise comparison
	  o multiattribute value/utility
	  o consensus modeling
	• ***Modeling uncertainty***
	  o data uncertainty
	  o decision rule uncertainty
	  o sensitivity analysis
	  o error propagation analysis

Dialog Management	• ***User friendliness***
	  o consistent, natural language comments
	  o help and error messages
	  o novice and expert mode
	• ***Variety of dialog styles***
	  o command lines pull-down menus
	  o dialogue boxes
	  o graphical user interfaces
	• ***Graphical and tabular display***
	  o visualization in the decision space (high-resolution cartographic displays)
	  o visualization in the decision outcome space (e.g. two and three-dimensional scatter plots and graphs, tabular rapports)

Source: Sprague and Watson (1996)



Source: Sprague and Watson, 1996

Figure 6 Three levels of DSS technology for building an SDSS

6. Mathematical Modeling for Decision Making with GIS

There are two major thrusts in mathematical modeling within GIS environment: Optimization and simulation (Fotheringham and Rogers 1994, Steyaert and Goodchild 1993). Each represents a fundamentally different approach to problem solving. Broadly speaking, the output of optimization models is a prescription of strategy. Simulation, on the other hand, is a descriptive approach.

6.1 Optimization Modeling

Optimization is a normative approach to identify the best solution for a given decision problem (Wilson et. al. 1981; Thomas and Huggett, 1980). An optimization method is a modeling method that seeks to find the best (maximum or minimum) solution to a well-defined management problem. A well-defined problem is one, which has been structured in a way that the optimization method can utilize. Common to all optimization models is a quantity to be minimized or maximized. The quantity is often termed the objective or criterion function. The constraints define the set of feasible solutions. The solution to an optimization problem determines the values of decision variables subjective to a set of constraints. Thus, in the most general term an optimization model can be written as follows:

Minimize or maximize f(x)

Subject to $x \in X$

Where f(x) is a criterion function, x is a set of decision variables, and X is a set of feasible alternatives. If the problem involves a single criterion function, the problem is referred to as a single-criterion decision model. When more than one criterion function is to be optimized simultaneously, the model is called a multi-criteria problem.

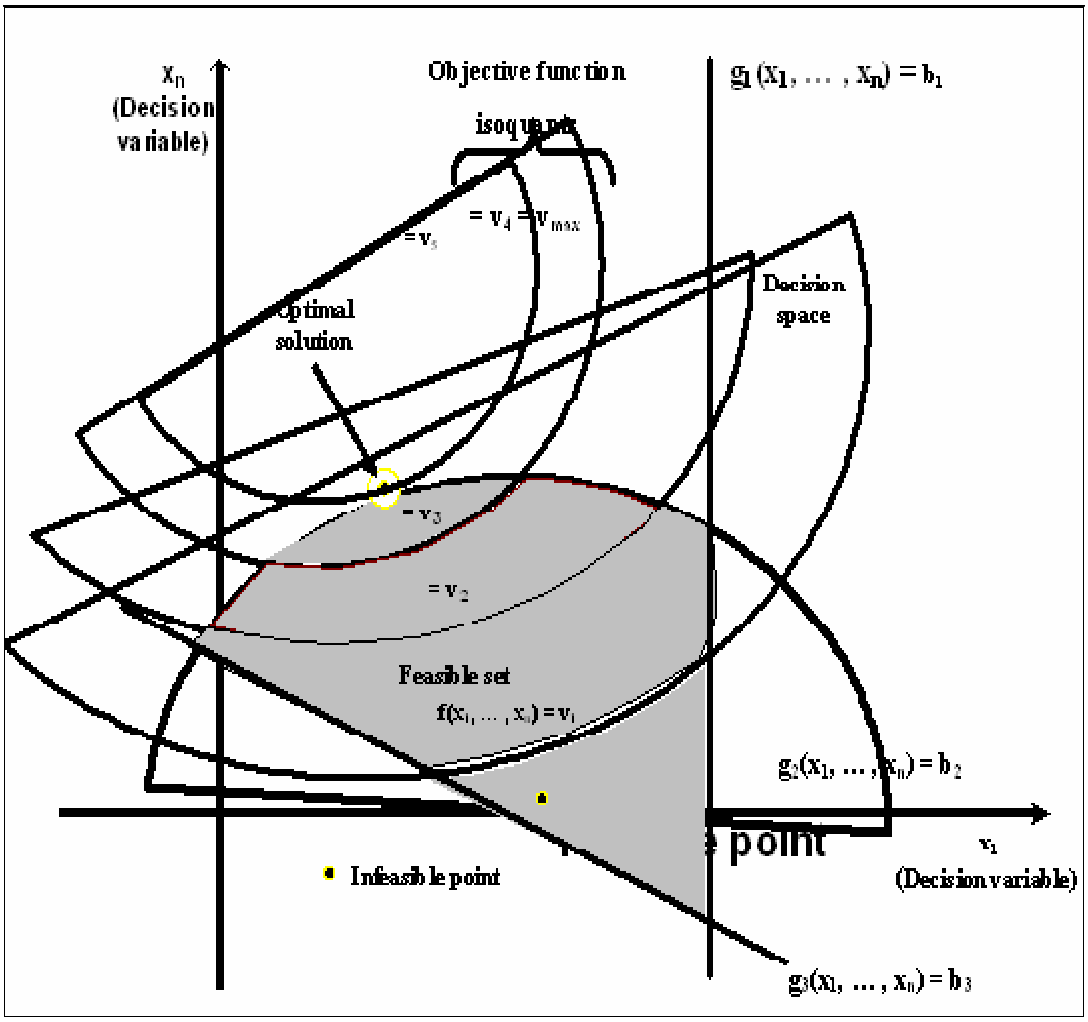
6.1.1 Linear Programming (LP)

One special type of optimization is linear programming (LP) (Dantzig1963, Greenberg 1978, Thomas and Huggett 1980; Dykstra 1984; Killen 1983). It is a tool developed for use in operations research, a science dealing with the development of mathematical decision models for management. In a linear programming model both the objective function and the constraints are linear and additive. The problem also assumes that the decision variables are of continuous type. Most linear programming problems have an economic objective function which seeks to optimize such economic concepts as profit, cost, or net present value. This objective function is comprised of a set of decision variables, each of which is multiplied by a constant coefficient. These coefficients correspond to each decision variable's contribution to the objective function value. Decision variables represent those portions of the total resource base that are allocated to particular activities. Some examples of decision variables that have been used in resource management are the mount of land allocated to specific activities, such as housing, recreation, or transportation; or the number of acres assigned to riparian area restoration, intensive timber management. The primary role of linear programming is to serve, as an allocator of scarce resources to competing activity demands (Goicoechea et al. 1982; Dykstra 1984).

Because resources are not limitless and other potentially conflicting consideration need to be taken into account, a set of constraints are employed to restrict unlimited growth of the objective function in maximization problems and to force some activity occur in minimization problems. Like the objective function, these constraints are also linear and form a geometric space known as the decision space (or feasible region) which constraints very feasible solution to the linear programming problem. Any point outside this solution space is considered infeasible (i.e., a point that leads to a solution that violates one or more constraints and therefore can not be considered as a solution to the problem). The corner points of the solution space (i.e., points where two or more constraints converge) are the only candidates for solution consideration as shown in Figure 7.

6.1.2 Network Optimization (NO)

NO is one of the most widely applicable spatial decision models (Thomas and Huggett 1980; Ghosh and Rushton 1986). A network consists of nodes (supply, demand, and transshipment point for resources) and arcs (paths over which resources flow between nodes) (Killen 1983; Malczewwski and Ogryczak 1995). Network flow models generally involve the optimization of a function of the flows of resources between nodes subject to a conservation of flows constraint (flows into a transshipment node must flow out of the node). The objective of network flow analysis is to determine the best allocation of resources among the nodes subject to resource availability and flow restrictions across arcs (Lupien et al. 1987). Many linear programming problems can be formulated as network flow problem without a great deal of difficulty. However, conversion of other linear programming problems to network flow problems may be either too abstract to be of much value, or simply not be feasible to do. The two principal advantages of network flow models are vastly improved solution times over standard linear programming models and graphic representation of the network which can make problems more intuitive to users (Golden and Bodin 1986; Camm et al. 1997)



Source: http://sunset.usc.edu/classes/cs510_2003/notes/ec-files/bigproject1618.ppt

Figure 7 Geometric View of DSS

6.1.3 Single and Multiple Objectives

The problems associated with managing land water and other resources have never been simple. The concept of watershed management which tries to compromise water yield, socio – economic, and other impacts utilization in the system seems impossible to determine for the best management practice. Fortunately, there is an analytical process that is able to reduce those difficulties to manageable levels. The applications that have most fruitful are based on the mathematical programming model by means of optimization techniques (Haith, 1982). To solve the management problems, the following techniques must be understood.

6.1.3.1 Single Objective Programming

Linear programming is a mathematical technique provides only one objective function to be maximized or minimized. The program refers to the use of certain mathematical techniques to get the best possible solution to a problem involving limited resources. The models have certain characteristics in common. Thus, it is essential to understand those characteristics. The characteristics can be grouped into two categories : components and assumptions. The components relate to the structure of a model, whereas the assumptions reveal the conditions under which the model is valid (Levin *et al*., 1982 and Stevenson, 1992). The characteristics of LP model are listed in Table 5. The following discussion will provide insight into the nature of linear programming problems and models.

(1) Components of LP Model

In formulation of LP model, the following components must be understood.

Objective : The objective in problem solving is the criterion by which all decisions are evaluated. In linear programming models, a single, quantifiable objective called "Objective function" must be specified by the decision maker. According to the optimal solution, hence, it will be either a maximization problem or a minimization problem.

Decision variable: Decision variables represent choices available to a decision maker, usually with respect to the amount or quantity of either an input to a process or an output from a process. In terms of the LP model, the decision variables represent those unknown quantities.

Constraints : The ability of a decision maker to select values of the decision variables in an LP program is subject to certain restrictions or limits. The restrictions may reflect availabilities of resources (e.g. raw material, labor time), legal or contractual requirements (e.g., product or work standards), technological requirements, or they may reflect other limits based on forecasts, organization policies, and so on. In an LP model, the restrictions, are referred to as **constraints**. Only solutions that satisfy all constraints in a model are acceptable. These are referred to as **feasible solutions**. The optimal solution is the feasible solution that yields the best value in terms of the objective.

Table 5 Characteristics of Linear Programming Model

Model validity	**Model structure**	*Model validity*
Components	1. Objective	
	2. Decision variables	
	3. Constraints	
	4. Parameters	
Assumptions		1. Proportionality
		2. Additivity
		3. Divisibility
		4. Certainty
		5. Non – negativity

Source : Modified from Stevenson (1992)

Parameters: An LP model consists of a mathematical statement of the objective function, and a set of mathematical statements of the constraints. Those statements consist of symbols that represent the decision variables (for example, X_1,X_2,X_3) and numerical values called parameters. The parameters are fixed values that specify the impact that one unit of each decision variable will have on the objective and on any constraint, it pertains to as well as to the numerical value of each constraint.

(2) Assumption of LP Model

The following characteristics are assumed in applying the LP model:

Proportionality: The proportionality requirement is that each decision variable has a linear impact in the objective function and in each constraint in which it appears. This means that change in activities proportionally affects outputs. Furthermore, the assumption implies that average value does not change as quantities change (Bell, 1977). This means, for example, that if the profit of x_1 is \$ 4 per unit, the same figure must hold regardless of the quantity of x_1 : it must be true over the entire range of possible values of decision variable.

Additivity: The terms of objective function and each constraint must be additive. Additivity requires that activities be independent, So that the sum of the outputs of the individual activities will be equal to the output if these activities are combined.

Divisibility: In general, divisibility is not severely limiting. It means that all activities or variables in the problem may be divided into smaller and smaller parts.

Certainty: The LP solution is deterministic. For given inputs, one must be willing to assume that outputs will occur with certainty. If it does not produce certainty, a body of theory is available for dealing with uncertainty and risk in decision making. (Bell, 1977). The certainty requirement involves two aspects of LP models. One aspect relates to the model parameters. It is assumed that these values are known and constant. In practice, production times and other parameters may not be truly constant. Therefore, the model builder must take an assessment as to the degree to which the certainty requirement is met. Another aspect is the assumption that all relevant constraints have been identified and represented in the model.

Non – negativity: The requirement is that negative values of variables are unrealistic and, therefore, will not be considered in any potential solutions; only positive and zero value will be allowed.

(3) <u>Limitation of LP Model</u>

Linear programming allows only one objective function to be maximized or minimized, which is not suitable for real world conditions. It has become more and more difficult to see the world around us in a unidimensional way and to use only a single criterion when judging what it is. Things should be compared, ranked and ordered for the objectives of choice with respect to criteria. But only in a very simple, straightforward, or routine situation can be assumed that a single criterion of choice be fully satisfactory. On the other hand, using no criteria or too many criteria are both undesirable extremes and usually signal bad management. Usually decision criteria or objectives are not all equally important. Traditionally, different weighting schemes have been devised to address the problem of differential levels of important for objectives. (Zeleny, 1982)**.**

6.1.3.2 <u>Multiple Objectives Programming</u>

Today the problems are more complex and difficult than those of an earlier era. All of these problems occur simultaneously and on a worldwide basis. In the multiple-use management of watershed resources, numerous and often conflicting objectives exist. To appreciate what is involved in the modeling process, certain concepts need to be understood clearly.

Romero and Rehman (1989) explained some basic concepts of multi-objective modeling as follows:

(1) Some Basic Concepts of Multi-Objectives Modeling

The first step is to establish the conceptual differences among attributes, objectives and goals, and also the distinction between goals and the conventional interpretation of constraints. After that, the idea of an efficient or a Pareto optimal solution is introduced, as it is essential to the development of the multiobjectives programming approach.

It should be pointed out that some of the concepts may have the same dictionary meanings, for example, goals and objectives, and, in the context of some problems, can be used interchangeably without creating confusion. However, the meaning and use of some concepts in the analysis of a decision-making problem changes according to the theoretical structure, single or multi-objectives framework, within which the problem is being studied. The followings are steps to modelling the multi-objectives function:

(2) Attributes, Objectives and Goals

Attributes can be defined as a decision maker's (DM's) values related to an objective reality. These values can be measured independently from a DM's desires and in many cases can be expressed as a mathematical functions f(x) or in a ration formulation model of the decision variables. It can be clearly seen in terms of a set of inequality equations in the model structure.

The concept of an objective represents the direction of improvement of one or more of attributes. The improvement can be interpreted in the sense either "more of the attribute, the better" or "less of the attribute, the better". The first case means a maximization process and the latter situation minimization is at work. Therefore, objectives imply the maximization or the minimization of the functions representing one or several attributes reflecting the values of the DM.

A goal is an aspiration level or a target. A target is an acceptable level of achievement for any one of the attributes. On combining an attribute with a target will get a goal. In short then, in term of planning process will compose of many attributes or constraint, to maximize or minimize, an objective, and, to achieve a certain target, a goal. Finally, a criterion is a general term comprising the three preceding concepts. That is, criteria are the attributes, objectives or goals to be considered relevant for a certain decision-making situation.

3) Distinction between Goals and Constraints

In fact, goals and constraints have the same mathematical structure and look exactly the same as both of them are inequalities. The difference between them lies in the meaning attached to the right - hand of the inequality. With goals the right - hand side is a target aspired by the DM, which may be achieve or not. With constraints, however, the right - hand side must be satisfied otherwise an unfeasible solution ensues.

6.1.4 Goal Programming (GP)

Goal programming (GP) is a variation of linear programming that can be used for problems that involve multiple objectives. This technique originally developed by Charnes and Cooper since 1960 which has been applied in various fields such as quality control, capital budgeting, resource allocation, manpower planning, project selection, etc. (Ignizio, 1983). GP models are quite similar to LP models, both are formulated under the same requirements and assumptions (e.g., linearity, certainty, non – negativity etc.)

In the context of GP, multiple objectives are referred to as goals. Each goal relates to a target level of performance (Stevenson, 1992). The general aim of GP is simultaneous optimization of several goals. For that reason the deviations from the desired targets and what is actually achievable are minimized. The minimization process can be accomplished by several methods. Each method is a specific variant of

GP. The most two widely used variants of GP are lexicographic goal programming (LGP) (preemptive goal programming or priorities model) and weighted goal programming (WGP) (Romero and Rehman, 1989).

In LGP, higher priority goals are satisfied first, and only then are lower priorities considered. WGP, on the other hand, considers all goals simultaneously within a composite objective function composed of the sum of all deviations among the goals and their aspiration levels. The deviations are weighted according to the relative importance of each goal. (Romero and Rehman, 1989**.** According to the latter, one comes up with a set of weights that truly reflect differences in importance. Some decision makers have found this process to be difficult and some what artificial. More recently, interest has centered on priority models (Stevenson, 1992).

It should be pointed out that there are two different types of goal. The first type are the goals which represent the decision maker's desires to reach a specific value and the second type of goals refer to the existence of limited resources. (Romero and Rehman, 1989)**.**

The setting of goals, targets, or aspiration level is an old and useful tactic in the pursuit of human objectives. Setting goals is an art. They should be neither too high nor too low. Everybody knows the agony and frustration of failing to achieve a goal set too high; everybody knows the disappointment and dissatisfaction which often sets in after one has "succeeded" in attaining a goal that was set too low. Given a portfolio of properly established goals, one tries to achieve them as closely as possible. Attaining a goal is necessary and sufficient prerequisite for setting a new goal it is not an end in itself (Zeleny, 1982).

GP needs to set some estimated targets for each of their goals and to put priorities on them that is to rank them in order of importance. The program tries to minimize the deviations from the targets that were set. It begins with the most important goal and keeps on until the achievement of a less important goal would cause management to fail to achieve a more important one. However, typical of ranking goal can be divided into 3 models : A single - goal, equally ranked multiple goals and priority ranked multiple goals (Levin *et al.*, 1982)**.** Stevenson (1992) clearly explained some important aspects of the goal model:

In GP models, goals are expressed as constraints. However, ***goal constraints*** are somewhat different to those encountered in LP. In LP models, a solution would not be considered feasible if it violated any of the constraints. Because of the absolute requirement that constraints be satisfied and given as ***hard constraints***. In contrast, goal constraints specify desirable levels of performance. These are treated as approximate rather than absolute amounts which should be achieved to the extent possible. Therefore, a goal constraint will be called as ***soft constraints*** or goal constraints.

The models may consist entirely of soft constraints (goal constraints), or a combination of soft and hard constraints. The solution to a GP model must also satisfy any hard constraints, although it may not necessarily achieve the target levels of the soft constrains. When one or more goals are not achieved by a solution, it is because there are conflicts either between goals or between goals and hard constraints. Deviations from goals are permitted if they are needed to obtain a solution. Thus, in GP, the objective is to satisfy the hard constraints. (if any) and achieve reasonably acceptable levels for the goal constraints. This is referred to as ***satisfying***.

The following details are the main steps in applying the GP model:

(1) Deviation variables

In order to account for possible deviation from goal, deviation variables are incorporated into each goal to represent the differences between actual performance and its target. There are two possible kinds of deviation from a target: being under the target amount (underachievement, u), and being over the target amount (overachievement, v). Deviation variables are included in each goal constraint. Adding these two deviation variables to a goal constraint create an equality because the deviation variables account for any discrepancy between actual and target. In effect, the deviation variables are equivalent to slack (amount of underachievement, u) and surplus (amount of overachievement, v). Hence, u is added and v is subtracted in a goal constraint. In addition, one of the two deviation variables in each goal constraint would equal zero in any solution because it would be physically impossible to be over and under a goal simultaneously. For more details Romero and Rehman (1989) indicated that: A goal cannot be both underachieved (u) and overachieved (v). Hence, in a solution at least one of the deviation variables for each goal is zero. When a goal matches its aspiration level exactly then both u = v = 0. If a certain goal's achievement must be greater than or equal to its target then its deviation variable (u) must be minimized. If a certain goal must be less than or equal its target then the v deviation variable must be minimized. Finally, if a certain goal must be exactly equal to its target, then both u and v deviation variables must be minimized.

(2) Model formulation

A GP model consists of an objective and a set of constraints. The constraints may be goal constraints or they may be a mix of goal and nongoal constraints. In addition, there is non - negativity requirement that all variables must be non - negative.

In priority models, the objectives indicate which deviation variables will be minimized and their order of importance. Thus, the objective is to minimize specified deviations from certain goals according to priority. The formulation steps of GP model would be as follows:

- Identified the decision variables
- Identified the constraints and determine which ones are goal constraints
- Formulate the nongoal constraints (if any)
- Formulate the goal constraints.
- Formulate the objective

- Add the non - negative requirement statement.

The following example illustrates the above ideas:

$$\textbf{Minimize } Z = P_1u_1+P_2u_2+P_3u_3 \tag{16}$$

$a_{11}\, x_1 + a_{12}\, x_2$	$\leq$	b_1	Hard constraint
$a_{21}\, x_1 + a_{22}\, x_2 + u_1 - v_1$	$=$	b_2	$goal_1$
$a_{31}\, x_1 + a_{32}\, x_2 + u_2 - v_2$	$=$	b_3	$goal_2$
$a_{41}\, x_1 + u_3 - v_3$	$=$	b_4	$goal_3$

All variable $\geq$ o

where :

Z = Represent the objective minimization of the deviation variables or achievement function

P = The P's represent priorities, and their subscripts indicate order of importance

a_{ij} (i = 1...4; j = 1,2) = coefficient of variable j in constraint i

x_j (j = 1, 2) = decision variable j

b_i (i = 1...4) = right - hand side value of constraint i

u_i,v_i = the deviations of under and over target level

(3) Computer - assisted solutions

GP problems can be solved using either a simplex method or a standard LP package. The above example can be examined by computer approach. The computer-assisted approach adds goals sequentially according to priority and generates a solution after each goal is added.

The process begins by solving a model that includes any hard constraints and one goal constraint. The goal constraint that contains the deviation variable that has the highest priority. The solution for that model fixes the value of deviation variable for the remainder of the analysis. Consequently, that variable is deleted from the model. This process is repeated using remaining deviation variable that has the highest priority and so on, until all priorities have been considered. The following example illustrates the 3 steps of the process.

From the above example:

$$\textbf{Minimize } Z = P_1u_1 + P_2u_2 + P_3u_3 \qquad (17)$$

Subject to :

$a_{11}\, x_1 + a_{12}\, x_2$	$\leq$	b_1	(Hard constraint)
$a_{21}\, x_1 + a_{22}\, x_2 + u_1 - v_1$	$=$	b_2	(goal$_1$)
$a_{31}\, x_1 + a_{32}\, x_2 + u_3 - v_3$	$=$	b_3	(goal$_2$)
$a_{41}\, x_1 + u_4 - v_4$	$=$	b_4	(goal$_3$)

All variable $\geq$ o

(3a) ***Focusing on the first priority (goal$_1$)***

The first model must focus on the deviation variable with the highest priority, which is u_1 in this problem. Consequently this first problem consists of hard constraint, first goal constraint and an objection function that includes all decision variables as well as the deviation variables in the first goal constraint. The model is:

$$\textbf{Minimize } Z = 0X_1 + 0X_2 + u_1 + 0v_1 \qquad (18)$$

Subject to :

$a_{11}\, x_1 + a_{12}\, x_2$	$\leq$	b_1	(Hard constraint)
$a_{21}\, x_1 + a_{22}\, x_2 + u_1 - v_1$	$=$	b_2	(goal$_1$)

Note that the decision variables are now represented in the objective function. All of the variables except the highest priority deviation variable have coefficients of zero. The zero coefficients reflect the fact that the quantities of these variables will have no impact on the objective, which is to minimize the amount of under - deviation on the first goal.

Suppose that the optimal Z = 0, that is $u_1 = 0$ then substitute this value into the first goal constraint and delete u_1 from the model. This, essentially, fixes the value of u_1 at zero for the remainder of the analysis.

(3b) ***Minimize the second priority (goal$_2$)***

The next priority is to minimize u_2, which is the second goal constraint. That constraint is now brought into the model, and the objective is modified accordingly. The revised model is:

$$\textbf{Minimize } Z = 0X_1 + 0X_2 + u_2 + 0v_2 \tag{19}$$

(u_1 is omitted)

Subject to :

$\mathbf{a_{11}x_1 + a_{12}x_2 \quad \leq \quad b_1}$ (Hard constraint)

$\mathbf{a_{21}x_1 + a_{22}x_2 - v_1 \quad = \quad b_2}$ (subtracting the value of u_1) (goal1)

$\mathbf{a_{31}x_1 + a_{32}x_2 + u_2 + v_2 \quad = \quad b_3}$ (goal 2)

Again, all objective function coefficients are zero except for the deviation variable being minimized. Note that the previous deviation variable, u_1 is now removed from the objective function, although v_1 still remains. The u_1 also has been removed from the first goal constraint. Thus, the revised model consists of the previous model with one additional goal constraint added, the previous deviation variable of interest has been deleted, and the objective function has been revised accordingly.

Suppose that the optimal solution Z = b_5, so that $u_2 = b_5$. This information is used to modify the second goal constraint. Substituting the value of $u_2 = b_5$ into the constraint and then subtracting this amount from both sides gives:

$\mathbf{a_{31}\,x_1 + a_{32}\,x_2 + b_5 - v_2 \quad = \quad b_3}$

$\mathbf{a_{31}\,x_1 + a_{32}\,x_2 \quad = \quad b_3 - b_5}$

This puts the constrain on the right - hand side, and fixes the value of u_2 at b_5, so that, the value of u_2 cannot change as further solutions are generated.

(3c) ***Minimize the last priority (goal$_3$)***

The third and last priority relates to deviation variable u_3. Removing the previous variable, u_2, for the model and incorporating the deviation variables for the third goal, the revised model is now:

$$\textbf{Minimize } Z = 0X_1 + 0X_2 + 0v_1 + u_3 + 0v_2 \tag{20}$$

Subject to :

$a_{11}\,x_1 + a_{12}\,x_2 \leq b_1$ (Hard constraint)

$a_{21}\,x_1 + a_{22}\,x_2 - v_1 = b_2$ (subtracting the value of u_1) (goal$_1$)

$a_{31}\,x_1 + a_{32}\,x_2 - v_2 = b_3 - b_5$ (subtracting the value of u_2) (goal$_2$)

$a_{41}\,x_1 + u_3 - v_3 = b_4$

Again, note that all variables in the objective function have coefficients of zero except the deviation variable that currently is being minimized, and all higher priority deviation variable, that were previously minimized are eliminated for the revised model.

Because all priorities have been accounted for at this point, this solution completes the analysis. The solutions can be concluded that only goal 1 reach to the achievement level according to the deviation variable (u_1) is equal to zero, but goal 2 and goal 3 are failed under their targets value by b_5 and b_6, as summarized in Table 6.

Note that once the value of a deviation variable is determined, subsequent solutions do not change it. The same fashion is not necessarily true for the decision variables; they may or may not change in value in subsequent solutions.

Table 6. Summary of computer solutions showing the achievement and underachievement target levels.

Model	Value of decision variables		Value of deviation variabl		
	X_1	X_2	u_1	u_2	u_3
1. Hard constraint + goal$_1$	$Value_1$	$Value_2$	0	-	-
2. Hard constraint + goal$_1$ + goal$_2$	$Value_3$	$Value_4$	0	b_5	-
3. Hard constraint + goa l$_1$ + goal$_2$ + goal$_3$	$Value_5$	$Value_6$	0	b_5	b_6

Source: Vinarant (2000)

6.2 Simulation Modeling for Decision Making

In the broad sense, simulation is a methodology for performing experiments using a model of the real-world system (Rubinstein 1981; Mather 1991; Englund 1993). The primary difference between optimization and simulation is their starting point. Optimization procedures start with a definition of the system objectives and specify the actions that will satisfy those objectives at the optimum level. Once the optimum conditions are established, the vicinity of the optimal points is analyzed to determine the effect of variations in the system. Simulation modeling starts with the actions and studies their effects on the overall system objectives by testing different policies under various external conditions. Simulation is the exploratory approach to decision problems. It either reproduces a process or obtains a sample of many possible outcomes. Components of a system being simulated are defined mathematically and related to each other in a series of functional relationships. The results are a mathematical description of the complete decision process. The model is solved repeatedly using different parameters and different decision variables every time. As those values are changed, a range of solutions is obtained for the problem and the best solution is chosen from that range. This approach is similar in philosophy to post-optimality analysis, except that it is not restricted to the neighborhood of the optimum point.

Given that simulation is based on a mathematical model, two classifications of simulation approaches can be identified: static versus dynamic and deterministic versus stochastic (Rubinstein, 1981). A static simulation is one in which experiments are performed on a model having variables and parameters that are not time dependent. A dynamic simulation includes systems that change over time. Deterministic simulations involve variables and parameters that are fixed and known with certainty, whereas stochastic simulations assign probability distributions to some or all of the variables and parameters. This type of simulation provides a powerful tool in solving probabilistic problems, where the distribution of the final results is more important that a point estimate for the result. Such simulations are also sometimes referred to as Monte Carlo simulation because of their use of random variables (Openshaw and Whitehead 1985; Openshaw 1991; Fisher 1991).

7. Applicability of Linear Programming, Goal Programming in Natural Resources Management

Consideration of alternative use of forest and its products nearly always raises the question " What is the best way? ". According to the number of alternatives, the complexity of the product interactions and the conflicting desires of the public, the optimal answer may be impossible to derive. Managing natural resources for multiple use requires complex decisions that involve many diverse aspects. Fortunately, some help has been provided for the manger by the decision tool known as mathematical programming called " Goal programming "(Bell, 1977 and Schuler *et al*.,1977).

7.1 Applicability of Linear Programming (LP)

LP provides an excellent opportunity to introduce the idea of "what-if" analysis, due to the powerful tools for post-optimality analysis developed for the LP model. Linear Programming (LP) is a mathematical procedure for determining optimal allocation of scarce resources. LP is a procedure that has found practical application in almost all facets of business, from advertising to production planning. Transportation, distribution, and aggregate production planning problems are the most typical objects of LP analysis. In the petroleum industry, for example a data processing manager at a large oil company recently estimated that from 5 to 10 percent of the firm's computer time was devoted to the processing of LP and LP-like models.

Linear programming deals with a class of programming problems where both the objective function to be optimized is linear and all relations among the variables corresponding to resources are linear. This problem was first formulated and solved in the late 1940's. Rarely has a new mathematical technique found such a wide range of practical business, commerce, and industrial applications and simultaneously received so thorough a theoretical development, in such a short period of time. Today, this theory is being successfully applied to problems of capital budgeting, design of diets, conservation of resources, games of strategy, economic growth prediction, and transportation systems. In very recent times, linear programming theory has also helped resolve and unify many outstanding applications.

It is important for the reader to appreciate, at the outset that the "programming" in Linear Programming is of a different flavor than the "programming" in Computer Programming. In the former case, it means to plan and organize as in "Get with the program!", it programs you by its solution. While in the latter case, it means to write codes for performing calculations. Training in one kind of programming has very little direct relevance to the other. In fact, the term "linear programming" was coined before the word "programming" became closely associated with computer software. This confusion is sometimes avoided by using the term linear optimization as a synonym for linear programming.

Any LP problem consists of an objective function and a set of constraints. In most cases, constraints come from the environment in which you work to achieve your objective. When you want to achieve the desirable objective, you will realize that the environment is setting some constraints (i.e., the difficulties, restrictions) in fulfilling your desire or objective.

What is a function: A function is a thing that does something. For example, a coffee grinding machine is a function that transform the coffee beans into powder. The (objective) function maps and translates the input domain (called the feasible region) into output range, with the two end-values called the maximum and the minimum values. When you formulate a decision-making problem as a linear program, you must check the following conditions.

The objective function must be linear. That is, check if all variables have power of 1 and they are added or subtracted (not divided or multiplied). The objective must be either maximization or minimization of a linear function. The objective must represent the goal of the decision-maker. The constraints must also be linear. Moreover, the constraint must be of the following forms (>=, <=, or =, that is, the LP-constraints are always closed).

For most LP problems one can think of two important classes of objects: The first is limited resources such as land, plant capacity, or sales force size; the second, is activities such as "produce low carbon steel", "produce stainless steel", and "produce high carbon steel". Each activity consumes or possibly contributes additional amounts of the resources. There must be an objective function, i.e. a way to tell bad from good, from an even better decision. The problem is to determine the best combination of activity levels, which do not use more resources than are actually available. Many managers are faced with this task everyday. Fortunately, when a well-formulated model is input, linear programming software helps to determine the best combination.

7.2 Applicability of Goal Programming (GP)

To date, many applications of GP have been outside forest management; they have included for instances: choosing optimal executive compensation plans; planning manpower management; scheduling production; employment; inventories to satisfy known demand over a finite time; and other applications to financial and market strategy. Recently they have been several applications in forestry; they have included selecting forest residue treatment alternatives; analyzing potential gains from tree improvement programs; and evaluating land - use planning decision on national forest (Schuler *et al*.,1977).

In 1977, a pilot study by F.K. Martinson at the University of Colorado implemented by the Bureau of Land Management (BLM) on a trial basis demonstrates the feasibility of using a multiple linear programming approach to help the area manager with his or her decisions. The following actual multiple-objective decision problems were pointed by Daellenbach *et al.* (1983) as follows:

The Federal Land Policy and Management Act, passed by the 94th U.S. Congress in 1976, gives the following mandate to the Bureau of Land Management (BLM) for the management of the approximately 473 million acres of federally owned land under its jurisdiction :

- that the management to be on the basis of multiple use and sustained yield ;
- that the land be managed in a matter that will

(a) protect the quality of scientific, scenic, historical, ecological, environmental, air and atmospheric, water resource, and archaeological values ;

(b) where appropriate, preserve and protect certain public lands in their natural condition ;

(c) provide food and habitat for fish, wildlife, and domestic animals; and

(d) provide for outdoor recreation and human occupancy and use.

Many of above objectives are in direct conflict with one another. For some tracts of land, the BLM will be under fire from different pressure groups to have their vested interest prevail. These groups included farm lobbies who want more grazing land, mining companies who want prospecting rights, and conservation groups who want to keep some areas in their natural state. How does the BLM resolve these conflicts?

Roughly, the BLM's current procedure consists of first compiling a detailed inventory of the area's topography, soils, vegetation, and other physical features and a description of existing use for each tract in the area. This is followed by an assessment of the unlimited potential of each tract for each possible use, without regard to any other uses by means of " MinMax approach ". Independently of this, a socio - economic profile is compiled that provides relevant information on attitudes of current and prospective uses of the area, on special interest groups, and on economic factors relating to the importance of natural resources. Armed with these two basic documents, the area manager has to develop a compromise solution that reflects both the best intrinsic use of the various tracts and the relevant socio - economic factors.

In 1991, Cornett and Williams (1991) used goal programming technique for multiple land-use planning on 16,000 acres in South Sierra Nevada at mineral King of California, USA. The model evaluated three levels of development: retaining the status quo, moderate development or intensive development. Multiple land-use products were considered as goals, including both developed and dispersed outdoor recreation, timber production, livestock grazing and deer population management.

Comparison of the various solution sets revealed tradeoffs resulting from changing management priorities. Evaluation of modeling results and consideration of other environmental impact information showed that the intensive development alternative would have caused excessive degradation of existing watershed and cultural values. A more acceptable approach would be initiate a moderate scale of development following a conservative construction schedule, then closely monitor adverse impacts and compile an improve information base. Furthermore, it would allow for much more accurate projection of the consequences of further developments if they were desired.

8. Modeling with GIS for Selected Site Suitability Analysis and SDSS

GIS analysis can be divided into four main categories: Overlaying, Buffering, Modeling, and Network Analysis. These four components of analysis represent the basic tools of GIS. Each one of these tools is simple, and it can be combined to produce complex, spatial analysis. Understanding these techniques will help you understand the workings behind GIS analysis and map products. Each tool is discussed in the following sections.

8.1 Overlaying

Combining two or more maps by overlaying them is a fundamental operation of Geographic Information Systems. Before computer GIS programs became common, overlying was done by taking two maps, transferring them to clear mylar sheets, and literally overlaying them on a light board. The view coming through would be a combination of the two maps. (Figure 8)

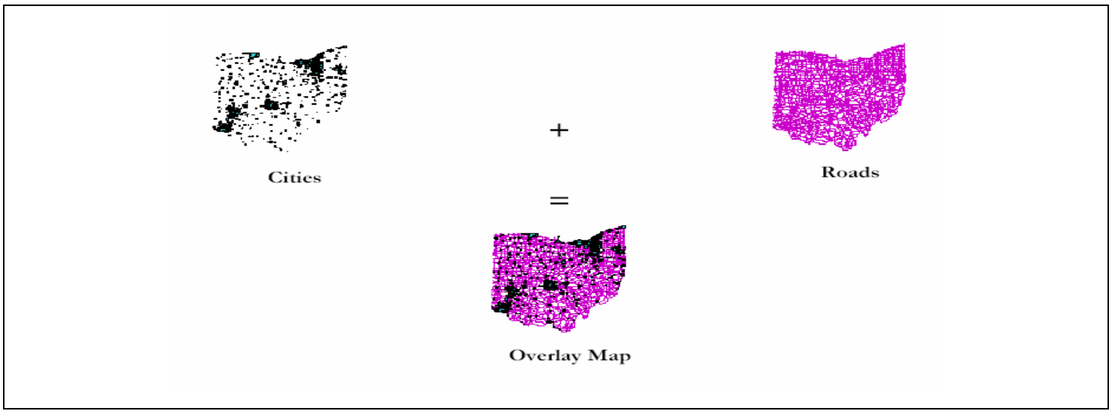


Figure 8 Example map by overlaying in GIS

Today in a GIS, we can be a little more sophisticated. The process of overlaying usually involves taking two layers and combining them by some mathematical operation. Layers can be added, subtracted, multiplied, or divided according to the values of certain attributes. For example, if we have two data layers of the same area, taken five years apart. Both layers show polygons of soil areas. One of the attributes of the soil polygons is a value for the Universal Soil Loss Equation (USLE). The USLE calculates how much soil is lost over each acre every year (units are in tons per acre per year, or tons per hectare per year).

If we **overlay** the two layers and compare the USLE attribute (by subtracting the values of one layer from another), we can identify areas where the annual soil loss has changed in the past five years. After the subtraction operation, a new data layer will be created which shows the change as a positive, negative, or zero value. This can quickly show us where changes have occurred due to farm practices or construction. These changes are important because they may affect such things as sedimentation and non-point source pollution. Overlaying is frequently combined with other analysis methods to produce even more valuable results. For instance, one could combine this operation with a model that automatically calculates the USLE from existing data. That would save tremendous amounts of time. Or, one could use a buffer to highlight changing soil losses within riparian corridors.

8.2 Buffering

Among the simpler GIS applications, buffering is a process of identifying objects within a specified distance of a reference object. The reference object may be a point location, a line, or a polygon. The buffering process creates a new polygon around the reference object. A simple environmental example would be to create a buffer around the site of a chemical spill. This buffer could be used to assess health risks to the affected population. One could create multiple, concentric buffers for different levels of exposure. Often buffering is combined with overlaying to isolate certain features. One such application could identify riparian areas, since they are associated with streams. A buffer layer combined with a selected land cover layer could easily identify riparian corridors.

8.3 Modeling

One of the most productive and powerful innovations in GIS has been the incorporation of modeling. This involves joining the GIS database to a computer-driven model of some process or procedure. The GIS can then combine pieces of data for every object, put it through the model process, and get back a new piece of information. This allows spatial data to be processed in mass quantities using powerful, complex formulas.

8.3.1 What is a Model?

A model is a representation of the real world. In the GIS world, this occurs through mathematics. A series of mathematical formulas are linked together to explain the workings of a particular phenomenon. A good model has the ability to predict the outcome of a set of inputs as they would affect the real world. There are two applicable types of modeling we'll be discussing. The first type is called a **simulation model**. Simulation modeling involves using the GIS to simulate a complex phenomenon in nature. This generally requires a high degree of technical expertise, and can vary in the degree to which it is linked to the GIS. However, once the GIS and the model are linked, they can be used to evaluate different features of the data, whether it is spatial or non-spatial. The other, more powerful modeling tool is **predictive modeling**. In this form of modeling, an expert acquires data and uses it to build a statistical model, which is tested by regression analysis. Once the model has been tested on known data, it is applied to new data in order to predict results. This type of modeling has been used to predict processes like flooding, groundwater contamination, and soil loss. The ability to link GIS to these models has greatly increased the usefulness of GIS as a scientific tool.

1) Simulation Models

A **simulation model** is used to analyze the known information about a data feature. This could be a stretch of stream, a point-source of pollution, or a census tract. A simulation model uses information from the data table associated with the object, plugs that information into a formula, and creates a new result based on the information from one or more variables. An example of this would be using a model to find all the upstream tributaries of Section X of a river. The model would look for a field in the associated information table that indicated what sections flowed into Section X. From those sections, it would look and find what sections flowed into them. The model would continue to look until it reached all the headwaters of the upstream tributaries. It would then return the results of all the upstream waters for Section X. This is just one example of a simulation model.

2) Predictive Models

A **predictive model**, on the other hand, is used to predict how a change in a variable will affect other conditions. Once again, this can be applied to any data feature, but it applies more to the attributes of a feature than the feature itself. As you can see, there is quite a difference between simulation and predictive models. Simulation models deal with extracting more information from what is already known about a feature. Predictive models deal with changes that will occur if certain variables of a feature change. Both these types of models can apply to groups of features or whole coverages, as well. These both have a variety of applications for managing environmental problems.

Using modeling, we can take the information in the GIS and process it with the model to create a new layer, showing the flow direction for every polygon. That may seem slightly interesting, but what purpose does it serve? Well, let's take the process one step further. Suppose we have a second model that is a little more complex. This model takes the flow directions for the polygons and combines them into "basins" (i.e. watersheds). Using this model, we can take the flow direction layer and process it to produce a map of all the watershed basins in an area. In fact, we could further simplify the process by linking the two models so the product of the first model gets immediately processed by the second. That would allow a GIS user to take her layer of slope information and, in one step, produce a map of watersheds. Using GIS, she has taken raw data and turned it into a useful, applicable product.

8.3.2 Network Analysis

Network Analysis is a special type of analysis for vector datasets that are joined by topology. Using these datasets, one can create a network connecting different points. This could be a stream or road network, for example. Network analysis, then, takes advantage of the connected network to solve certain problems.

8.4 Site Suitability Analysis and SDSS

One of the major applications that use a mix of procedures is SITE SUITABILITY - finding the most suitable site according to specific SPATIAL and ATTRIBUTE conditions. A typical application would be locating a new forest, where SEVERAL FACTORS have to be considered, such as proximity to transportation, Land-use, topography, land values, etc. In this type of application you are typically given a GOAL. In order to reach this goal you have to meet SPECIFIC CRITERIA. (Figure 9)

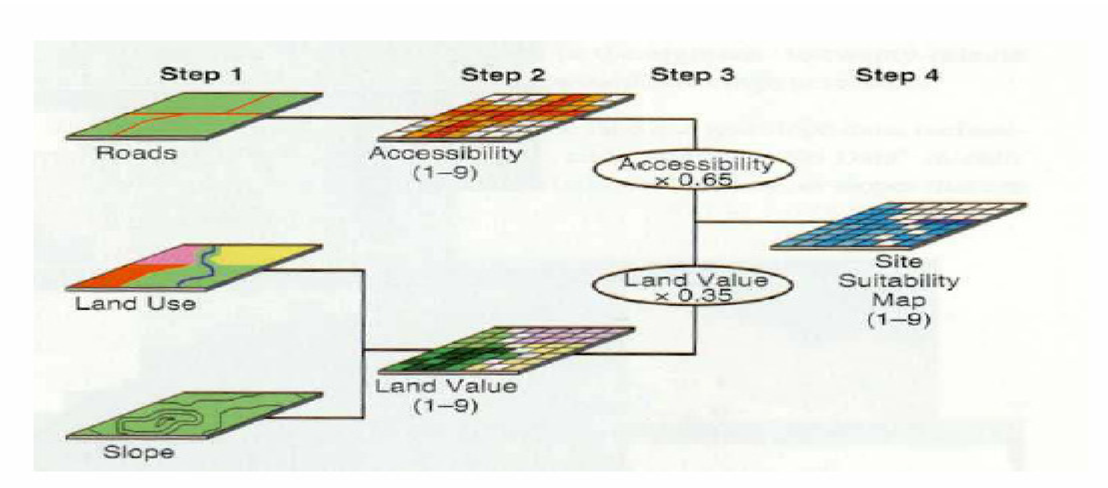


Figure 9 Example for Site Suitability Analysis and SDSS

Although the concept is easy, it can sometimes be a complicated process and a little confusing, particularly when multiple coverages (grids) are used. Good organization is therefore essential. FLOW CHART will use to plan the next steps as shown in Figure 18 (methodology section).

9. Previous Studies Related to DSS for Sustainable Watershed Management

9.1 Study in Western and European Countries

Many studies have been made of multi-objective land-use planning under various conditions, such as those applied in an industrial complex, a watershed, a river basin. However, very few of them focus on the evaluation of the optimal balance between economic development and environmental quality within a watershed. In the literature, Goicoechea and Duckstein (1976) illustrated the use of multi-objective programming in a watershed land management project without considering environmental factors. Van and Nijkamp (1976) presented a multi-objective decision model for optimizing regional development, environmental quality control, and industrial land-use. Das and Haimes (1979) applied multi-objective optimization techniques in a river basin planning project. Two broad-based planning objectives considered in their project are economic development and environmental quality. Impacts of both point and non-point source pollutants on water quality were evaluated in its various land management scenarios. Wright *et al*. (1983) used a multi-objective integer programming model for the land acquisition problem in which an efficient and specialized algorithm for finding non-inferior solutions of a multi-objective integer program was also developed. Glover and Martinson (1987) reported multiple-use land planning to match production objectives with management activities, constrained by resource limits, budget, and policies. Ridgley and Giambelluca (1992) applied a water-balance simulation model for calculating groundwater recharge as it varies with land-use in a multi-objective programming framework. This project was conducted in Hawaii for land-use plan design incorporated three objectives related to agricultural land retention, groundwater balance, and residential population growth. However, environmental impacts were not considered. Leone and Marini (1993) discussed the correlation between land-use and potential lake alteration in central Italy. The environmental assimilative capacity, lake state evaluation, mitigative actions, and possible development scenarios were defined in an integrated approach.

In Spain, Chuvieco (1993) demonstrated GIS are becoming basic tools for a wide variety of each science and land-use applications. His article presents linear programming (LP) as a promising tool for spatial modelling within a GIS. Although LP is not properly a spatial technique, it may be used to optimize spatial distributions or to guide the integration of variables.

9.2 Study in Asian Countries

Not many studies played around with decision support system, especially watershed management field and also not many investigators try to integrate of mathematical modelling and GIS for land-use planning. Some researches have done in Indonesia, Nepal, but all the investigators are come from outside Asia. Suhaedi., et.al (2002) has applied GIS and interactive multiple goal linear programming to develop a framework for spatial in the rural areas.

In Taiwan, Chang.,et.al (1994) has applied multi-objective programming to optimize management of environmental and land resource in a resource watershed. He used the compromise programming technique and the multi-objective simple method, and shown that increasing the residential area is a feasible option if pollution can be controlled properly in these new communities.

In Thailand, one of research applying linear programming and goal programming in watershed management was carried out by Vinarant (2000). His research has applied LP and GP to the solution of upper watershed management, but has not yet integration between LP, GP and GIS.

STUDY AREA DESCRIPTION

1. General Characteristics

1.1 Location and Sub-basin Catchments Area

Geographically the study area - Upper Nan basin, above the Sirikit Reservoir lies between 18^{o} 00' 45" and 19^{o} 37' 53" N latitude and 100^{o} 20' 34" and 101^{o} 06' 29" E longitude in the North Region of Thailand (Figure 10). The catchments area of Upper Nan Basin are about 13,129 Km^2. (Table 7). The almost boundaries of Upper Nan covers with Nan province land area in the North more than 90 % or 13,100 sq.km, the rest land area in the South of basin in Uttaradit province 7 % and Phrae province only 3 %. There are several river and rivulets in the watershed, which drain in the main river, called as Nan River. The name of watershed, that is Nan Basin, is derived form this river. Nan Basin has been divided in to sixteen sub-basin and Upper Nan Basin has been divided in to 9 sub-basin ; B0902 Upper Part of Mae Nam Nan, B0903 Nam Yao(1), B0904 Second Part of Mae Nam Nan, B0905 Nam Yao(2), B0906 Nam Samun, B0907 Third Part of Mae Nam Nan, B0908 Nam Sa, B0909 Nam Wa, B0910 Nam Haeng .

Table 7 Sub-watershed and Catchments Area in Upper Nan Basin

Sub_basin Code	Sub_basin Name	Catchment Area(vector format)		
		Km^2	%	Hectares
B0902	Upper Part of Mae Nam Nan	2,222.20	16.93	222,219.90
B0903	Nam Yao(1)	788.05	6.00	78,805.38
B0904	Second Part of Mae Nam Nan	1,528.73	11.64	152,873.25
B0905	Nam Yao(2)	591.31	4.50	59,131.14
B0906	Nam Samun	591.59	4.51	59,158.99
B0907	Third Part of Mae Nam Nan	3,375.63	25.71	337,563.18
B0908	Nam Sa	778.44	5.93	77,843.98
B0909	Nam Wa	2,209.40	16.83	220,940.47
B0910	Nam Haeng	1,043.80	7.95	104,380.26
Total	9 Sub-Basin	13,129.17	100.00	1,312,916.55

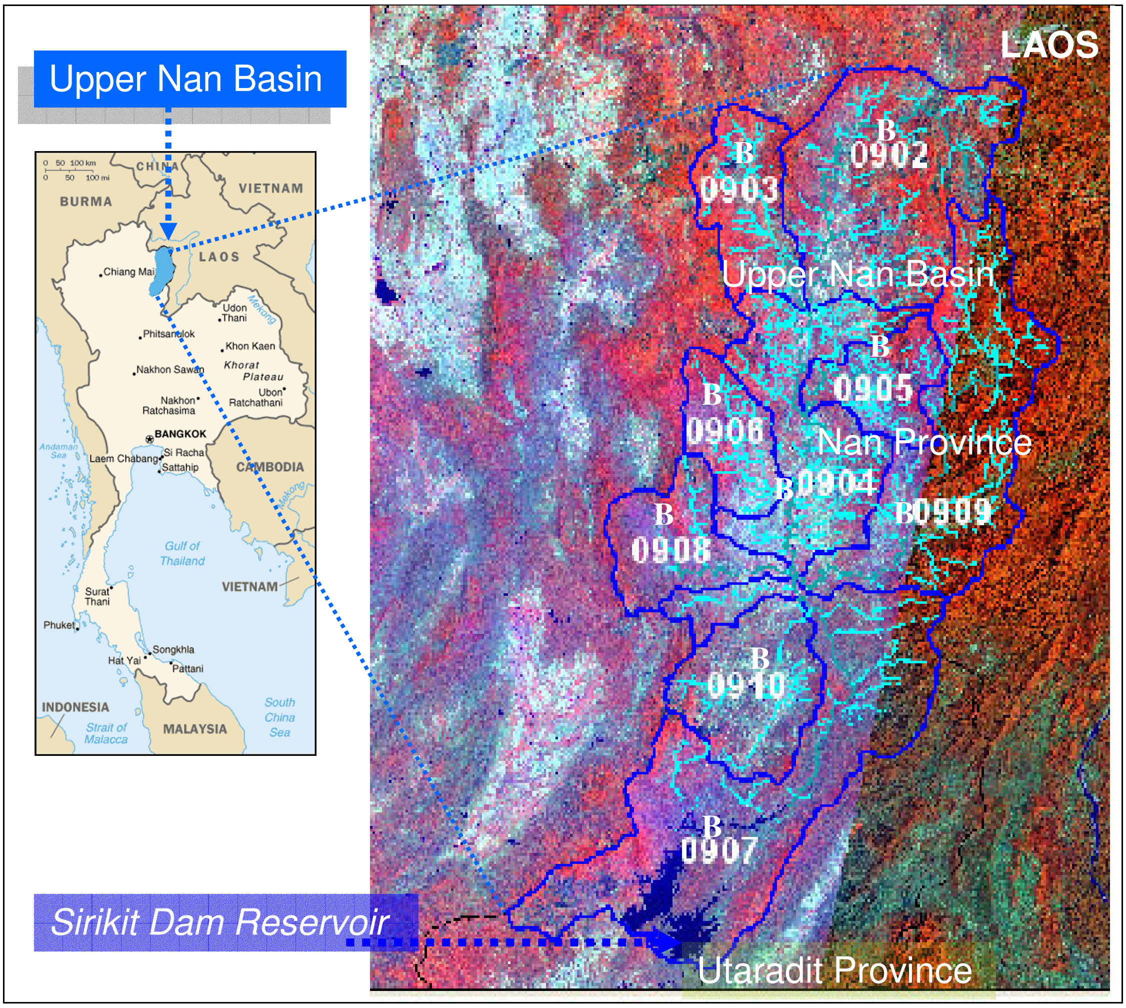
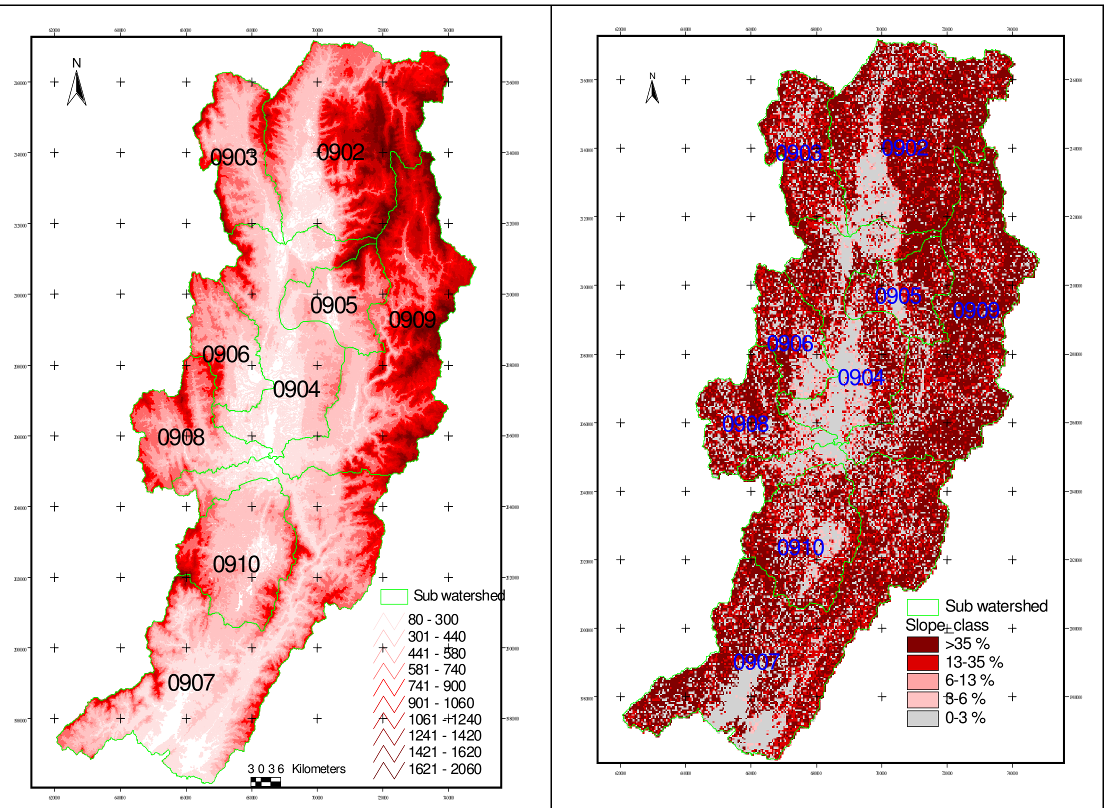


Figure 10 Map of Upper Nan Basin, Northern Thailand

1.2 Topographical Features

1.2.1 Topography

The study area is characterized by mountainous topography ,which consists of a series of parallel and longitudinal folded mountains as a continuation of the Laung Pha Bang System. The folding in this part has resulted in long and narrow river valleys divided by steeply rising uplands with considerable variation in elevation, from about 80 m at the basin outlet to 2,060 m above mean sea level at the highest (Figure 11a.) and slope area as shown in Figure 11b and Table 8



(a) Map of Digital Elevation Model	(b) Slope (%) Map of Upper Nan Basin

<u>Figure 11</u> Map of Digital Elevation Model and Slope (%) , Upper Nan Basin

<u>Table 8</u> Slope area percentage of Upper Nan Basin

Slope (%)	Area in grid cell(raster format)		
	Km^2	%	Hectares
0-3	3,685	28.05	368,450
3-6.	138	1.05	13,800
6-13.	237	1.80	23,700
13-35	2,956	22.50	295,575
>35	6,119	46.59	611,875
Total	13,134	100.00	1,313,400

1.2.2 Geology and Soils Resources

The regional geology of the Upper Nan River Basin comprises various kinds of rocks and rock units ranging in age from Carboniferous. The study area consists mainly of Paleozoic and Mesozoic sedimentary rocks and Mesozoic Ignous rocks. Paleozoic rocks ranging from Carboniferous rocks are consisting mainly of sandstone and shale , Permian rocks consists mainly of limestone sandstone and shale , Silurian Devonian rocks consists of Phyllite , Quartzite ,Schist and greywacke locally , Mesozoic rocks consists of conglomerate , sandstone and siltstone. Mesozoic rocks exposed locally in Nan Basin. Volcanic rocks ,Andezite and Rhyolite exposed locally in the basin. Plutonic Ultramafic rock as Gabbro and Pyroxenite are found at Amphoe Tha Pla , Changwat Uttaradit.(Figure 12)

In the part of northern Thailand including the project area, Mesozoic orogenic movement having two phases Triassic of Jurassic phase and Jurassic to Cretaceous phase occurred. The existing geological structure is affected by this orogenic movement and structures in the north and south or northwest and southeast directions are conspicuous. The study area is also subjected to this effect so that the strike of strata, the strike of folds and the strike of remarkable faults are mainly in the north and south or northwest and southeast directions.

The detailed reconnaissance soil resources of Nan Basin can be summarized as follows:

(a) Flood Plain and Low Terrace. The recent alluvial plains, which consists of 21.14 % of basin area as flood plain along rivers and streams, are low lands and have relatively flat topography , slope not more than 1-2 %. The soils formed on these low lying landscape are mostly young loamy soils and are classified as Alluvial Soils are relatively fertile soils and mainly used for rice cultivation or upland and tree crops in places. The main management problem is the risk of damage to crops by flooding unless adequately protected.

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(b) Middle and High Terrace. The undulating to rolling alluvial terraces which occupy high position between recent alluvial plains and mountainous areas , its area are about 6.38 % of basin area and slope less than 2-15 %. Management problems include stoniness and drought after rainy season. The non-gravelly and deep members which occupy a small extent, however, are moderately suited for upland crops under rain fed cultivation, but they are generally not suited for paddy land because they occur on position too high to impound water successfully without special water control measures.

(c) Dissected Erosion Surface. The undulating to rolling foot slopes and hills are erosion surfaces of various kinds of rock such as limestone, sandstone in combination with quartzite and shale. Its area are about 10.93 % of basin area and slope 15-35 %. Soils formed in the area vary widely in depth, texture, color, reaction, fertility as well as agricultural potential, depend largely upon the kind of parent rock of each soil.

(d) Mountainous Area. The steeply dissected area occupies a very large area, about 58.39 % of the whole basin area. This area is mapped as "Slops Complex" which consists of many kinds of soil that formed on land that has slope greater than 35% , including areas of rock outcrop, escarpment and other kinds of land surface features that are on this mountainous landscape. This mapping units is covered by many of valuable forest which generally are not suited to clear for agricultural land and should be preserved as national watershed area.

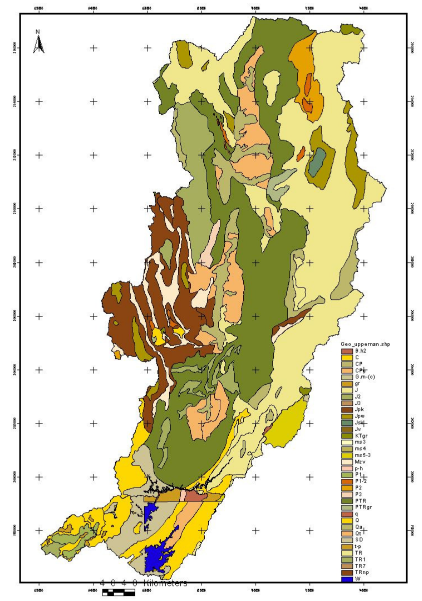
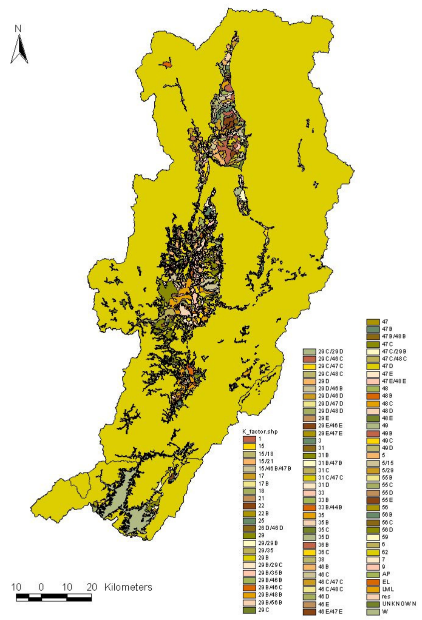
	
(a) Soils map of Upper Nan Basin	(b) Geology map of Upper Nan Basin

Figure 12 Soils and Geology Map of Upper Nan Basin

1.3 Climate and Meteorological Condition

The general climate of the study area is tropical monsoon and characterized by winter , summer and rainy season, influenced by the northeast and southwest monsoons. The rainy season brought about by the southwest monsoon originating from the Indian Ocean lasts from mid May until the end of October. July and August are usually the months of intense rainfall. The winter season, during the weather is cold and dry due to northeast monsoons, begins in November and ends in February. From mid February until mid May, the weather is rather warm. The annual rainfall is about 1,263 mm. More than 80 percent of the rainfall is concentrated in the wet season. Heavy rains usually come in July and August making the water level in the rice fields near the stream rise quickly causing short-term floods. The meteorological condition in terms of monthly rainfall during 1977 – 2000 are shown in appendix c. The annual rainfall amount, monthly mean maximum, minimum, average temperature was observed at 263 mm, 43.0 ^{o}C, 13.4 ^{o}C, 25.7 ^{o}C respectively during 1977 – 2000 in Nan Province are shown in Table 9

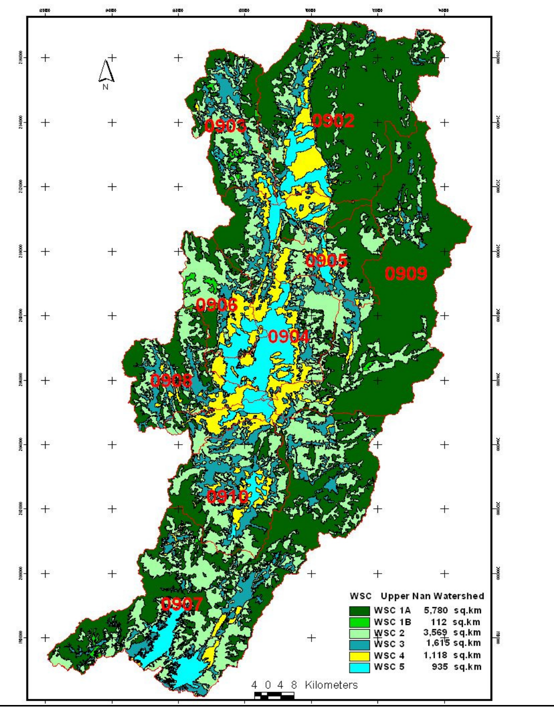
Table 9 Climate and Meteorological Condition in Nan Province during 1977 – 2000

Month	Temperatures (^{0}C)			Wind Speed(notch)		Evaporation	Relative Humidity		Rainfall	
	Max	Min	Avg.	Max	Min	mm.	Min	Max	Avg.mm.	No.day
January	35.2	3.5	20.8	16	0.9	81.8	18	70	8.1	1.4
February	38.3	7.0	23.3	33	1.2	90.9	15	76	14.1	1.9
March	40.8	9.1	26.4	40	1.4	117.8	13	65	27.5	3.2
April	43.0	16.2	28.9	40	1.6	142.1	16	67	103.1	9
May	42.0	16.5	28.6	40	1.5	137.7	21	76	175.0	17.0
June	38.7	20.1	28.1	38	1.6	110.3	38	80	155.6	16.3
July	37.4	19.6	27.5	33	1.6	100.8	42	83	207.2	20.0
August	38.4	19.4	27.1	33	1.5	97.6	37	85	247.6	22.3
September	36.3	18.8	27.0	40	1.1	99.5	42	85	205.3	17.8
October	35.7	12.1	26.2	33	1.0	101.1	34	83	94.5	11.0
November	34.9	6.2	23.8	33	0.9	86.3	31	81	19.1	4.1
December	33.8	4.9	20.7	21	0.8	77.6	26	79	5.9	1.4
	43.0	**13.4**	**25.7**	**-**	**-**	**1,243.5**	**13**	**78**	**1,263.0**	**125.4**

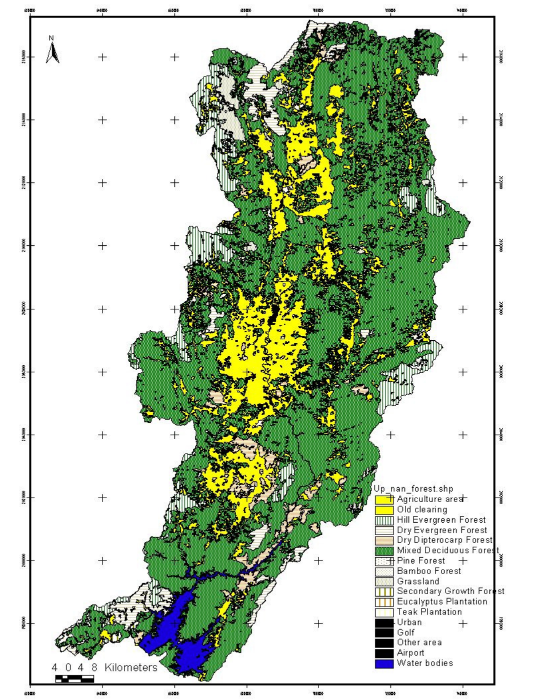
Source: Meteorological Department(2000)

2. Watershed Classification (WSC) and Forest Resources

Watershed classification is the macro-land-use planning project .The classification was based on land elevation, slope, land form, geology and soils of the area. The WSC area of Upper Nan Basin are following ; WSC-1A 5,780 sq.km (44.02 %) , WSC-1B 112 sq.km (0.85 %) , WSC-2 3,569 sq.km(27.18 %) ,WSC-3 1,615 sq.km (12.30 %) , WSC- 4 1,118sq.km (8.51 %) and WSC-5 935 sq.km (7.12 %) . They are shown in figure 13a . The forest area in 2000 was divided be 7 Classes following ; Hill Evergreen Forest 757.30 sq.km (5.77%) Dry Dipterocarp Forest 410.62 sq.km (3.13%) Dry Evergreen Forest 470.74 sq.km (3.59%) Mixed Deciduous Forest 7,867.10 sq.km (59.92%) Bamboo Forest 7.70 sq.km (0.06%) Pine Forest 8.50 (0.06%) and Grassland 168.68 sq.km (1.28%) shown in Figure 13b and Table 10



(a) WSC map of Upper Nan Basin



(b) Forest map of Upper Nan Basin in 2000

Figure 13 WSC and forest map of Upper Nan Basin

Table 10 Forest and land-use area in 2000 ,Upper Nan Basin

Land-use Classification	Area		
	Km^2	%	Hectares
1.Agriculture area	**2,962.76**	**22.57**	**296,276.00**
2.Forest	**9,690.64**	**73.81**	**968,764.01**
2.1 Hill Evergreen Forest	757.30	5.77	75,730.09
2.2 Dry Dipterocarp Forest	410.62	3.13	40,761.76
2.3 Dry Evergreen Forest	470.74	3.59	47,073.77
2.4 Mixed Deciduous Forest	7,867.10	59.92	786,710.34
2.5 Bamboo Forest	7.70	0.06	770.20
2.6 Pine Forest	8.50	0.06	849.82
2.7 Grassland	168.68	1.28	16,868.02
3.Plantation Forest	**119.17**	**0.91**	**11,916.56**
3.1 Secondary Growth Forest	73.34	0.56	7,333.66
3.2 Teak Plantation	42.11	0.32	4,211.21
3.3 Eucalyptus Plantation	3.72	0.03	371.69
4.Urban	**50.39**	**0.38**	**5,038.71**
5.Water bodies	**306.76**	**2.34**	**30,675.88**
Total	**13,129.71**	**100.00**	**1,312,971.16**

Source: Department of Land Development (2001)

3. Socio-Economic Characteristics

The total population of Nan Province are 458,000 (Population and housing Census 2000) of which majority (86.9 %) of the people live in highland area. Only 6 % of the total population are educated , 72 % of the people are involved in agricultural activities . The details are shown in table 11.

Table 11 Socio-economic characteristics census 2000 in Nan province

Items	
Demographic characteristics	
Total population ('000)	458.0
Population in Municipal Area (%)	13.6
Sex ratio (Males per 100 females)	101.7
Population by age group	
0-14 years (%)	24.3
15-59 years (%)	65.4
60 years and over (%)	10.3
Age dependency ratio (per 100 adults 15-59 years)	
Total	52.8
0-14 years	37.2
60 years and over	15.7
Sinuate mean age at first marriage (SMAM)	
Males	27.4
Females	23.0
Thai nationality (%)	99.7
Buddhism (%)	95.8
Minority population	
Muslims (%)	1.0
Population speaking hill tribe languages (%)	10.5
Education	
Average years of education attainment of population aged 15 years and over	5.9
Population aged 6-24 years not attending school (%)	32.6
Employment characteristics of population aged 15 years and over	
During last year industry	
Population in the agricultural sectors (%)	72.0
Work status (%)	
Employers	0.4
Own account worker	37.9
Employees	21.8
Unpaid family workers	39.8
Members of producers' cooperatives	0.1
Housing characteristics	
Average household size	3.8
Female headed households (%)	16.9

Source : Population and Housing Census 2000

4. Policy for Highland Basin Development

4.1 Reforestation

The reforestation programmed of RFD seeks to solve the problem of timber shortages, degradation of forest land, and help to address rural poverty (RFD 1984). The programme has the following main objectives:

Economic: Planting forest for economic benefit to produce income in various ways such as from logs, fuel wood, posts or wood pulp.

Conservation**:** Planting forest for protection means that there is no direct economic return but instead watershed areas are protected and soil erosion is prevented.

Social**:** Planting forests can give direct and indirect social benefits especially in rural areas where people's lives are bound to the forest. This is based on the assumption that if people in or nearby the forest areas have secure work and income besides having land to farm, then the problems of forest destruction will be gradually reduced.

4.2 Soil and Land-use Policy and Implementation Guidelines

4.2.1. Soil Resources and Land-use

1) Policy 1 : Protect the soil resources from degradation and loss, and rehabilitate soil quality.

a. Increase awareness of the value and usefulness of soil by extension and training programs, and effective land-use practices;

b. Promote soil improvement and conservation of soil and water resources by using measures favorable to environmental quality and the sustainable use of soil and land;

c. Formulate specific laws for land-use zoning and control activities that may affect the soil resources such as removing top soil and sand mining; and laws and regulations effectively;

d. Improve and establish mechanisms for effective administration and management that facilitate national control of land-use;

e. Have entrepreneurs take responsibility for soil rehabilitation, and regular monitoring;

f. Formulate guidelines for protection and solution of coastal erosion problems and formulate criteria and measures for landfills on river banks, beaches, shorelines and sea beds in order to rehabilitate privately-owned lands that have been eroded by river and seawater;

g. Support environmental and ecological studies and research regarding soil quality and rehabilitation techniques for improving degraded soils and promote the application of appropriate research results for the current situation and socio-economic circumstances; and

h. Develop a systematic soils and land information network, as a support unit for administration and management at policy and implementation levels.

2) <u>Policy 2 : Increase effective land-use practices that are relevant to soil capacity.</u>

a. Encourage local administration units and community groups to participate in the administration and management of soil resources;

b. Use economic incentives as a mechanism for promoting appropriate land-use based on potential and capacity;

c. Improve administration and management of agricultural land reform, according to the intention of the law, and promote coordination for efficient land management;

d. Develop public land and abandoned area as deemed appropriate, for the benefit of the community;

e. Rehabilitate Royal Forest Department reserve forest concession lands exceeding 100 *rais*; and

f. Upon expiration of the concession 16 ha to be reforested.

4.2.2 Agricultural Land-use

1) Policy 1 :Conserve and protect areas that are suitable for agriculture; at least equal to 35 percent of the country's total area with 25 percent designated for farming and 10 percent for pasture.

a. Designate fertile land and irrigated areas for protection as agricultural areas;

b. Develop grasslands and waste land as grazing areas for the promotion of livestock raising based on their capacities and the ecosystem;

c. Designate management guidelines for agricultural land in irrigated areas that conform to its land-use and socio-economic capacities; and

d. Use legal and fiscal measures to preserve and protect fertile agricultural areas.

2)Policy 2 : Promote and support suitable agricultural land-use practices.

a. Promote restructuring of agricultural production based on soil capacity and economic efficiency, appropriate for sustainable agricultural development;

b. Increase the capacity of farmers to undertake efficient production that enhances conservation and rehabilitation of natural resources;

c. Monitor and control agricultural practices or other activities that may cause soil degradation in areas suitable for agriculture; and

d. Promote inter-disciplinary research, and encourage integrated conservation and development by providing incentives for agricultural development that support natural resources and environmental conservation.

5. General Problems in the Highland Basin

The problems of catchments area of major rivers which are being largely degraded by forest encroachment and agricultural exploitation are now the serious situation of the highland Basin. The effects have caused severe erosion and sediment transportation downstream as well as many other changes in hydrological characteristics. The proposed of mitigation measures are as follows:

1) Conservation of existed abundant forest areas; promote the conservative groups to advise people not to destroy forest and helping forest fire protection.

2) Rehabilitation of trespassed and non abundant forest areas; conduct the forest plantation in the watershed classes 1A and 1B and creation of new forest villages in pilot project under the King's contemplation.

3) Promotion of the project on vetiver grass cultivation on steep slope to protect soil erosion

4) Promotion and training on use of manure and organic fertilizer in stead of chemicals, as well as introducing fish farming in paddy fields

5) Promotion of extra occupation in order to reduce dry season cultivation

MATERIALS AND METHODS

The Spatial 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:

1.Materials

The necessary materials for this investigation were set up for the purpose of secondary data of socio-economic within and outside of the study area were also taken into account. The materials are as follows:

1. Topographic map scale 1 : 50,000 ; Soil map (1:100,000); Land-use map (1:250,000) Satellite data: Landsat TM 2001(1:250,000)
2. Personal Computer and LIDO 6.0 software for quantifying the solution (Schrage, 1999).
3. GIS software (ArcView 3.3, Arc Info 8).
4. Database software (MS Access XP, MS Excel XP)
5. Statgraphics Plus 5.0

2.Methods

2.1 Problem Identification and Solution Approach

Thailand has always been blessed with an abundance of natural resources, and particularly so for Northern Thailand. Only a century ago, forests covered 72 percent of Thailand's territory. This accounted for approximately 230 million *rai* (1 ha = 6.5 *rai*) of land. In 1961, less than 40 years ago, that number was still relatively high at 171 million *rai* or 53 percent of the country. However, most recently (1995), only one quarter or 26 percent (82 million *rai*), of Thailand remained under forest cover. From 1961 to 1995, Thailand lost an average of 2.6 million *rai* of forest every year.

Northern Thailand possesses a large share of Thailand's forest resources. It has the highest percentage of land covered by forest area and the largest amount of forest cover in absolute terms. The Northern region has experienced sharp declines in forest cover over the last ten years. In 1961, 69 percent of Northern Thailand was covered by forest, for some 73 million *rai* of forest cover and by 1995, these figures had dropped to 44 percent and 46 million *rai*, respectively. However, given that the North accounts for the major share of the total forest cover in Thailand, it often sustains the greatest proportion of the total forest losses per period .Between 1982 and 1985, over 60 percent of the total forest area loss in Thailand occurred in the North . Notably, the north also has maintained a near majority of the losses since that time. For both the Northern region and Thailand as a whole, the worst losses came during the 1976 to 1978 period when the forest cover in Northern Thailand declined at an average annual rate of 3.61 percent, and 5.84 percent for the whole of Thailand. However, from that time the average annual rates of forest cover loss have generally demonstrated an improving trend, for both the North region and Thailand as a whole.

Land-use change to agricultural land has a significant influence on soil erosion and catchments hydrology. In Thailand, an estimated 30 percent of the land area is moderately to severely eroded, according to the Department of Land Development. Erosion reduces not only the soil's depth, but also its capacity to hold water and the amount of nutrients it contains. It also has serious consequences downstream-polluting drinking water, silting up rivers and irrigation systems, degrading coastal ecosystems.

In addition, the widespread destruction of the watershed forest upstream from the Nan River that supplies the Chao Praya River, could deplete that river's flow from 11 billion cubic meters at present to 6.685 billion cubic meters in the next seven years. At least 480,000 ha of the total 1,280,000 ha of forest have been affected by deforestation.

From the above cause and effect, therefore, it is there for necessary to study on A Spatial Decision Support System for Highland Basin Conservation and Rehabilitation, Upper Nan Basin Northern Thailand to be case study.

2.2 Data Collection

2.2.1 Types and Sources of Data

Available data and information related to the Spatial Decision Support Systems (SDSS) for Highland Basin Conservation and Rehabilitation especially Upper Nan Basin such as maps, statistic data, forest area, forest cover, income, soil erosion parameter, precipitation, sediment and other related data were collected by the offices of local authorities and relevant professional institutions. The types of data and their sources are shown in Table 12.

Table 12. Data collection and their sources for Spatial Decision Support Systems (SDSS) for sustainable watershed in Upper Nan Basin

Types of data collection	Year	Sources of data
1. Physical Data		
-Topography	1994	Geo-Informatics and Space Technology Development Agency(GISTDA)
-Precipitation	1977-2002	Meteorological Department(MD)
-Sediment		Land Development Department(LDD)
-Soil erosion	1977,1994,2002	Royal Irrigation Department(RID)
-Watershed Class map	1994	Office of the National Resource and Environmental Policy and Planning(OEPP)
2. Biological		
-Agricultural	1977,1994,2002	Department of Agricultural Extension(DOAE)
-Population	2001	Office of Agricultural Economic. Department of Local Administration.
-Forest cover and land-use	1977,1994,2002	Royal Forest Department(RFD) National Parks, Wildlife and Plants Conservation Department .
3. Income	2000-2002	Department of Agricultural Extension(DOAE) Office of Agricultural Economic. Department of Local Administration.

2.2.2 Land-use/ Land Cover Change Data

The categories of land cover in 1977, 1994 and 2000 that were interpreted from field observation processing with GIS technique consist of (1) forest, (2) upland crop (3) Trees, (4) paddy field, (5) urban and (6) water body. The definition and characteristics of each land cover type are described as follows:

P_1 (Forest): The permanent natural forest and reforestation. The main natural forest is *Evergreen forest (Hill Evergreen, Dry Evergreen and Pine forests) and Deciduous forest (Mixed Deciduous and Dipterocarps Deciduous forests)* type.

P_2 (Upland crop) : The permanent or temporary agriculture area that are mostly occurred in flat plain, lowland or highland including active shifting cultivation on highland. The upland crop includes upland rice, field crop and cash crops.

P_3 (Trees): The trees include plantation forest, horticulture, trees and grass land.

P_4 (Paddy fields): Paddy fields that are mostly occurred in flat plain lowland or highland including active shifting cultivation on highland.

P_5 (Urban): The built-up areas consisting of residential, industrial and commercial areas, and bare land.

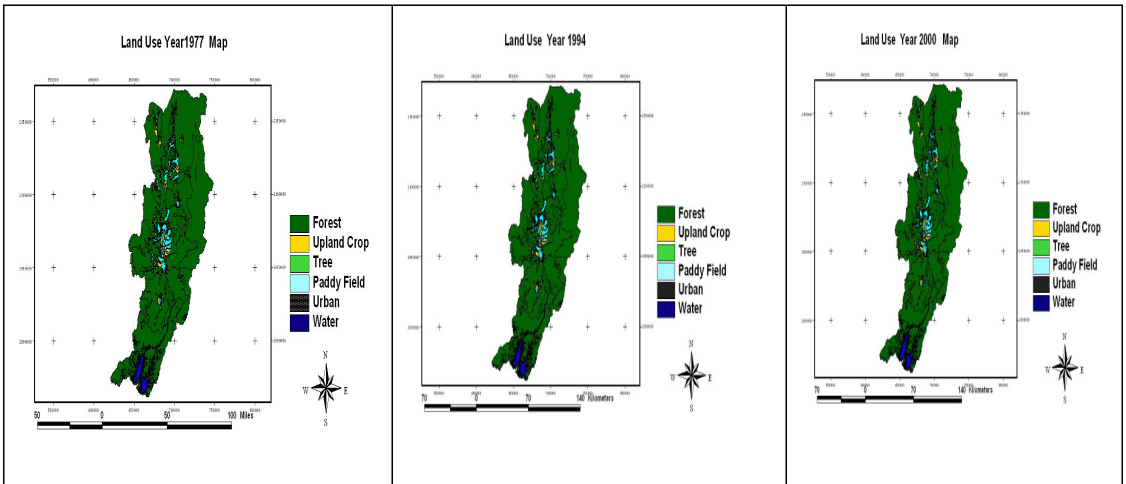
P_6 (Water body): The water bodies includes river, natural and man-made reservoir.

Based on data obtained from Upper Nan (Land Development Department, 2001) land-use and land cover types and their distribution in 1977, 1994 and 2000 in Upper Nan Basin are shown in Table 13, and Figure 14a,14b and 14c.

Table 13. Area of Upper Nan land-use and land cover types in 1977, 1994 and 2000.

Land cover types	1977		1994		2000	
	Area (ha)	Percent	Area (ha)	Percent	Area (ha)	Percent
1.Forest	1,187,475	90.44	1,098,900	83.69	773,750	58.93
2.Upland Crop	24,150	1.84	108,825	8.29	390,775	29.76
3.Tree	22,325	1.70	29,950	2.28	62,500	4.76
4.Paddy Field	53,950	4.11	38,675	2.95	48,675	3.71
5.Urban	250	0.02	11,275	0.86	11,300	0.86
6.Water Body	24,850	1.89	25,375	1.93	26,000	1.98
Total	1,313,000	100.00	1,313,000	100.00	1,313,000	100.00

Source: Department of Land Development (2001)



(a)Land-use in 1977 (b)Land-use in 1994 (c)Land-use in 2000

Source: Department of Land Development (2001)

Figure 14 Land-use in 1977 1994 and 2000, Upper Nan Basin

2.3 The Scenario Planning Process

The idea for the system design is to put the data, the model and the decision analysis process all together into the environment of the GIS. The GIS we use is Arcview, a GIS software package with a high-level object-oriented programming. Figure 15 shows the structure of the GIS-based DSS. Upper Nan basin is represented by spatial objects, which represents the real world entities, thematic objects which include the network, attributes, logical and policy relations and models. A mathematical programming model is generated based on the network, attributes, physical laws and control policies and users' interaction. In this study, the DSS can generate three models or three DSSs, the details in briefly as following;

OUNLP-DSS (Overall Upper Nan Land-use Planning DSS): The purpose of this DSS is to help decision maker to know how land-use change in overall of Upper Nan Basin both year-by-year between 1977 to 1994 and 1994 to 2000, and also trend in the future up to 2012 by using Markov Chain Model and Mathematical Model .

PSD-SDSS (Priority of Sub-watershed Degradation-SDSS): Practically watershed deterioration, improper and unwise utilization of watershed resources occurs throughout the watershed in varying degree i.e. higher in some places, moderate or low in other places even within the sub-watershed. Considering the watershed conservation work with limited time and budget, it is not feasible to take whole area at once especially in highland area where the deterioration occurs generally in terms of forest loss and land degradation by soil erosion. So the purpose of this SDSS is to prioritize Upper Nan sub-watershed based on its present condition, extent of degradation and sensitivity between forest loss and increment of soil loss in specified year for conservation work. The results obtained by integrating GIS with forest area (indicating forest loss) and USLE (indicating soil loss), determined by three parameters – Degradation speed index (DSI), Sensitivity index (SI) and Present environment impact index (PEI); rated by priority index; analyzed priority by weighting method and ranked thereafter, all can help decision maker or stakeholder to select priority sub-watershed for planning to conservation and rehabilitation according to their ranks.

OSLUR-SDSS (Optimal Sub-watershed Land-use Relocation-SDSS): The purpose of this SDSS is to help decision maker or stakeholder to reduce the conflicting use of land and water resources among the beneficiaries and affected groups . Two approaches were employed for mapping new location of allocated land-uses. First, linear programming was considered as a tool to optimize land-use allocation; then the derived results were applied as a criteria of spatial suitability in GIS environment. Since the linear programming (LP) and goal programming (GP) do not provide a spatial representation for the suggested land-use allocations or have no indication which specific hectares should be altered, but show only how many hectares proportion of each land-use should be changed; so the intention of this research is to mapping the allocation of land-uses by using GIS techniques with given criteria and calculate in Arc-view grid technique, then proceed step by step until meet all criteria requirements (complete desired land-use proportion from LP and GP results)

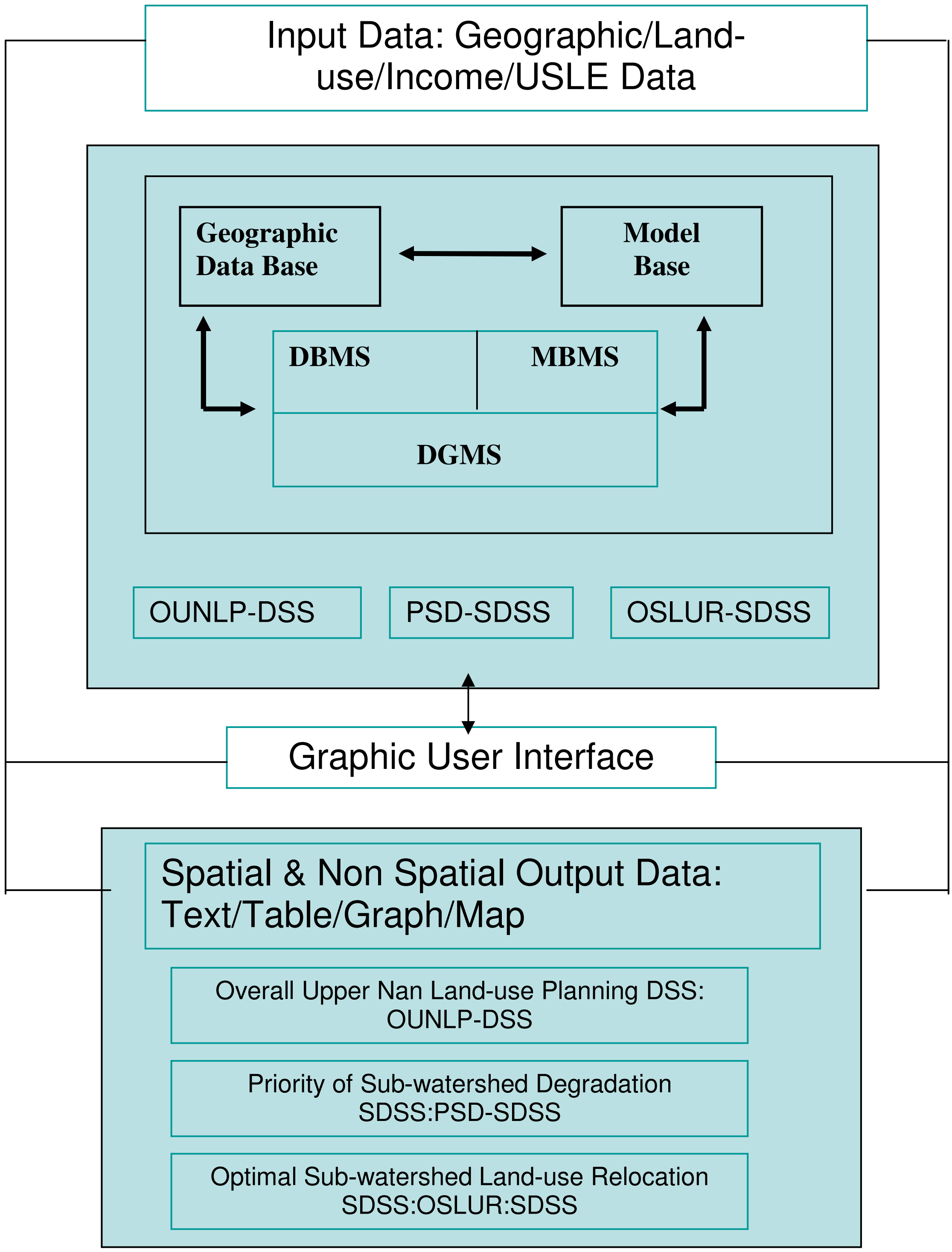


Figure 15. General methodology in development SDSS for highland basin conservation and rehabilitation, Upper Nan Basin Northern Thailand

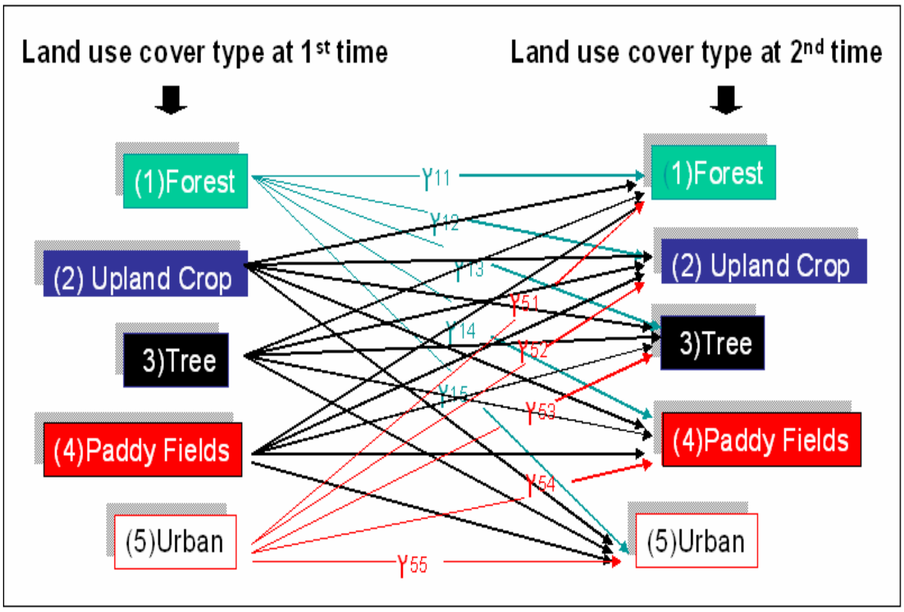
2.4 Overall Upper Nan Land-use Planning DSS: OUNLP-DSS

The purpose of this DSS is to help decision maker to know how land-use change in overall of Upper Nan Basin both year-by-year between 1977 to 1994 and 1994 to 2000, and also trend in the future up to 2012 by using Markov Chain Model and Mathematical Model .

2.4.1 Models for predicting annual land-use changes

Land cover map of 1977, 1994 and 2000 were obtained by Department of Land Development(DLD). Only 6 categories of land-use patterns including forest land (code=1), upland crops(code=3), tree(code=5), paddy field(code=7), urban (residential) area(code=9), and water bodies(code=11) are considered in this analysis and analyses of land-use (processes in ARCVIEW 3.1 and ArcviewGRID technique) the forest loss had been obtained.

In order to obtain year-by-year land-use changes, the Markov Chain model was applied to determine probability of land-use change based on the land-use evolution between two given periods. The general form of the model to predict land-use change from 1st date (year) to the 2nd date (year) is expressed herein as:



Where γ_{ij} : is probability of change determined from analyses in ArcviewGRID technique of two different periods of land-use map. The prediction of the next (forward and backward) period of land-use distribution can be expressed as:

$$\left(\text{Proportion of land use of the first date}\right) * \left(\text{Matrix of probability of land-use change}\right) = \left(\text{Proportion of land-use of the second date}\right)$$

This can be transformed (backward) in general matrix multiplication as:

$$[V_1, V_2, \ldots, V_5]_1 * \begin{pmatrix} \gamma_{11}, \gamma_{12}, \gamma_{13}, \ldots \ldots \gamma_{15} \\ \gamma_{21}, \gamma_{22}, \gamma_{23}, \ldots \ldots \gamma_{25} \\ . \\ . \\ \gamma_{51}, \gamma_{52}, \gamma_{53}, \ldots \gamma_{55} \end{pmatrix} = [V_1, V_2, \ldots, V_5]_2$$

In this studying, land-use and land cover changes in Upper Nan Basin, were approached using modeling techniques recommended by Chunkao and Rakariyatham (1997) steps in deriving year-by-year land-use proportion are:

(1) Land-use /land cover unit design

The term "Patch" (P), which is used to represent the homogenous appearance of plants community in the landscape that appears uniformly, was initially designed herein as:

P1 = Forest	P2 = Upland Crop
P3 = Tree	P4 = Paddy Field
P5 = Urban	P6 = Water Body

(2) Rule for change between periods

Changes in land-use and land cover in each Patch at any given time vary implicitly according to interaction between of population, technology, education, economic and policy. In this study, at time t_1, area of each Patch is a function of a coefficient (c_i) at t_1 and the patch area (AP_i) at time t_o which can be simply written as:

$$(AP_1)_{t1} = c_1\ AP_{1(to)} \qquad (21)$$

$$(AP_2)_{t1} = c_2\ AP_{2(to)} \qquad (22)$$

$$(AP_3)_{t1} = c_3\ AP_{3(to)} \qquad (23)$$

$$(AP_4)_{t1} = c_4\ AP_{4(to)} \qquad (24)$$

$$(AP_5)_{t1} = c_5\ AP_{5(to)} \qquad (25)$$

$$(AP_6)_{t1} = c_6\ AP_{6(to)} \qquad (26)$$

where

c_1 to c_5 is land-use and land cover change coefficients;

t = time;

AP_1 to AP_6 is area for P_1 to P_6.

Thus, the equation (1) to (5) can be generally re-written as:

$$(AP_n)_{(t+1)} = c_n AP_{n\,(t)} \tag{27}$$

For the year 1977, 1994 and 2000, the size of area under investigation considered as a function human activities can be expressed as:

$$1977\text{: } A_{(t1)} = AP_{1\,(t1)} + AP_{2\,(t1)} + AP_{3\,(t1)} + AP_{4\,(t1)} + AP_{5\,(t1)} \tag{28}$$

$$1994\text{: } A_{(t2)} = AP_{1\,(t2)} + AP_{2\,(t2)} + AP_{3\,(t2)} + AP_{4\,(t2)} + AP_{5\,(t2)} \tag{29}$$

$$2000\text{: } A_{(t3)} = AP_{1\,(t3)} + AP_{2\,(t3)} + AP_{3\,(t3)} + AP_{4\,(t3)} + AP_{5\,(t3)} \tag{30}$$

where

$A_{(t1)} = A_{(t2)} = A_{(t3)}$ = total study area (Upper Nan Basin area).

(3) Estimating annual change of land-use units

Changing in land-use and land cover in each Patch at any given time (t_1) varies according to the change (Δ) of population, technology, education, economic and policy among the time interval ($t_o - t_1$). For this study, between the time $t_o - t_1$, the changes between different patches are expressed in Table 14.

Table 14. Matrix coefficient land-use and land cover change between time t_o to t_1.

to t_1	P_1	P_2	P_3	P_4	P_5	P_6
P_1	γ_{11}	γ_{12}	γ_{13}	γ_{14}	γ_{15}	γ_{16}
P_2	γ_{21}	γ_{22}	γ_{23}	γ_{24}	γ_{25}	γ_{26}
P_3	γ_{31}	γ_{32}	γ_{33}	γ_{34}	γ_{35}	γ_{36}
P_4	γ_{41}	γ_{42}	γ_{43}	γ_{44}	γ_{45}	γ_{46}
P_5	γ_{51}	γ_{52}	γ_{53}	γ_{54}	γ_{55}	γ_{56}
P_6	γ_{61}	γ_{62}	γ_{63}	γ_{64}	γ_{65}	γ_{66}

Change of patch P_1, between $t_o - t_1$, to other land-use can be logically expressed as:

$$(AP_1)_{t1} = c_1 AP_{1(to)}$$

$$= AP_{1(to)} - \gamma_{12}AP_{1(to)} - \gamma_{13}AP_{1\,(to)} - \gamma_{14}AP_{1\,(to)} - \gamma_{15}AP_{1(to)} - \gamma_{16}AP_{1(to)} + \gamma_{21}AP_{2\,(to)} + \gamma_{31}AP_{3\,(to)} + \gamma_{41}AP_{4\,(to)} + \gamma_{51}AP_{5\,(to)} + \gamma_{61}AP_{6\,(to)} \qquad (31)$$

In the same manner, change of patch P_2, P_3, P_4, P_5, between t_o- t_1, to the others land-use patches can be expressed as:

$$(AP_2)_{t1} = c_2 AP_{2(to)}$$

$$= AP_{2(to)}) - \gamma_{21}AP_{2(to)} - \gamma_{23}AP_{2\,(to)} - \gamma_{24}AP_{2\,(to)} - \gamma_{25}AP_{2(to)} - \gamma_{26}AP_{2(to)} + \gamma_{12}AP_{1\,(to)} + \gamma_{32}AP_{3\,(to)} + \gamma_{42}AP_{4\,(to)} + \gamma_{52}AP_{5\,(to)} + \gamma_{62}AP_{6\,(to)} \qquad (32)$$

$$(AP_3)_{t1} = c_3 AP_{3(to)}$$

$$= AP_{3(to)} - \gamma_{31}AP_{3(to)} - \gamma_{32}AP_{3\,(to)} - \gamma_{34}AP_{3\,(to)} - \gamma_{35}AP_{3(to)} - \gamma_{36}AP_{3(to)} + \gamma_{13}AP_{1\,(to)} + \gamma_{23}AP_{2\,(to)} + \gamma_{43}AP_{4\,(to)} + \gamma_{53}AP_{5\,(to)} + \gamma_{63}AP_{6\,(to)} \qquad (33)$$

$$(AP_4)_{t1} = c_4 AP_{4(to)}$$

$$= AP_{4(to)} - \gamma_{41}AP_{4(to)} - \gamma_{42}AP_{4\,(to)} - \gamma_{43}AP_{4\,(to)} - \gamma_{45}AP_{4(to)} - \gamma_{46}AP_{4(to)} + \gamma_{14}AP_{1\,(to)} + \gamma_{24}AP_{2\,(to)} + \gamma_{34}AP_{3\,(to)} + \gamma_{54}AP_{5\,(to)} + \gamma_{64}AP_{6\,(to)} \qquad (34)$$

$$(AP_5)_{t1} = c_5 AP_{5(to)}$$

$$= AP_{5(to)} - \gamma_{51}AP_{5(to)} - \gamma_{52}AP_{5\,(to)} - \gamma_{53}AP_{5\,(to)} - \gamma_{54}AP_{5(to)} - \gamma_{56}AP_{5(to)} + \gamma_{15}AP_{1\,(to)} + \gamma_{25}AP_{2\,(to)} + \gamma_{35}AP_{3\,(to)} + \gamma_{45}AP_{4\,(to)} + \gamma_{65}AP_{6\,(to)} \qquad (35)$$

$$(AP_6)_{t1} = c_5 AP_{6(to)}$$

$$= AP_{6(to)} - \gamma_{61}AP_{6(to)} - \gamma_{62}AP_{6\,(to)} - \gamma_{63}AP_{6\,(to)} - \gamma_{64}AP_{6(to)} - \gamma_{65}AP_{5(to)} + \gamma_{16}AP_{1\,(to)} + \gamma_{26}AP_{2\,(to)} + \gamma_{36}AP_{3\,(to)} + \gamma_{46}AP_{4\,(to)} + \gamma_{56}AP_{5\,(to)} \qquad (36)$$

where

$(AP_1)_{t1}$ = Area of patch P_1 at time t_1

$(AP_1)_{to}$ = Area of patch P_1 at time t_0

c_1 = Coefficient of change for patch P_1 which implicitly caused by human dimension in the study area during period t_o to t_1.

γ_{ij} = Coefficient indicating, probability of land-use change from patch P_i to patch P_j.

In equation (30) "plus (+)" indicates the transformation from Patch "P_2, P_3, P_4, P_5, P_6" to Patch P_1, and "minus (-)" indicates the conversion from Patch P_1 to Patch "P_2, P_3, P_4, P_5, P_6". The other equation the same pattern of "plus (+)" and "minus (-) explain the transformation according to γ_{ij} and AP_i.

2.5 Priority of Sub-watershed Degradation SDSS:PSD-SDSS

Forest change to agricultural land has a significant influence on soil erosion and catchments hydrology. In Thailand, an estimated 30 percent of the land area is moderately to severely eroded, according to the Department of Land Development. Erosion reduces not only the soil's depth, but also its capacity to hold water and the amount of nutrients it contains. It also has serious consequences downstream-polluting drinking water, silting up rivers and irrigation systems, degrading coastal ecosystems. To estimating the forest and soil loss of the watershed, and to prioritize the sub-watershed based on its present condition, extent of degradation and sensitivity and to recommend the sub-watershed conservation activities, an integrated approach of digital image processing of satellite data and visual interpretation of aerial photograph combined with GIS and USLE was carried out for land cover change and soil loss estimation. The methodology as shown in Figure 16 as following;

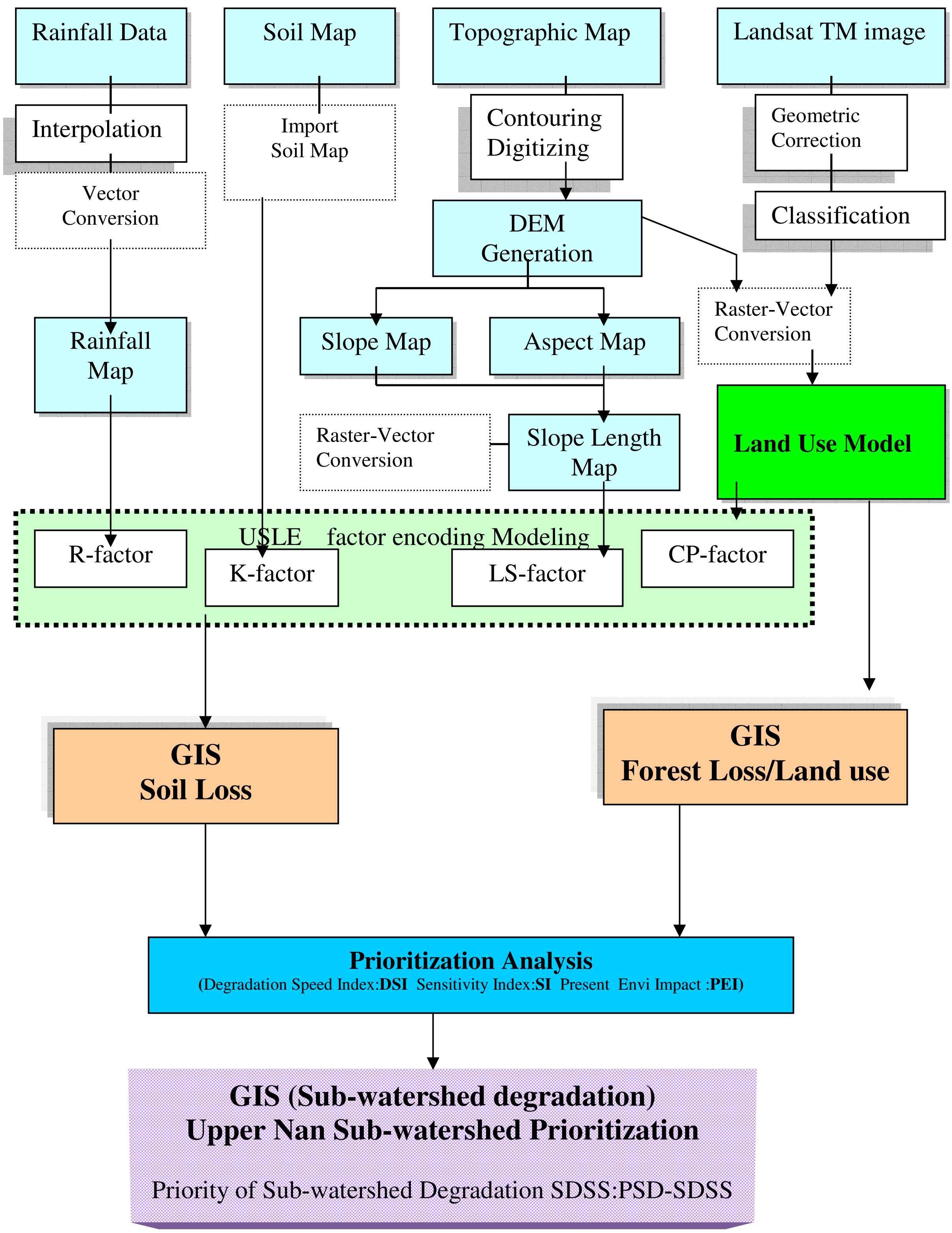


Figure 16. Land-use & USLE Model in conjunction with RS & GIS to estimate land-use change and soil erosion

2.5.1 Delineation of Sub-watershed in Upper Nan Basin

From the topographic map in scale 1:50,000., 9 sub-watersheds were delineated and after the main river of that subwatshed (Figure 17). The forest cover of the sub-watershed and the soil loss status were taken as the basis for their prioritization. Furthermore, the contribution from each sub-watershed to the total amount of soil loss from whole watershed area was also considered for such evaluation.

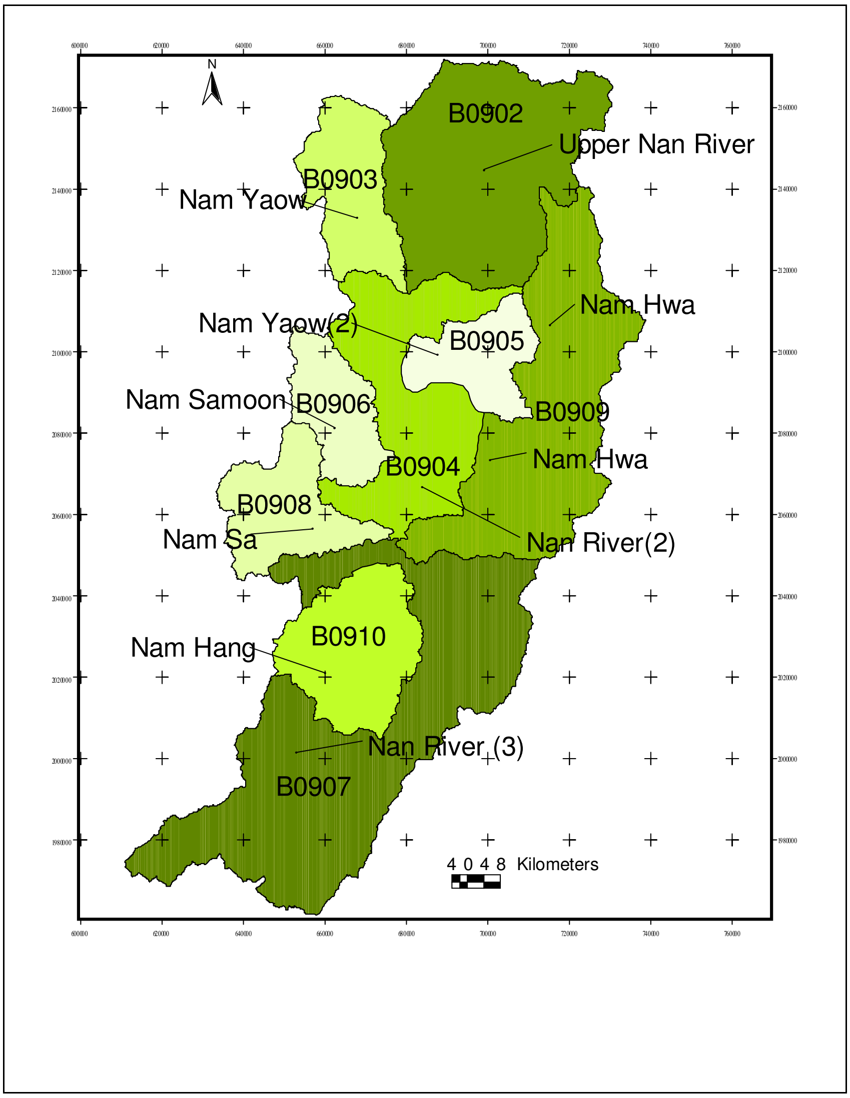


Figure 17 Map of 9 sub-watersheds, Upper Nan Basin

2.5.2 Defining the Parameters and Formulating Indices (Condition Indicator)

1) Degradation Speed Index (DSI)

The soil and forest are main resources of the watershed. Their amount of change in specified period of time is the indication of the status changing speed. So by assessing the forest and soil loss change between 1977 and 2000 and contribution to the total soil loss from each sub-watershed. DSI has been formulated (Sah et al, 1997). The DSI is defined as the degradation speed of the sub-watersheds.

DSI = 0.35*forest change (%) + 0.35 *rate of soil loss change (t/ha/yr.)
+0.25*contribution to soil loss change (%) (37)

The weight of individual factor has been decided on the basis of their importance to the land degradation. The equation (37), Sah studied in the Eastern Region of Nepal. For head forest watershed in Upper Nan Basin, the deterioration occurs generally in terms of forest loss and land degradation by soil erosion, the weight of individual factor for forest change*0.45, rate of soil loss change* 0.45 and contribution to soil loss change* 0.10 because contribution to soil loss change it depended on the size of sub-watershed. The modified DSI that suitable for head forest watershed as shown in equation (38)

DSI = 0.45*forest change (%) + 0.45 *rate of soil loss change (t/ha/yr.)
+0.10*contribution to soil loss change (%) (38)

2) Sensitivity Index (SI)

Impact of forest loss in sub-watersheds causes various level responses, which is soil loss increase in this case. It depends on the characteristics such as steepness of sub-watersheds, way of cutting tree or deforestation area. For example forest loss in steep slope is more critical than in flat area. To assess this characteristic, land sensitivity had been proposed and SI is defined.

SI = Soil loss increment (t/ha/yr.)/Forest loss (%) (39)

3) Present Environment Impact Index(PEI)

The soil erosion rate of in the year 2000 is considered as PEI of the sub-watersheds. Among several indicators, the higher rate of soil erosion can be considered as one indicator of the conditions of the sub-watershed.

PEI = Soil loss in present year (t/ha/yr.) (40)

2.5.3 Estimating Forest Loss and Soil Loss using GIS and RS

An integrated approach of digital image processing of satellite data and visual interpretation of aerial photograph as well as land-use map in 1977 and 2000 combined with GIS and USLE was carried out for land cover change (Forest loss) and soil loss estimation. By using these data, the general methodology was followed as presented in Figure. 17

1) Estimating Forest Loss

Land-use data in 1977 and 2000 combined with GIS technique was carried out for land cover change (Forest loss).

2) Estimating on –site Soil Loss using USLE model and GIS

The purpose of this method is to establish spatial information of soil erosion using the Universal Soil Loss Equation (USLE) and GIS. From USLE, soil loss is the function of six different factors as shown in the following equitation. The preparations of data for input to the equitation are discussed here under.

A=R*K*L*S*C*P

Where, A= computed soil loss per unit area (tons/ ha / yr)

R= Rainfall erosivity Index
K= Soil erodibility
L= Slope length
S= Slop steepness
C= Cover types
P= Management and Conservation practice

Annual on-site soil erosion of Upper Nan Basin in particular year was estimated based on USLE in equation 3. The parameters in USLE were calculated using the following investigation:

(1) Rainfall Erosivity (R) Factor

In this research, the values of rainfall erosion index generally equals R for the soil loss equation directly from report "Vietnam soil erosion map" of Tran and Nguyen (1999). Based on annual rainfall (P), following Roose (1975) equation:

$$R = 0.5 \times P \times 1.73 \qquad (41)$$

(2) The soil erodibility factor, K-Factor.

In Upper Nan Basin, the soil erodibility factor (K-factor) was based on equation suggested by Wischmeier and Smith (1978), and computed from mean analytical results determined from soil samples.

$$100K = [\ 2.1 * 10 -4\ (\ 12-a\ )\ M1.4 + 3.25\ (b-2) + 2.5\ (\ c-3)] \qquad (42)$$

Where, a = % of organic matter b = soil structure class c = soil permeability class
M= (% silt + % very fine sand) or (100- % clay)

The soil erodibility (K-factor) in Upper Nan Basin was determined by Department of Land Development (2001). Based on termed as soil erodibility is the integrated effect of processes that regulate rainfall acceptance and the resistance of the soil to particle detachment and subsequent transport. These processes are influenced by soil properties, of which soil texture is an important factor that affects to the erodibility.

(3) The topographic factors, L and S.

Digital topographic data for the Upper Nan Basin were obtained by digitizing sheets of topographic maps of scale 1:50,000. The contours were digitized separately and used to build up the DEM (Digital Elevation Model) of the watershed. The contour interval used was 20 m, taking into account available computer memory and technology at the time in Thailand. A grid cell of 500 m was used in building the DEM, as this was considered to be less than the maximum slope length, based on reconnaissance surveys. The resulting DEM was used to determine the slope steepness and slope length in ArcView GRID.

The calculation equation of L - factor and S – factor is:

$$L = (\lambda/22.13)^{0.5} \qquad (43)$$

where

λ = slope length (ft), and

$$S = 0.065 + 0.045\ s + 0.0065\ s^2 \qquad (44)$$

where

s = percent slope ,

Finally, the calculation equation of LS – factor as follows:

$$LS = (\lambda/22.13)^{0.5} \times (0.065 + 0.045\ s + 0.0065\ s^2) \qquad (45)$$

(4) Cover and Management factor, CP - factor.

CP – factor in this research based on C-factor was found out by Wishmeier and Smith, (1978), Morgan and Finney, (1982).

From Figure 17, the USLE-GIS integration can be established by converting all parameters of USLE into a raster-based format and by evaluating these digital parameter layers. Each parameter (R, K, C, P) and topography (LS) are digitized from the associated maps. LS factor of the watershed is derived from digital elevation model (DEM) obtained from topography. Then, the digital maps in vector format are converted into raster format in which each parameter of a specific pixel is known. The USLE equation is applied to five digital parameter-layers (R, K, C, P, and LS) by overlaying them. It must be noted that the results are more reliable when small grid sizes are selected, since USLE is essentially developed for analysis of small areas, preferably those at farmland scale.

2.5.4 Prioritization Analysis

As discussed earlier, the DSI, SI and PEI were taken as the condition and used for the prioritization analysis by weighting method in GIS technique. To create this method, Firstly, the range of quantitative value has been defined for qualitative value (Max – Min / Number of Range). Secondly, from the qualitative rating, DSI, SI and PEI had been done by equal interval technique and they were grouped into 5 classes as following: very low, low, medium, high, very high and the group has been decided on the basis of the logical combination of the indicators. Lastly, prioritization analysis by weighting DSI*0.30+SI*0.40 +PEI*0.30 in 5 class of three indexes in GIS technique to prioritize and create mapping, which is spatial distribution of 9 sub-watershed Upper Nan Basin mapping for conservation prioritization work. The SI was considered to be first priority in head watershed because it's higher value indicating critical condition of watershed. The DSI and PEI value were considered to be the second priority with the same weighting value because of their secondary importance to watershed degradation than SI value.

2.6 Optimal Sub-watershed Land-use Relocation-SDSS

2.6.1 Modelling for Land-use Suitability and Land Allocation for Maximizing Economic

The objective of this scenario is to establish the optimal land-allocation for each of the competing land-uses within each of the Sub--watershed of Upper Nan Basin. This scenario utilizes is based upon a similar methodology put forth by Chuvieco (1993), which integrates linear programming and GIS for land-use modelling. The allocation for maximizing economic scenario approach is shown in Figure 18.

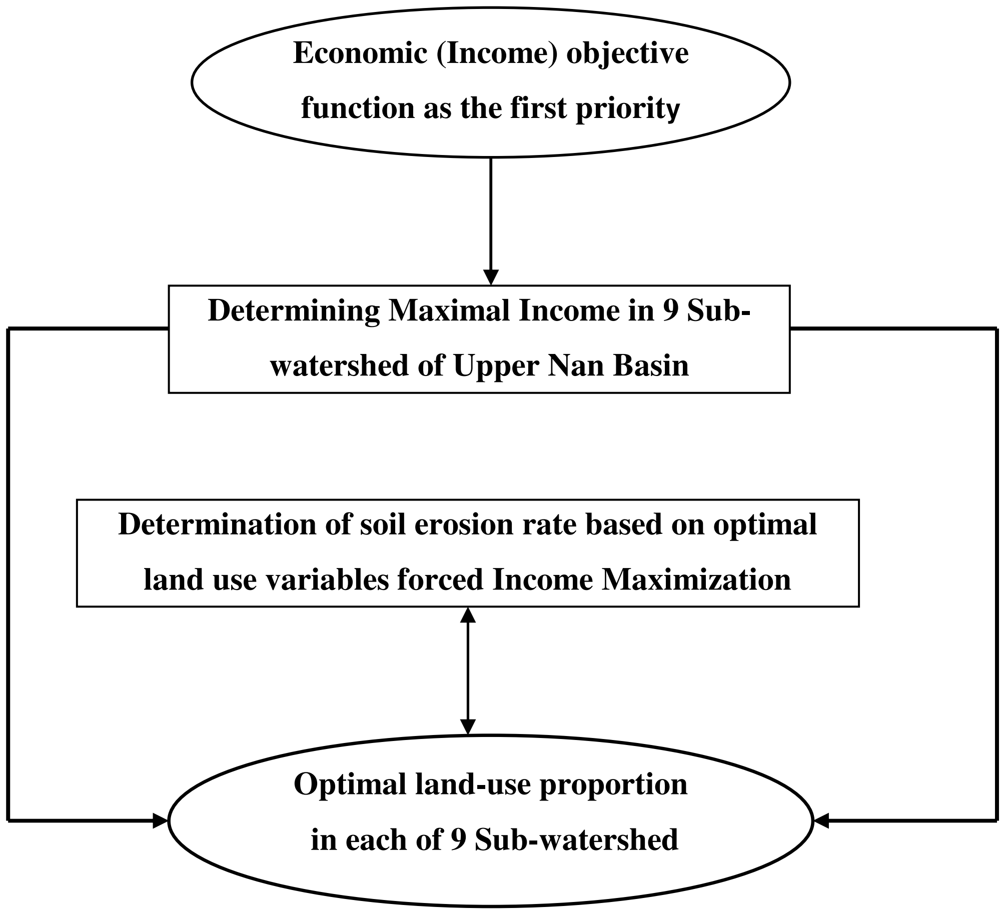


Figure 18. Land allocation for maximizing economic

The optimal land allocation of each land-use categories within each of the Sub--watershed of Upper Nan Basin based upon the constraints put forth in the model which include: environmental protection, existing agricultural land, minimum soil loss, and maximum income. The land transition rules and a land-use/ compatibility matrix have been used to decide the most suitable location of the projected land demand with respect to land supply in each of the Sub--watershed of Upper Nan Basin. Steps in obtaining this scenario results are described hereafter:

1) <u>Data Acquisition and Model Building</u>

In each of the Sub--watershed of Upper Nan Basin, data for building the model for this objective are rather limited. The objective functions developed for this purpose are based on the best available data, thus only two objective functions, net income and soil erosion function. Only 8 categories of land-use patterns (i.e. 8 decision variables), including forest land (X_1), forest plantation(X_2), upland crops(X_3), tree(X_4), paddy field(X_5), grass land(X_6), urban (residential) area(X_7), and water bodies(X_8) are considered in this analysis. In addition, direct income by land development is included as the economic indicators in the objective function. The types of environmental impacts(soil erosion) were selected as a control part of land-use planning that reflects directly the needs of the current watershed.

Much physical, environmental, and economic data for land resource and watershed management were compiled to build up the objective function. Economic database information was mainly collected from government agencies. After such a series of environmental and economic investigations the coefficients of the two objectives function are derived for using in the model formulation. The mentioned objectives have to be optimized and coordinated with site specific information, such as the specified value of land availability, required minimum upland crops area, required forest plantation, etc.

The objective functions that need to maximize or minimize under the given constraints are as follows:

- **Goal constraints**

(1) Maximize watershed inhabitants net incomes (Bath/yr)

$$MaximizeZ\ 1 = \sum_{j=1}^{n} fjXj \tag{46}$$

(2) Minimize soil loss (ton per hectare per year)

$$MinimizeZ\ 2 = \sum_{j=1}^{n} gjXj \tag{47}$$

- **Hard constraints**

(1) Watershed area (ha) constraint: The maximum area in each of the Sub--watershed of Upper Nan Basin(9 sub-watershed) allowed in developing various land-use programs is shown in Table 15

(2) Forest area (ha) constraint: The Government regulation requires that the minimum forest area should be not less than 40 % watershed area in Upper Nan Basin, but for the purpose of natural resource conservation. The forest area (ha) constraint in each of sub-watershed not less than forest area in year 2000 which are shown in Table 15

(3) Minimum Forest plantation: The forest plantation area (ha) constraint in each of sub-watershed not less than plantation forest area in year 2000 which are shown in Table 15

(4) Agricultural area constraint : Agricultural area constraint which consist of fruit tree, upland crop and paddy fields. Its constraint depend on the area of watershed class 3-5 in each of sub-watershed and fruit tree area(x3) plus upland crop area(x4) plus paddy fields area(x5) constraints not more than total area of watershed class 3-5

(5) Grass land,Urban and water bodies area constraint: Because of little change of land-use (Grass land, Urban and water bodies area) in year 1994 to 2000. So, these area constraint have to be fixed in the same area in 2000

According to local government policy and watershed class area in each of sub-watershed class, the minimum of constrain in (3) to (4) are shown in Table 15

(6) Non-negative constraint: All the decision variables must be non-negative

$$X_j \geq 0 \tag{48}$$

In the above formulation:

X_j = Decision variables refer to various land-use types for j = 1, 2, 3….,n (ha)

The coefficient of decision variables are defined as:

f_j = Watershed inhabitants gross incomes (Bath/yr)

g_j = soil erosion rate(ton per hectare per year)

The objective functions of the above GP model corresponding to watershed management scale can be stated as a function of deviation variables or achievement function. The closer deviation from the target levels the more chance to achieve their goals. Thus, the minimization technique is applied by the followings:

U_1,V_1 = Under and over achievement of income;

U_2, V_2 = Under and over achievement of soil erosion rate.

Minimize $Z = U_1 + V_2$

Z = Overall achievement deviation of objective.

Table 15 Decision variables and hard constraints

Decision Variables	Hard Constrains(Hectare)								
	B0902	B0903	B0904	B0905	B0906	B0907	B0908	B0909	B0910
X_1(Forest)	=107,811	= 39,666	= 67,226	= 30,601	= 30,743	= 244,678	= 58,403	= 147,364	= 47,948
X_2(Plantation)	>= 534	>= 2,523	>= 3,364	>= 0	>= 3,019	>= 4,885	>= 46	>= 161	>= 4,532
X_3(Upland crops)	>= 14,265 <= 72,852	>= 4,699 <= 54,694	>= 34,649 <= 122787	>= 1,930 <= 38,653	>= 9,538 <= 46,735	>= 9,008 <= 178093	>= 10,479 <= 50,649	>= 3,200 <= 52,837	>= 21,364 <= 80,219
X_4(Trees)	>= 1,100	>= 56	>= 13,955	>= 1,946	>= 3,574	>= 1,744	>= 518	>= 330	>= 600
X_5(Paddy Fields)	>= 7,488 <= 13,471	>= 254 <= 2,147	>= 18,219 <= 33,965	>= 395 <= 2651	>= 7,223 <= 7,600	>= 2,737 <= 25,572	>= 117 <= 3,416	>= 1,357 <= 8,104	>= 3,154 <= 4,748
X_6(Grass Land)	= 2,479	= 1,841	= 9,053	= 479	= 1,102	= 1,100	= 1,967	= 440	= 1043
X_7(Urban)	= 2,446	= 261	= 3,704	= 404	= 971	= 1439	= 366	= 276	= 940
X_8(Water Bodies)	=601	= 95	= 1,113	= 185	= 19	= 23295	= 289	= 873	= 149
$X_3 + X_4 + X_5$	<= 60,530	<= 50,014	<= 93,376	<= 36,591	<= 37,029	<= 175,755	<= 47,539	<= 52,945	<= 76,420
X_j(total)	<= 222,221	78,810	152,874	61,131	59,158.9	339,580.2	77,848	220,950	104,493.7
X_1 ,X_2 ,X_3 ,X_4 X_5 ,X_6 ,X_7 ,X_8	> 0	> 0	> 0	> 0	> 0	> 0	> 0	> 0	> 0

2) Solution Techniques

The goal programming and compromise programming using the criteria of minimum distance from the ideal solution are observed to be ranked first in solving various multi-objective watershed resource problems. Thus, the non-inferior solutions and trade-offs among the objectives in this analysis are accordingly examined using goal programming and compromise programming techniques.

In solving resources allocation using linear programming, the dimensionless function which is the relative measure of the decision maker's preference is the most compromising one. The equation is:

$$\text{Min } d_a = \text{Min } \left\{\sum_{k=1}^{p} \lambda_k^a \left(\frac{Z_k^*(x) - Z_k(x)}{Z_k^*}\right)^a\right\}^{1/a} \qquad (49)$$

Where $\quad 1 < a < \infty, \lambda_k^a > 0; \ \sum_{k=1}^{p} \lambda_k^a = 1$

The parameter "*p*" represents the total number of objectives, and λ_k^a is the corresponding weight of each objective. For a = 2 (i.e. which is the case of d_2), the problem becomes a linear program and the LINDO software package can be employed as a solver in this analysis. While a = 3 (i.e. which is the case of d_3), the solution will be the non-inferior feasible solution which is closest to the ideal solution Z_k^x in terms of a weighted geometric distance. In this situation, the LINGO software package can be employed. If $a = \infty$ (i.e. which is the case of d_x), the model can be transformed into a linear programming model in which the largest weighted deviation determines the preferred solution and the situation among trade-off mechanics turns out to be not only competitive but non-compensatory.

2.6.2 Relocating Land-use Allocation Mapping

Based on results from linear programming, and goal programming of the two objectives(Maximize income and Minimize soil loss), the final step of this research is to mapping the location of land-uses allocated by using GIS techniques with the given criteria. Since the linear programming (LP), and goal programming (GP) do not provide a spatial representation for the suggested land-use allocations only how many hectares proportion of each land-use should be changed, but have no indication which specific hectares should be altered. Thus, two approaches were employed for mapping new location of allocated land-uses. First, linear programming was considered as a tool to optimize land-use allocation; then the derived results was applied as a criteria of spatial suitability in GIS environment.

In order to obtain the necessary information for setting up the above criteria, some of the land-use types 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 provides a value for the area which meets all the criteria requirements. For instance, about 5% watershed area that should be changed from any land-use to new forest plantation land can be located by selecting auxiliary variables. The same fashion 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 located. In other word, from all the grid cells of land-use (excepted existing forest, grassland, urban and water bodies because these land-use is fixed proportion constrain from LP and GP), which these grid cell should be selected to transform to same land. The selection of another remain cells is performed using 5 criteria variables: watershed class (1-5), land-use area in year 2000(1-8), %slope(1-5), rate of soil loss(1-5) and land-use area in year 1977(1-8. Besides 6 criteria variables, we can set up one - that is distance of local area from the existing forest land to new forest plantation land, if above 5 variables could not meet new forest plantation land area we need. The selection of transition cells from any land-use to a new land-use is performed in a similar manner. For example in the new additional forest plantation land could be found out by setting the criteria in the first selecting step (this method export to Excel software Program) : (i) watershed class should be wsc 1-3 (ii) land-use area in year 2000 should be Upland Crops or Paddy fields or tree /fruit tree (iii) % slope should be between 16 to 35 or more than 35 % (iv) rate of soil loss should be class 1-2 (more than 93-125 ton/hectare/year). Table 16 show land use criteria and ranking type of land use in Grid Cell Code and Figure 19 show max-min value of grid cell such as 1111312 which indicating this grid cell located on WSC1, slope > 35%, soil loss>125 ton/ha/y, land use in 1977 was forest, land use in 2000 was upland crop and 12 indicating this grid cell located on administrative area class 12. So the suitable area for this cell should be forest plantation and tree.

The algorithm of conceptual framework for relocating land-use map of Upper Nan Basin after optimization is presented in Figure 20.

Table 16 Land-use criteria and ranking type of land-use in Grid Cell Code

Land -Use Criteria		
Watershed class	WSC-Code	Ranking type of Land-use in Grid Cell Code
1	1	1.Nation Forest 2.GrassLand 3.Forest Plantation 4.Tree/fruit tree
2	2	1.Forest plantation 2.Tree/fruit tree
3	3	1.Forest Plantation 2.Tree/fruit tree 3.Upland Crops
4	4	1.Tree/fruit tree 2.Upland Crop
5	5	1.Upland Crop 2.Paddy Fields 3.Water bodies
Slope(%) Class	Slope-Code	Ranking type of Land Use in Grid Cell
> 35 %	1	1.Forest Plantation 2.Tree/fruit tree
13-35 %	2	1.Forest Plantation 2.Tree/fruit tree
6-13 %	3	1.Forest Plantation 2.Tree/fruit tree 3.Upland Crops
3-6 %	4	1.Tree/fruit tree 2.Upland Crop
0 -3 %	5	1.Upland Crop 2.Paddy Fields 3.Water bodies 4.Urban
Rate of Soil Loss(Ton/ha/year)	Soil Loss-Code	Ranking type of Land Use in Grid Cell
>125	1	1.Forest Plantation
93.75-125	2	1.Forest Plantation 2.Tree/fruit tree
31.25-93.75	3	1.Forest Plantation 2.Tree/fruit tree 3.Upland Crops
12-31.25	4	1.Forest Plantation 2.Tree/fruit tree 3.Upland Crops
0-12.5	5	1.Upland Crop 2.Paddy Fields 3.Water bodies 4.Urban
Land-use data base Class 1977 and 2000	LU-Code	Ranking type of Land-Use in Grid Cell Code
1. Nation Forest	1	1.Nation Forest
2 .Forest plantation	2	1.Forest plantation
3. Upland Crops	3	1.Forest plantation 2.Tree/fruit tree 3.Upland Crop
4. Tree/fruit tree	4	1. Forest plantation 2.Tree/fruit tree 3.Upland Crop
5. Paddy Fields	5	1. Paddy Fields 2.Upland Crop 3.Water bodies 4.Forest plantation 5.Tree/fruit tree
6.Grassland	6	1.Grassland
7.Urban	7	1.Urban
8.Water Bodies	8	1.Water Bodies
Local Administration area	Code 1-29	

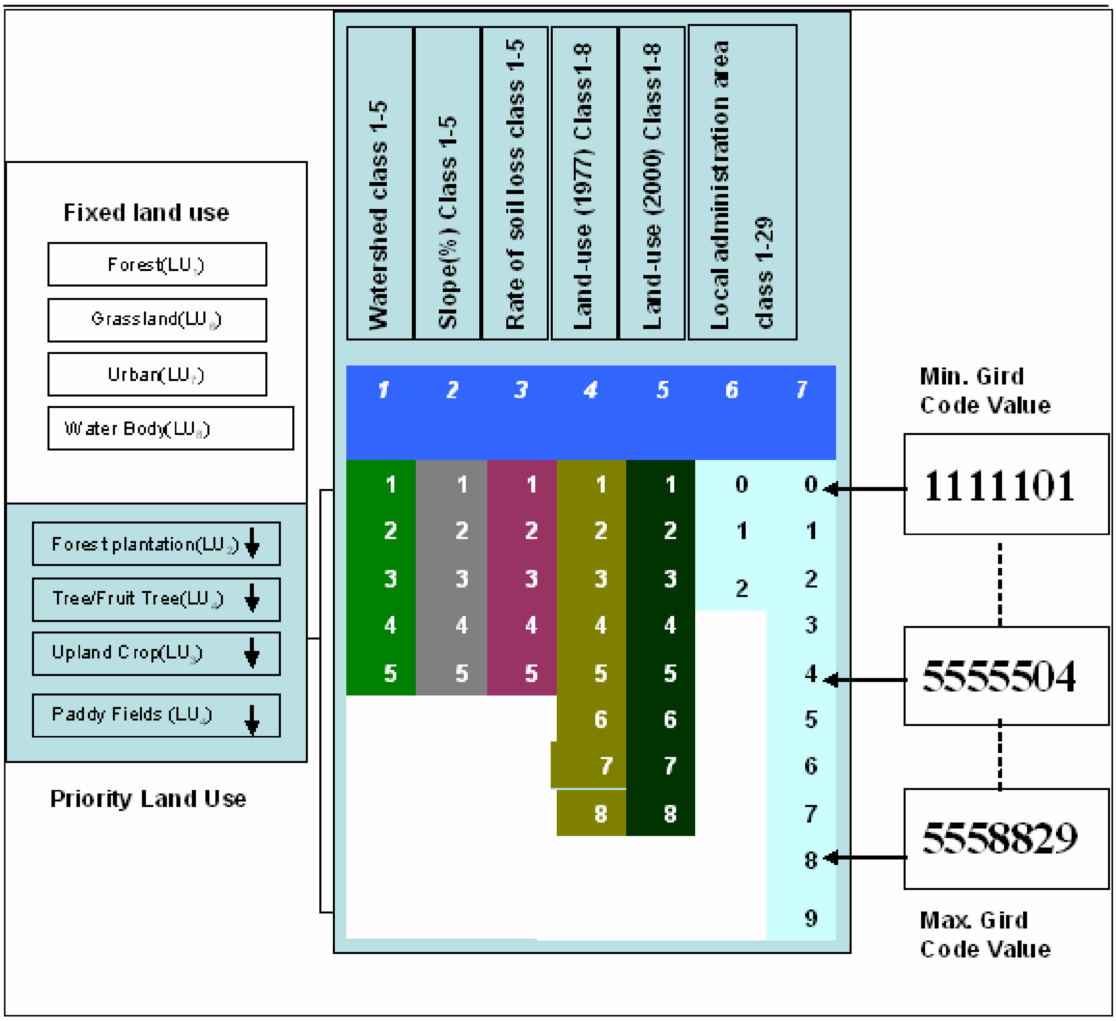


Figure 19 Land-use criteria and ranking type of land-use in Grid Cell Code

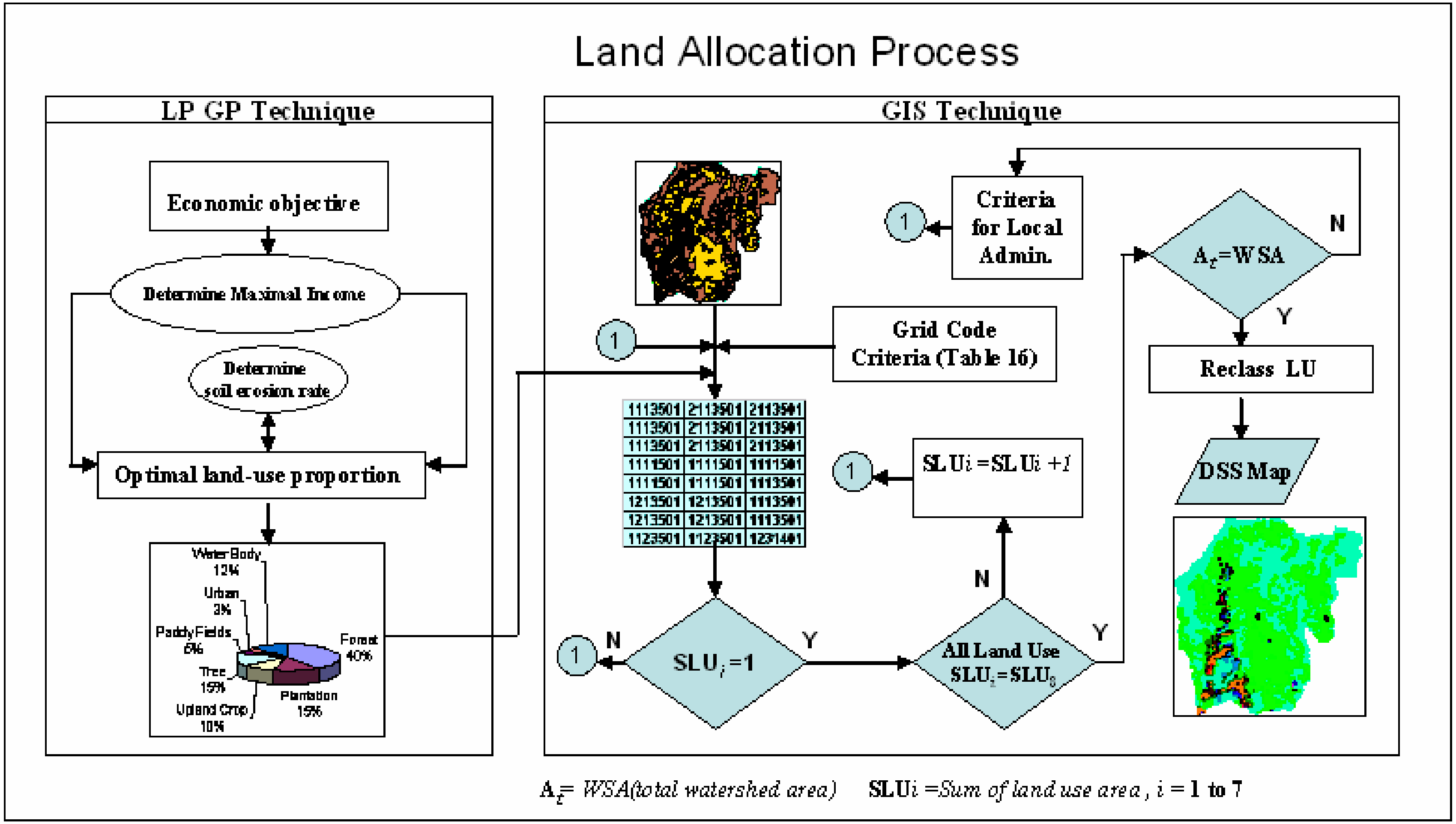


Figure 20 Conceptual frameworks for algorithm development to relocate land-use map in Upper Nan Basin

RESULTS AND DISCUSSION

1.Overall Upper Nan Land-use Planning DSS: OUNLP-DSS

1.1 Land-use and Land Cover Changes (LUCC) between 1977 and 1994

The LUCC between 1977 and 1994 conducting by matrix operation are shown in Table 17, Table 18 and Table 19 in the form of coincident matrix. The LUCC between 1977 to 1994 can be briefly described as follows:

- Forest: About 76,350 ha (6.4%) forest area in 1977 were converted to Upland crop in 1994, while about 8,025 ha, and 10,050 ha forest area in 1977 were minor changes to Tree and Paddy Fields in 1994.
- Upland crop: The upland crop areas of about 5,275 ha in 1977 were largely changed to forest land in 1994.
- Tree/Forest Plantation: The area of Tree/Forest Plantation about 5,500 ha in 1977 was change to upland crop area in 1994.
- Paddy Fields : The Paddy Fields areas of about 15,275 ha in 1977 were largely changed to upland crop in 1994.
- Urban : area of urban / settlement in 1977 little changed to other types in 1994.
- Water body: The water body areas in 1977 were not changed to other types in 1994.

Table 17. Coincident matrix of area of land-use/land cover change (in ha) between 1977 and 1994, Upper Nan Basin.

Unit: hectare

1977\1994	Forest	Upland Crops	Tree	Paddy Fields	Urban	Water	Total1977
Forest	**1,089,300**	76,350	8,025	10,050	3,225	525	1,187,475
Upland Crops	5,275	**11,575**	2,575	3,075	1,650	0	24,150
Tree	1,125	5,500	**15,150**	550	0	0	22,325
Paddy Fields	3,200	15,275	4,150	**25,000**	6,325	0	53,950
Urban	0	125	50	0	**75**	0	250
Water	0	0	0	0	0	**24,850**	24,850
Total 1994	1,098,900	108,825	29,950	38,675	11,275	25,375	1,313,000

Table 18. Probability coincident matrix of land-use/land cover change between 1977 and 1994, Upper Nan Basin.

1977\1994	Forest	Upland Crops	Tree	Paddy Fields	Urban	Water	Total
Forest	**0.917**	0.064	0.007	0.008	0.003	0.000	1.000
Upland Crops	0.218	**0.479**	0.107	0.127	0.068	0.000	1.000
Tree	0.050	0.246	**0.679**	0.025	0.000	0.000	1.000
Paddy Fields	0.059	0.283	0.077	**0.463**	0.117	0.000	1.000
Urban	0.000	0.500	0.200	0.000	**0.300**	0.000	1.000
Water	0.000	0.000	0.000	0.000	0.000	**1.000**	1.000

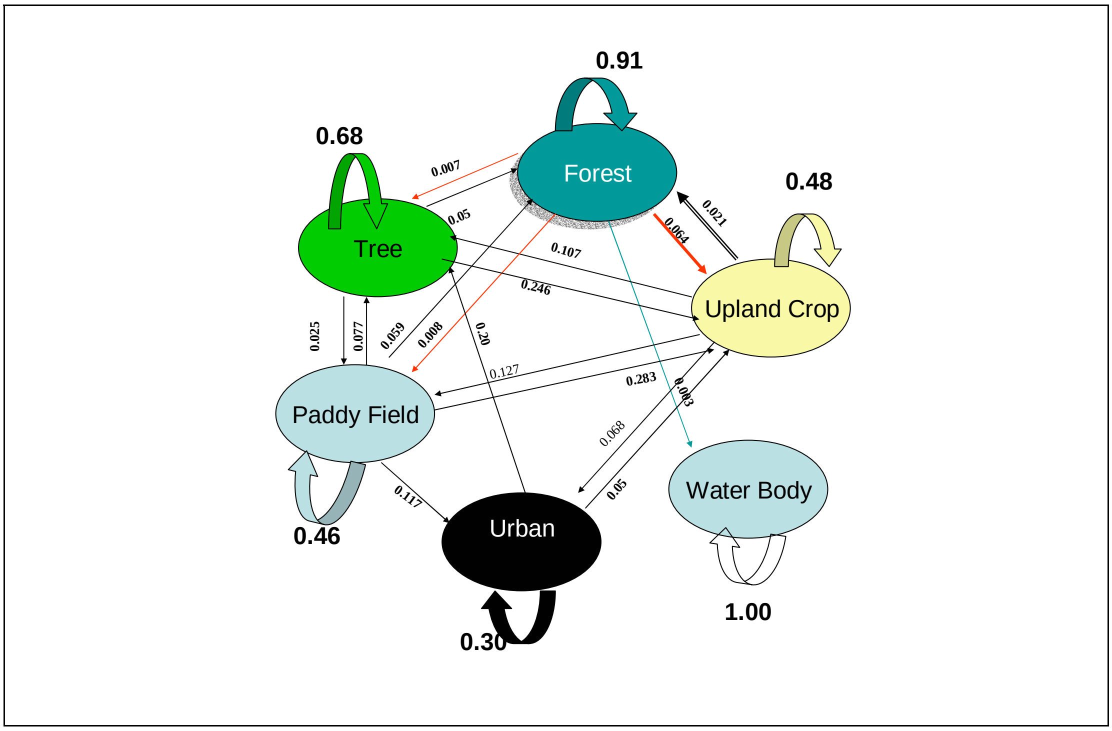


Figure 21 Probability of Land-use / land cover change pattern between 1977 and 1994, Upper Nan Basin.

The result derived from land-use transformation coefficient in Table 17 and the remaining land-use in Table 16 imply that between 1977 and 1994 forest area was decreased about 88,575 ha or about 6.75 percent of the studied area, while the others classes were increased. The largest increased category was upland crops, It was increased about 84,675 ha or 6.45 percent of the studied area, while the smallest increased class was urban(11,025 ha or 0.84 percent of the studied area). In addition, the change of land-use /land cover types between 1977 and 1994 are also summarized in Table 19 and Figure 22.

Table 19 The change of area of land-use and land cover types between 1977 and 1994, Upper Nan Basin.

Unit: hectare

Land-use types	In 1977	In 1994	Different	
			hectare	%
Forest	1,187,475	1,098,900	-88,575	-6.75
Upland Crops	24,150	108,825	84,675	6.45
Tree	22,325	29,950	7,625	0.58
Paddy Fields	53,950	38,675	-15,275	-1.16
Urban	250	11,275	11,025	0.84
Water	24,850	25,375	525	0.04
Total	1,313,000	1,313,000		

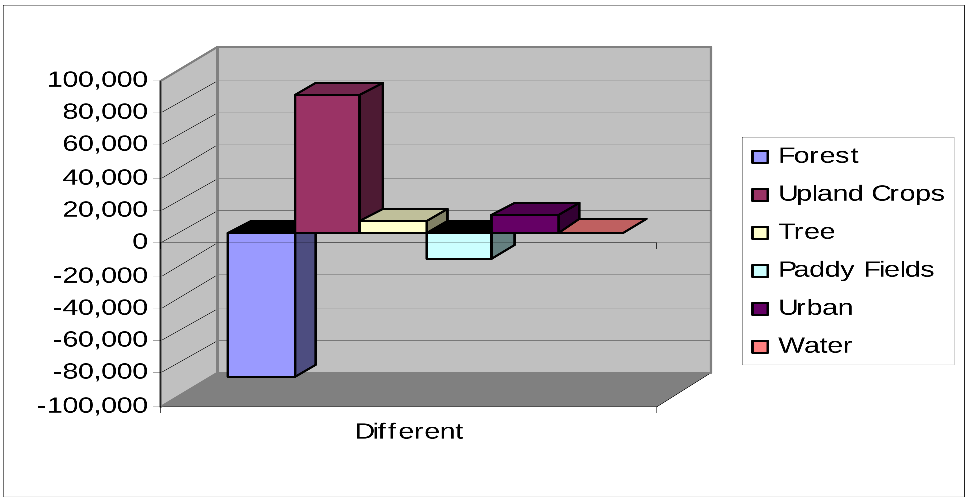


Figure 22 Comparison of change of land-use / land cover types between 1977 and 1994, Upper Nan Basin.

1.2 Land-use and Land Cover Change between 1994 and 2000

The LUCC between 1994 and 2000 was conducted by matrix operation as shown in Table 20, Table 21 and Table 22. The LUCC between 1994 and 2000 can be briefly described as follows:

- Forest: About 325,150 ha forest area in 1994 were converted to Upland crop in 2000, while about 22,575 ha, and 3,925 ha forest area in 1994 were minor changes to Tree and Paddy Fields in 2000.
- Upland Crop: The Upland Crop areas of about 30,375 ha in 1994 were largely changed to forest land in 2000.
- Tree/Forest Plantation: The area of Tree/Forest Plantation area of about 3,200 ha in 1994 was change to Paddy field area in 2000.
- Paddy Fields: The Paddy field areas of about 6,300 ha in 1994 were largely changed to Upland Crop in 2000, and 53,000 ha was changed to Tree in 2000.
- Urban : area of urban in 1994 little changed to other types in 2000.
- Water Body: The Water Body areas of about 2,900 ha in 1994 were largely changed to forest land in 2000.

Table 20 Coincident matrix of area of land-use/land cover change (in ha) between 1994 and 2000, Nan Basin.

Unit: hectare

1994\2000	Forest	Upland Crops	Tree	Paddy Fields	Urban	Water	Total 1994
Forest	**736,875**	333,325	22,575	3,925	75	2,125	1,098,900
Upland Crops	30,375	**47,675**	12,925	17,225	0	625	108,825
Tree	1,700	3,025	**21,675**	3,200	0	350	29,950
Paddy Fields	1,900	6,300	5,300	**24,275**	0	900	38,675
Urban	0	0	25	0	**11,225**	25	11,275
Water Body	2,900	450	0	50	0	**21,975**	25,375
Total 2000	773,750	390,775	62,500	48,675	11,300	26,000	1,313,000

Table 21 Probability coincident matrix of land-use/land cover change between 1994 and 2000, Upper Nan Basin.

1994\2000	Forest	Upland Crops	Tree	Paddy Fields	Urban	Water	Total
Forest	**0.671**	0.303	0.021	0.004	0.000	0.002	1.000
Upland Crops	0.279	**0.438**	0.119	0.158	0.000	0.006	1.000
Tree	0.057	0.101	**0.724**	0.107	0.000	0.012	1.000
Paddy Fields	0.049	0.163	0.137	**0.628**	0.000	0.023	1.000
Urban	0.000	0.000	0.002	0.000	**0.996**	0.002	1.000
Water Body	0.114	0.018	0.000	0.002	0.000	**0.866**	1.000

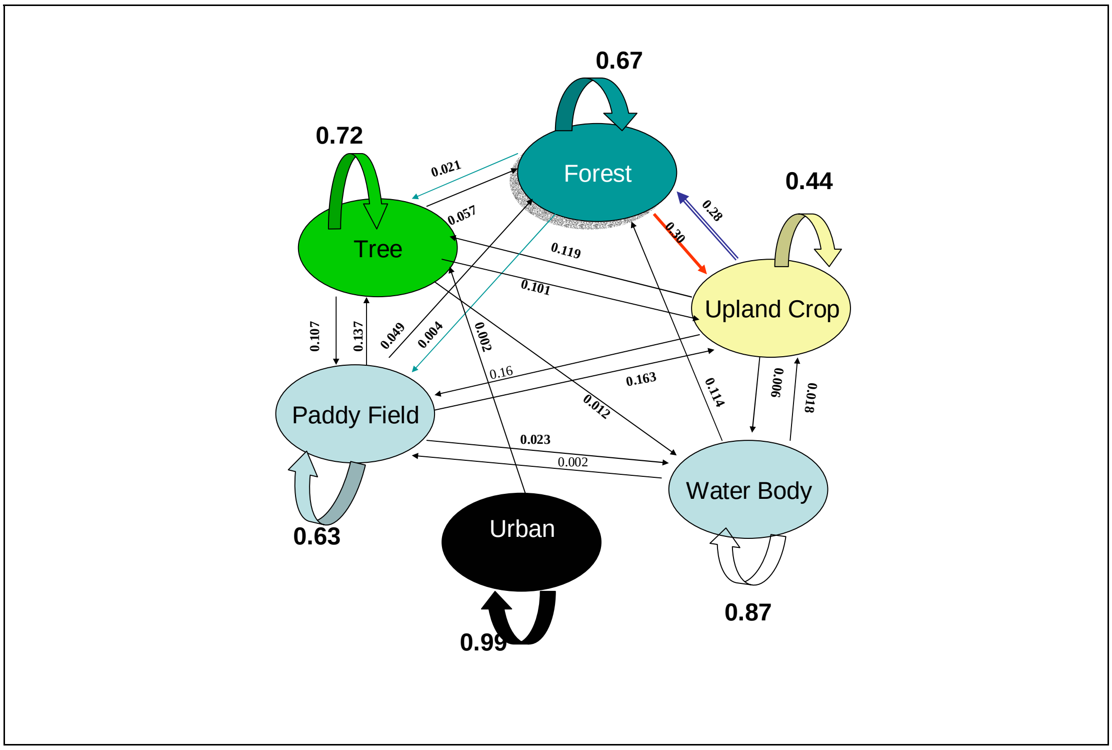


Figure 23 Probability of Land-use / land cover change pattern between 1994 and 2000, Upper Nan Basin.

The result derived from land-use transformation coefficient in Table 21 and the remaining land-use in Table 20 imply that between 1994 and 2000 forest area was decreased about 325,150 ha or about 24.76 percent of the studied area, while the others classes were increased. The largest increased category was upland crops, It was increased about 281,950 ha or 21.47 percent of the studied area, while the smallest increased class was water body (625 ha or 0.05 percent of the studied area). In addition, the change of land-use /land cover types between 1977 and 1994 are also summarized in Table 22 and Figure 24.

Table 22 The change of area of land-use and land cover types between 1994 and 2000, Upper Nan Basin.

Unit: hectare

Land-use types	In 1994	In 2000	Different	
			Hectares	%
Forest	1,098,900	773,750	325,150	-24.76
Upland Crops	108,825	390,775	281,950	21.47
Tree	29,950	62,500	32,550	2.48
Paddy Fields	38,675	48,675	10,000	0.76
Urban	11,275	11,300	25	0.00
Water Body	25,375	26,000	625	0.05
Total	1,313,000	1,313,000		

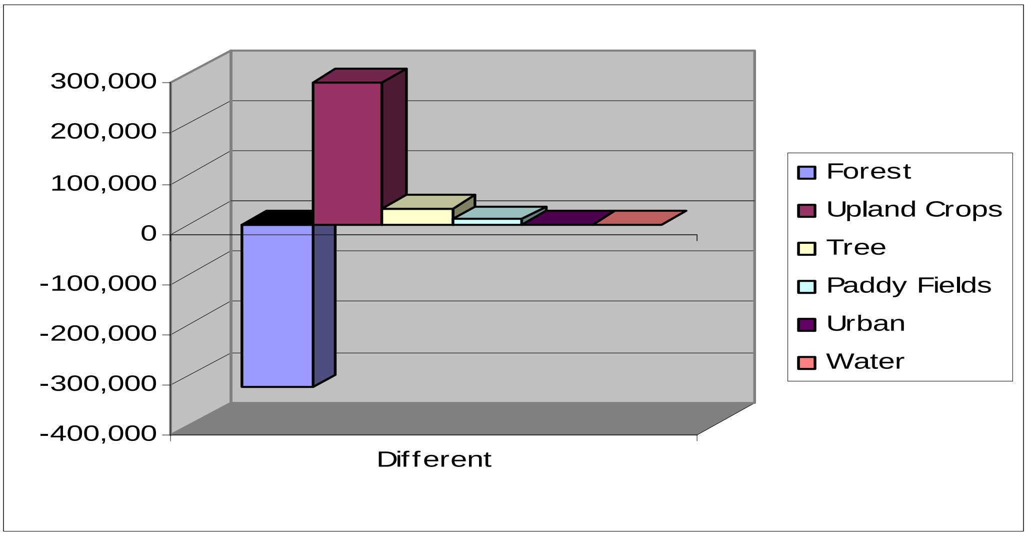


Figure 24 Comparison of change of land-use / land cover types between 1994 and 2000, Upper Nan Basin.

1.3 Forecasting the trend of annual land-use changes in the future

After modelling for predicting annual land-use changes by Markov Chain model and mathematical model, from 1977 to 2000 which use transformation coefficient from land-use/land cover change between 1977 to 1994 and 1994 to 2000. Then, forecast annual land-use changes in the future (from year 2000 to 2012), by use transformation coefficient from land-use/land cover change between 1994 and 2000. The results shows that overall trend of land-use types year by year from 2000 to 2012 as predicted by Markov Chain model and mathematical model indicate that a decrease of forest area will decrease continuously from year 2000 and will stand at about 559,131 ha (42.48 percent) or 16.35 percent decreased from 2000 to 2012, while Upland Crops will increase a little only 1.16 percent, but Tree/Fruit tree/Forest Plantation in creasing about 12.16 percent. It means in the future Upland Crops will rather stable in change while Tree/Fruit/ Forest Plantation tree will replace the forest area(Table 23 and Figure 25).

Table 23 The area of land-use types year by year from 1977 to 2000 and trend in the future between 2000 and 2012, calculated by Markov Chain Model and Mathematical Model.

Unit: hectare

Year	Forest	Upland Crops	Tree	Paddy Fields	Urban	Water Bodies
1977	**1,187,475**	**24,150**	**22,325**	**53,950**	**250**	**24,850**
1978	1,182,073	26,386	22,714	52,904	313	24,881
1979	1,176,695	28,829	23,110	51,878	391	24,911
1980	1,171,341	31,499	23,513	50,872	490	24,942
1981	1,166,012	34,416	23,923	49,886	613	24,973
1982	1,160,707	37,602	24,340	48,918	766	25,003
1983	1,155,426	41,084	24,764	47,970	959	25,034
1984	1,150,170	44,888	25,196	47,040	1,200	25,065
1985	1,144,937	49,045	25,635	46,128	1,501	25,096
1986	1,139,728	53,586	26,082	45,233	1,878	25,127
1987	1,134,543	58,548	26,537	44,356	2,350	25,157
1988	1,129,381	63,969	27,000	43,496	2,940	25,188
1989	1,124,243	69,893	27,470	42,653	3,678	25,219
1990	1,119,128	76,364	27,949	41,826	4,602	25,250
1991	1,114,037	83,435	28,437	41,014	5,757	25,281
1992	1,108,968	91,161	28,932	40,219	7,203	25,313
1993	1,103,923	99,602	29,437	39,439	9,012	25,344
1994	**1,098,901**	**108,825**	**29,950**	**38,675**	**11,275**	**25,375**
1995	1,036,491	134,667	33,857	40,186	11,279	25,478
1996	977,626	166,646	38,273	41,756	11,283	25,582
1997	922,103	206,219	43,265	43,387	11,288	25,685
1998	869,735	255,188	48,909	45,083	11,292	25,790
1999	820,340	315,787	55,288	46,844	11,296	25,895
2000	**773,750**	**390,775**	**62,500**	**48,675**	**11,300**	**26,000**
2001	749,039	395,594	69,109	55,053	11,300	26,346
2002	725,116	400,473	76,416	62,266	11,301	26,696
2003	701,958	405,411	84,497	70,425	11,301	27,051
2004	679,539	410,411	93,431	79,654	11,302	27,410
2005	657,836	415,472	103,311	90,091	11,302	27,775
2006	636,826	420,596	114,235	101,896	11,302	28,144
2007	623,165	418,137	120,795	108,075	11,301	28,715
2008	609,797	415,694	127,732	114,628	11,300	29,298
2009	596,715	413,264	135,067	121,579	11,299	29,893
2010	583,914	410,849	142,823	128,951	11,298	30,500
2011	571,388	408,447	151,025	136,770	11,297	31,119
2012	**559,131**	**406,060**	**159,698**	**145,063**	**11,296**	**31,750**
2000(%)	58.93	29.76	4.76	3.71	0.86	1.98
2012(%)	42.58	30.93	12.16	11.05	0.86	2.42
Different(%)	-16.35	+1.16	+7.40	+7.34	0.00	+0.44

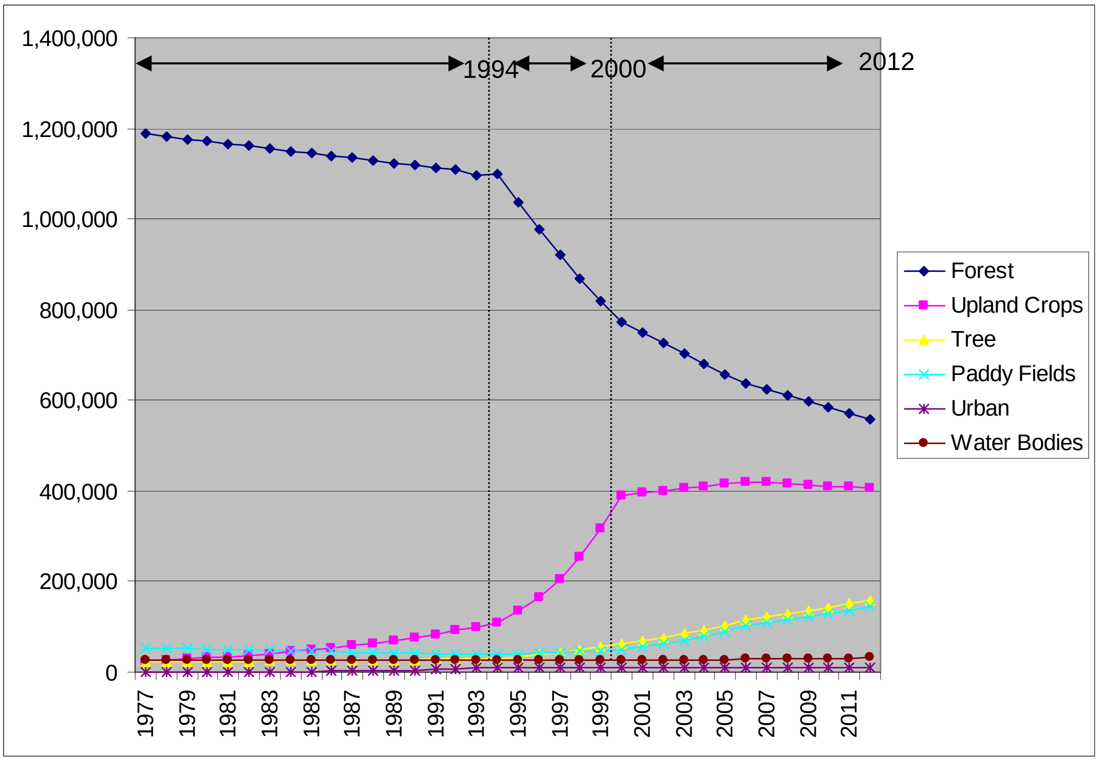


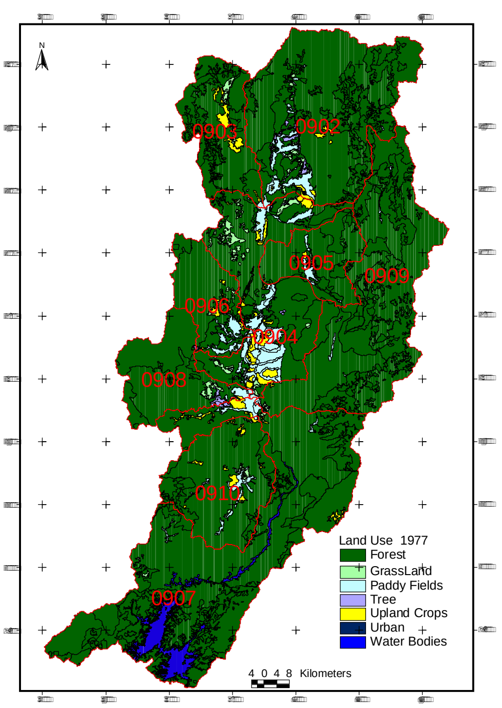
Figure 25 Trend of land-use types year by year from 1977 to 2012, Upper Nan Basin, between 2000 to 2012 using probability coincident matrix of land-use/land cover change between 1994 and 2000, calculated by Markov Chain Model and Mathematical Model.

2. Priority of Sub-watershed Degradation SDSS:PSD-SDSS

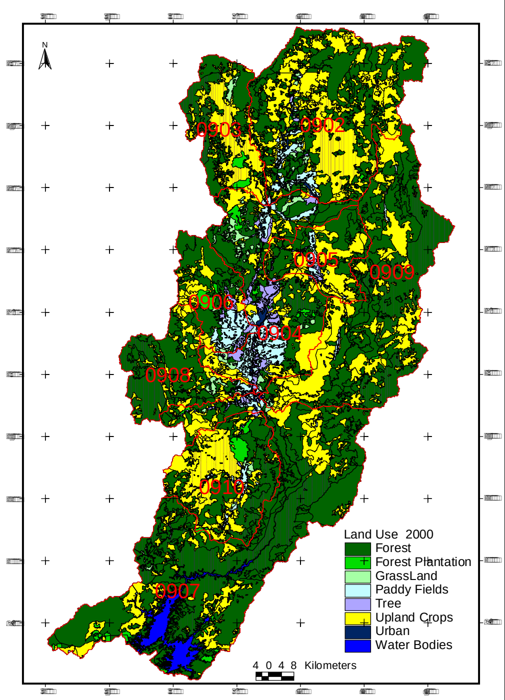
2.1 Land-use and Soil Loss Status of Upper Nan Basin

2.1.1 Overall Situation on land cover change and soil loss increment

Overall land cover change and soil loss increment for the duration of 23 years; between 1977 and 2000 are given in Figure 26, the rate for forest loss of the study area was 1.48 percent per year, which too high while considering the sustainability, along with 0.09 ton/ha./year increment in soil erosion rate between 1977 to 2000. Annual on-site soil erosion of Upper Nan Basin in particular year was estimated based on USLE and GIS in equation A=R*K*LS*CP are shown in Figure 27, 28 and Table 24 .



(a)Land-use in 1977



(b)Land-use in 2000

Figure 26 Map of Land-use in 1977 and 2000, 9 sub-watershed of Upper Nan Basin

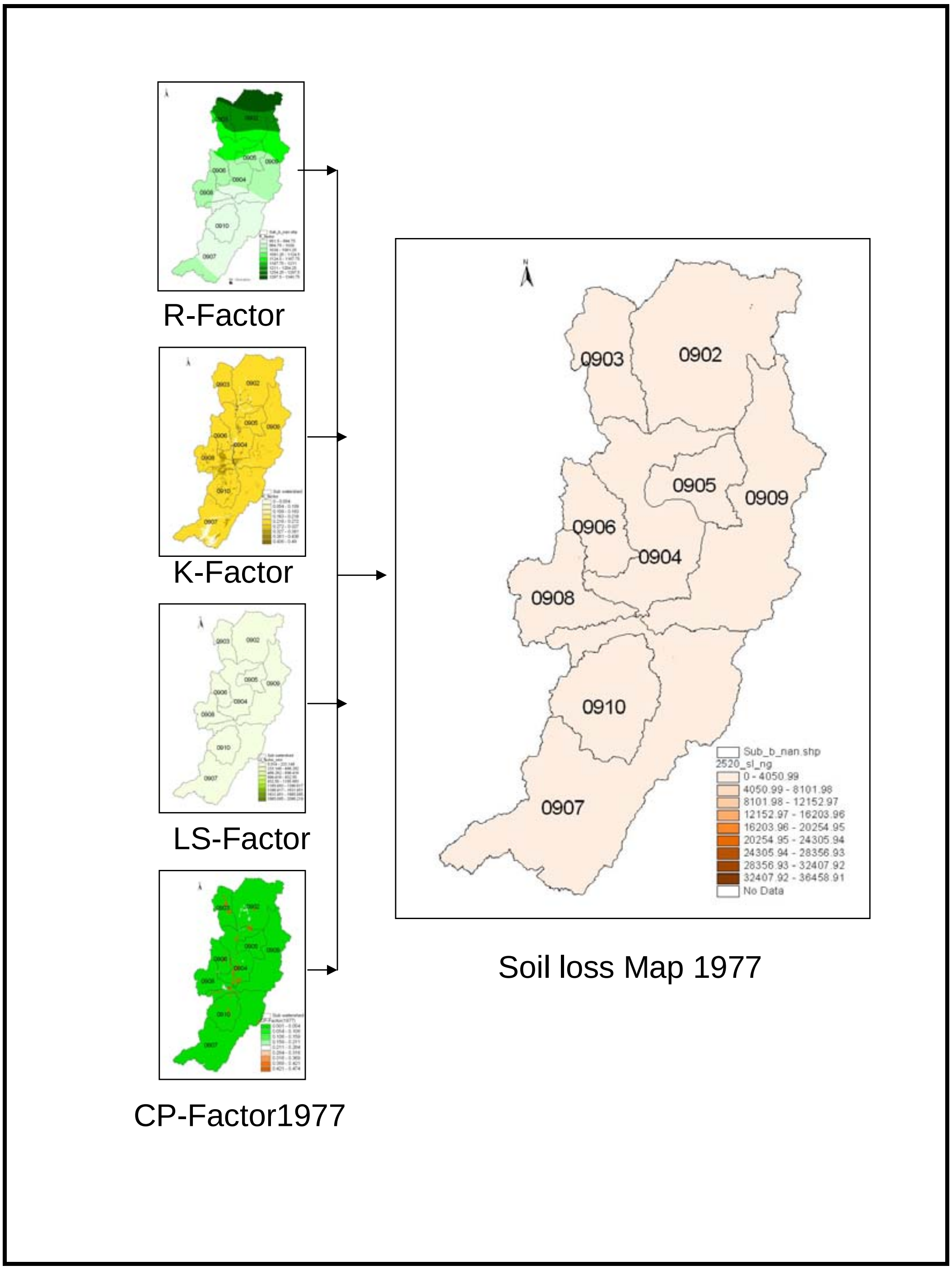


Figure 27 Map of soil loss in 1977, 9 sub-basin of Upper Nan Basin

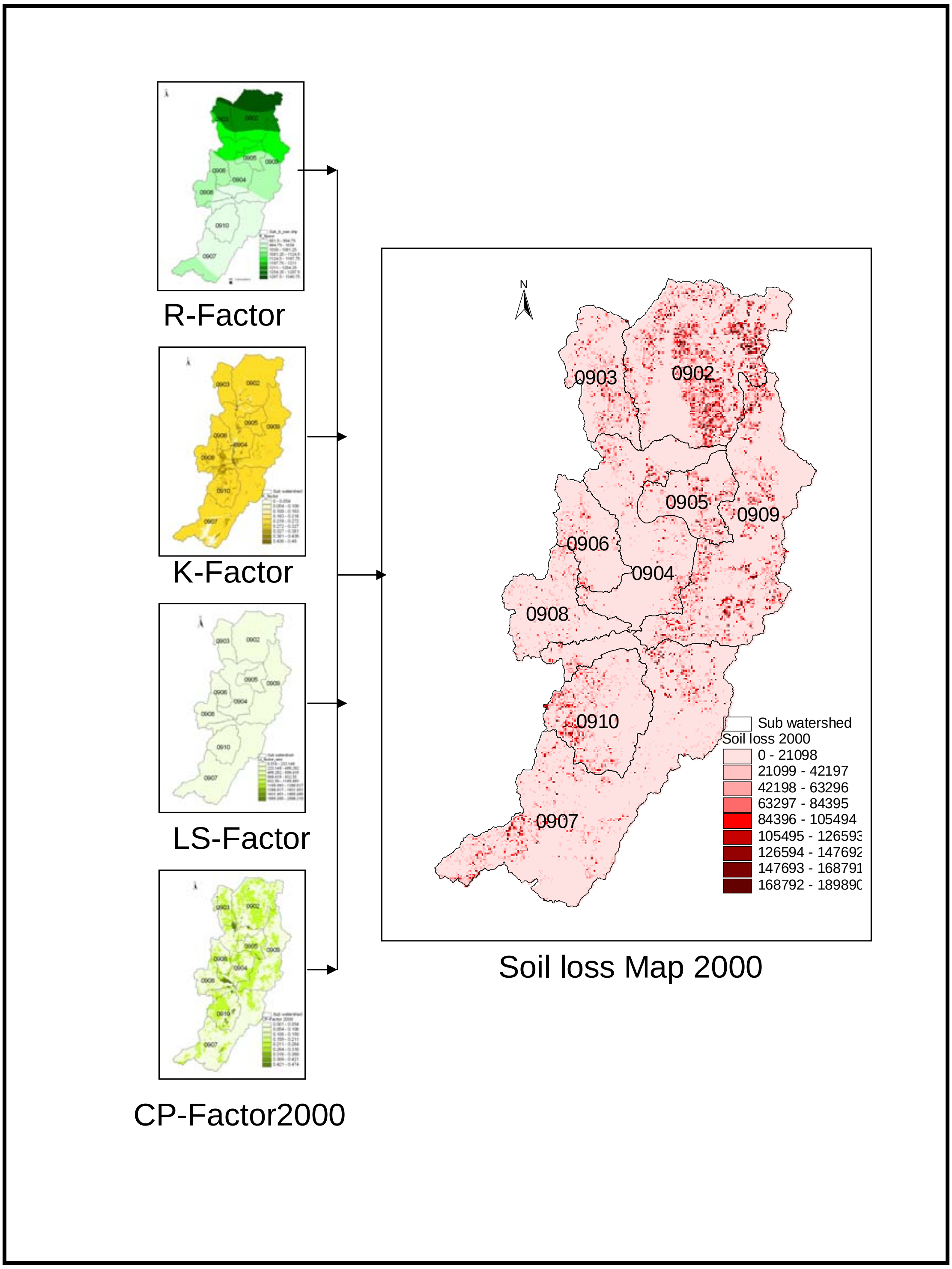


Figure 28 Map of soil loss in 2000, 9 sub-basin of Upper Nan Basin

Table 24 Land-use and Soil Loss Status of 9 sub- watershed, Upper Nan Basin

Sub Basin	Area (hectare)	soil loss(Ton/ha/y)		Forest		Forest Plantation		Upland Crops		Tree		Paddy Fields		GrassLand		Urban		Water Body	
		1977	2000	1977	2000	1977	2000	1977	2000	1977	2000	1977	2000	1977	2000	1977	2000	1977	2000
B0902	222,221	454,098	1,687,128	205,269	107,811	0	534	2,092	98,931	2,625	1,100	9,508	8,320	2,508	2,479	124	2,446	0	601
B0903	78,810	93,312	243,765	72,616	39,666	0	2,523	4,001	34,086	0	56	441	282	1,751	1,841	0	261	0	95
B0904	152,874	127,418	286,233	109,731	67,226	0	3,364	9,389	34,216	336	13,955	25,429	20,244	7,847	9,053	98	3,704	39	1,113
B0905	59,131	64,734	204,089	56,032	30,601	0	0	373	22,854	0	1,946	2,396	2,661	330	479	0	404	0	185
B0906	59,159	69,564	121,503	51,346	30,743	0	3,019	1,974	11,287	122	3,574	5,223	8,444	546	1,102	0	971	0	19
B0907	337,580	540,112	904,897	303,637	244,678	0	4,885	3,414	57,398	421	1,744	3,860	3,042	1,101	1,100	6	1,439	25,424	23,295
B0908	77,848	123,714	232,660	72,834	58,403	0	46	237	15,018	1,258	518	1,641	1,241	1,875	1,967	0	366	0	289
B0909	220,950	225,407	744,396	218,752	147,364	0	161	190	69,999	0	330	1,562	1,508	440	440	0	276	0	873
B0910	104,494	123,378	342,556	96,647	47,948	0	4,532	2,687	45,778	0	600	4,005	3,505	1,043	1,043	0	940	0	149
Total	1,313,069	1,821,737	4,767,227	1,186,863	774,440	0	19,064	24,357	389,567	4,762	23,823	54,065	49,246	17,439	19,503	228	10,807	25,464	26,619

Note: Land-use Unit in hectare.

2.2 Prioritization Analysis

2.2.1 Parameters and Formulating Indices (Condition Indicator)

1) Degradation Speed Index (DSI) Analysis

The soil and forest are main resources of the watershed. Their amount of change in specified period of time is the indication of the status changing speed. So by assessing the forest and soil loss change between 1977 and 2000 and contribution to the total soil loss form each sub-watershed. DSI has been formulated (Sah et al, 1997). The DSI is defined as the degradation speed of the sub-watersheds.

DSI = 0.45*forest change (%) + 0.45 *rate of soil loss change (t/ha/yr.) +0.10*contribution to soil loss change (%)

The weight of individual factor has been decided on the basis of their importance to the land degradation. The location of DSI value is given in figure 29 and Table 25. The percent of forest change, rate of soil loss change and percent contribution to the total soil loss form each sub-watershed Upper Nan Basin between 1977 and 2000 in that use to calculate DSI value as shown in Figure 30

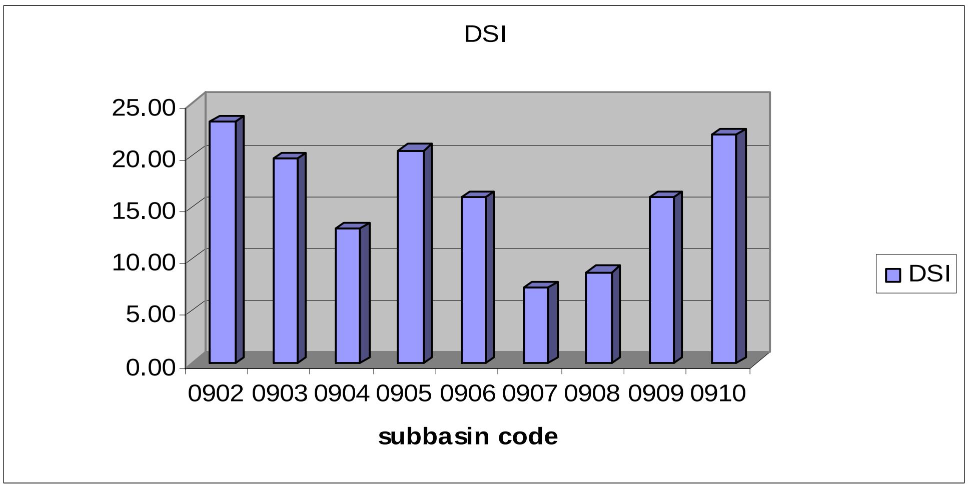
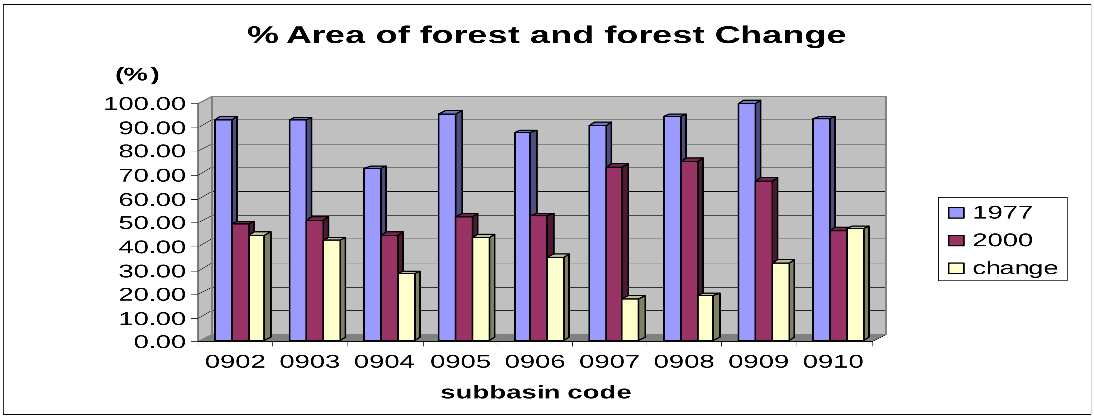


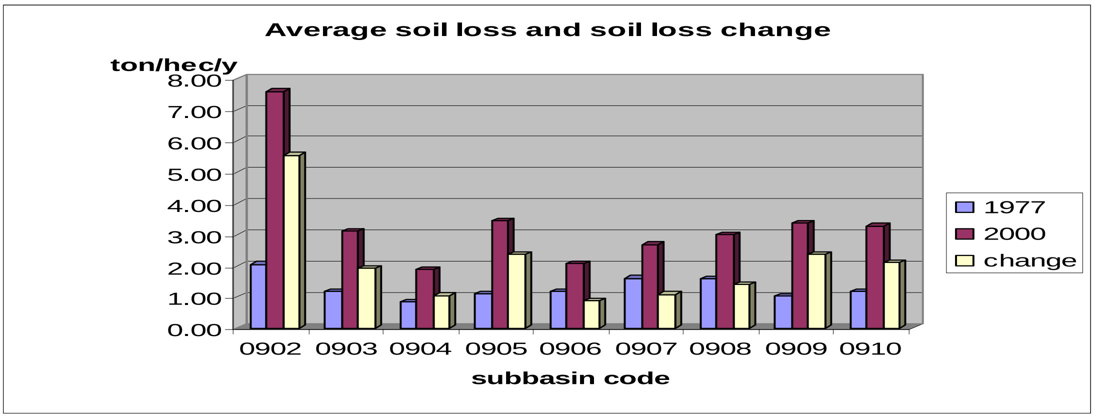
Figure 29 Bar Chart showing of Degradation Speed Index (DSI)

Table 25 Forest loss and soil loss status of 9 sub- watershed, Upper Nan Basin .

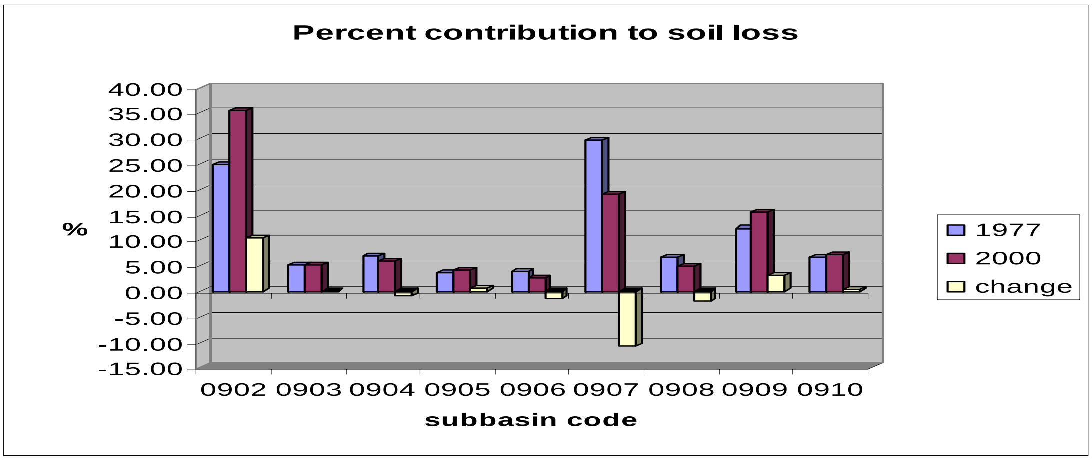
Sub-Basin Code	Sub-basin name	Area (sq.km)	Area of forest(%)			avg.soil loss(ton/ha/yr)			% contribution to soil loss			Indicator Value		
			1977	2000	change	1977	2000	change	1977	2000	change	DSI	SI	PEI
B0902	Upper Nan River	2,222	92.37	48.51	43.86	2.043	7.592	5.549	24.93	35.39	10.46	23.28	0.127	7.59
B0903	Nam Yaow	788	92.14	50.33	41.81	1.184	3.093	1.909	5.12	5.11	-0.01	19.67	0.046	3.09
B0904	Nan River(2)	1,529	71.78	43.97	27.80	0.833	1.872	1.039	6.99	6.00	-0.99	12.88	0.037	1.87
B0905	Nam Yaow(2)	591	94.76	51.75	43.01	1.095	3.451	2.357	3.55	4.28	0.73	20.49	0.055	3.45
B0906	Nam Samoon	592	86.79	51.97	34.83	1.176	2.054	0.878	3.82	2.55	-1.27	15.94	0.025	2.05
B0907	Nan River (3)	3,376	89.95	72.48	17.47	1.600	2.681	1.081	29.65	18.98	-10.67	7.28	0.062	2.68
B0908	Nam Sa	778	93.56	75.02	18.54	1.589	2.989	1.399	6.79	4.88	-1.91	8.78	0.075	2.99
B0909	Nam Hwa	2,210	99.00	66.70	32.31	1.020	3.369	2.349	12.37	15.61	3.24	15.92	0.073	3.37
B0910	Nam Hang	1,045	92.49	45.89	46.60	1.181	3.278	2.098	6.77	7.19	0.41	21.96	0.045	3.28



(a) Area of forest and forest change (%)



(b) Average soil loss and soil loss change



(c) Percent contribution to the total soil loss

<u>Figure 30</u> Bar Chart showing percent of forest change, rate of soil loss change and percent contribution to the total soil loss from each sub-watershed, Upper Nan Basin between 1977 and 2000.

2) <u>Sensitivity Analysis and Sensitivity Index (SI)</u>

Impact of forest loss sub-watersheds causes various level responses, which is soil loss increase in this case. It depends on the characteristics such as steepness of sub-watersheds of way of cutting tree and kind of crops or land-use that is replaced the forest loss. For example forest loss in steep slope is more critical than in flat area. To assess this characteristic, land sensitivity had been proposed and SI is defined and as shown in Table 26 and Figure 31. The land sensitivity analysis shown correlation between forest loss and soil increment which $\mathbf{R^2 = 0.296}$ that mean some sub-watersheds are more sensitive as slight loss of forest produced tremendous amount of soil loss, but some sub-watershed as low sensitivity. So, in this study for prioritization sub-watershed degradation of Upper Nan Basin, the **SI** is good effective index (Figure 32).

<u>Table 26</u> Forest loss (%) and soil loss increment data

Sub Basin Code	Sub Basin Name	Forest Loss (%)	Soil loss increment	SI
B0902	Upper Nan River	1.91	0.24	0.127
B0903	Nam Yaow	1.82	0.08	0.046
B0904	Nan River(2)	1.21	0.05	0.037
B0905	Nam Yaow(2)	1.87	0.10	0.055
B0906	Nam Samoon	1.51	0.04	0.025
B0907	Nan River (3)	0.76	0.05	0.062
B0908	Nam Sa	0.81	0.06	0.075
B0909	Nam Hwa	1.40	0.10	0.073
B0910	Nam Hang	2.03	0.09	0.045

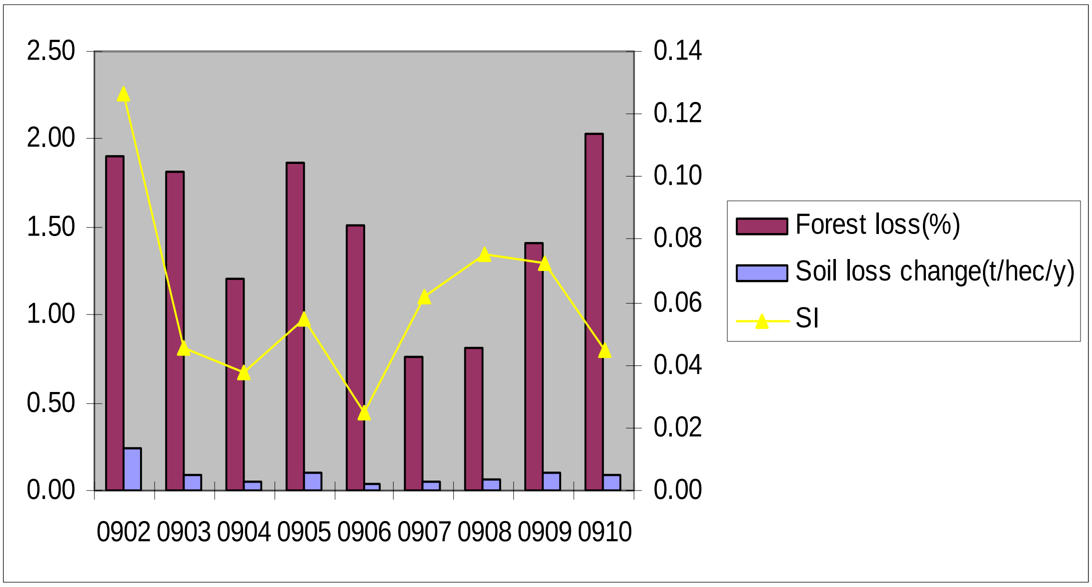


Figure 31 Chart showing forest loss (%) & soil loss increment data and Sensitivity Index Value.

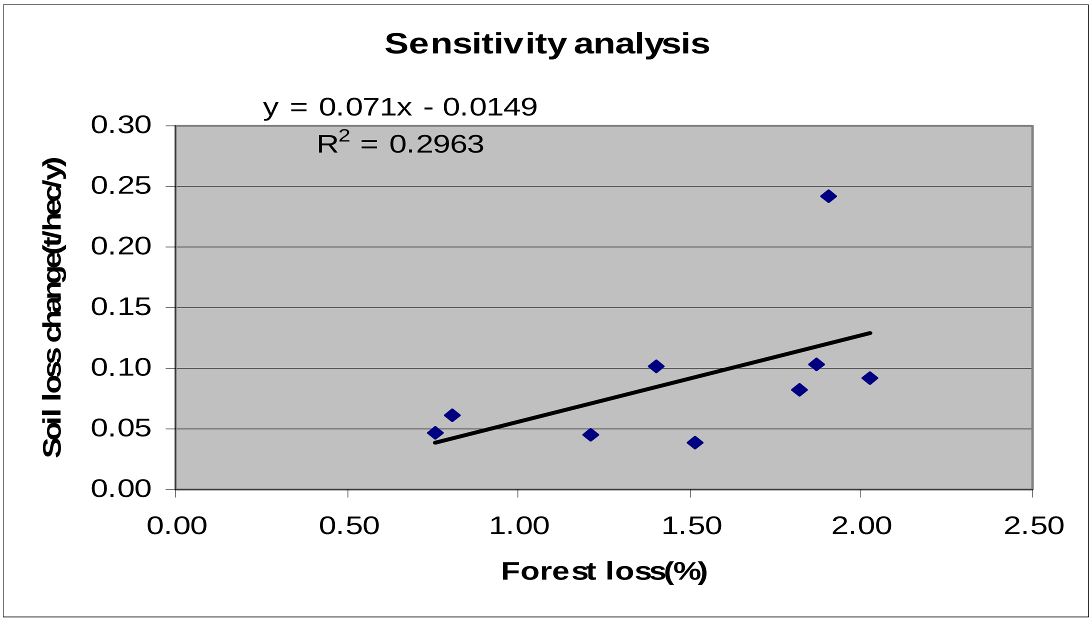


Figure 32 **SI correlations** between forest loss and soil increment

3) **Present Environment Impact Index (PEI)**

The soil erosion rate of the 2000 is considered as PEI of the sub-watersheds. Among several indicators, the higher rate of soil erosion can be considered as on indicator of the conditions of the sub-watershed (Table 25 and Figure 33).

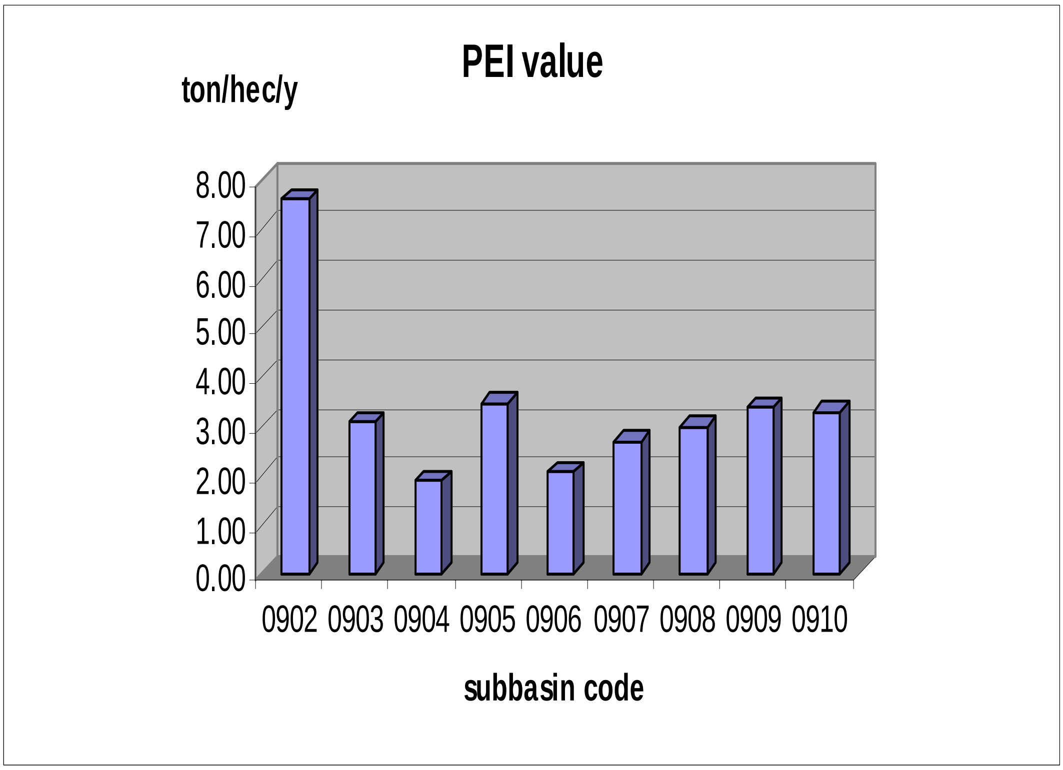


Figure 33 Chart showing Present Environment Impact Index (PEI)

4) **Percent of DSI SI and PEI Between 1977 to 2000**

The Percent of DSI, SI and PEI Between 1977 to 2000 are shown in Figure 34.

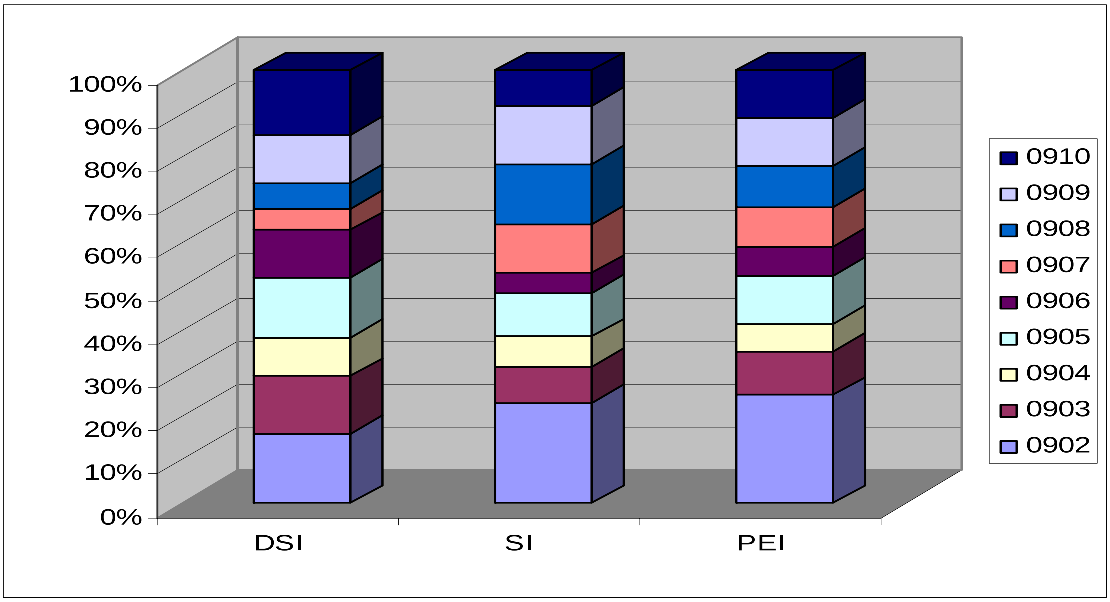


Figure 34 Chart showing percent of DSI, SI and PEI between 1977 to 2000

2.2.2 Rating of Index and Priority Map of Upper Nan Basin

As discussed earlier, the DSI, SI and PEI were taken as the condition in each of sub-watershed and used for the prioritization analysis by weighting method in GIS technique in methodology section 2.5.4. To create this method, firstly, the range of quantitative value has been defined for qualitative value (Max – Min / Number of Range) as shown in Table 27 and Table 28. Then, prioritization analysis by weighting method in GIS techniques, the conservation prioritization solutions of Upper Nan Basin can be described as follows:

First Priority (P1):	B0902 Upper Nan River	
Second Priority (P2):	B0905 Nam Yaow(2)	B0909 Nam Hwa
Third Priority (P3):	B0903 Nam Yaow	B0908 Nam Sa
	B0910 Nam Hang	
Fourth Priority (P4):	B0906 Nam Samoon	B0907 Nan River (3)
Fifth Priority (P5) :	B0904 Nan River(2)	

Table 27 Rating of Priority Index

Rating		DSI	SI	PEI	Score
Very Low	P5	7.28-11.27	0.025-0.050	1.87-3.30	1
Low	P4	11.28-15.27	0.050-0.075	3.30-4.73	2
Medium	P3	15.28-19.27	0.075-0.101	4.73-6.16	3
High	P2	19.28-23.27	0.101-0.126	6.16-7.59	4
Very High	P1	>23.28	>0.126	>7.59	5

Table 28 Prioritization analysis by weighting method

Sub_basin Code	Sub_basin name	Index Value							Priority
		DSI		SI		PEI		Total	
		Score	*0.30	Score	*0.40	Score	*0.30	Score	
B0902	Upper Nan River	5	1.5	5	2.0	5	1.5	5.0	P1
B0903	Nam Yaow	4	1.2	1	0.4	1	0.3	1.9	P3
B0904	Nan River(2)	2	0.6	1	0.4	1	0.3	1.3	P5
B0905	Nam Yaow(2)	4	1.2	2	0.8	2	0.6	2.6	P2
B0906	Nam Samoon	3	0.9	1	0.4	1	0.3	1.6	P4
B0907	Nan River (3)	1	0.3	2	0.8	1	0.3	1.4	P4
B0908	Nam Sa	1	0.3	3	1.2	1	0.3	1.8	P3
B0909	Nam Hwa	3	0.9	2	0.8	2	0.6	2.3	P2
B0910	Nam Hang	4	1.2	1	0.4	1	0.3	1.9	P3

By GIS technique conservation prioritization of the 9 sub-watersheds of Upper Nan Basin are shown in Table 29 and map is shown in Figure 35. This imply that, conservation work in the Upper Nan Basin area should be started according to the priority list of Table 29. Slope stabilization, slope failure protection, gully control by check dam, reforestation, growing of horticultural crop along with some other intensive soil conservation activities are required for the first and second ranking sub-watersheds. Fifth ranking sub-watershed need little attention like maintaining the crown cover and protection of the existing forest along with managed agriculture. Other sub-watersheds should be treated by intermediate activities according to their ranks.

Table 29 Conservation Prioritization of the Sub-watersheds

Conservation Prioritization		Number of sub basin	List of the sub-watershed
First Priority	P1	1	B0902 Upper Nan River
Second Priority	P2	2	B0905 Nam Yaow(2) B0909 Nam Hwa
Third Priority	P3	3	B0903 Nam Yaow B0908 Nam Sa B0910 Nam Hang
Fourth Priority	P4	2	B0906 Nam Samoon B0907 Nan River (3)
Fifth Priority	P5	1	0904 Nan River(2)

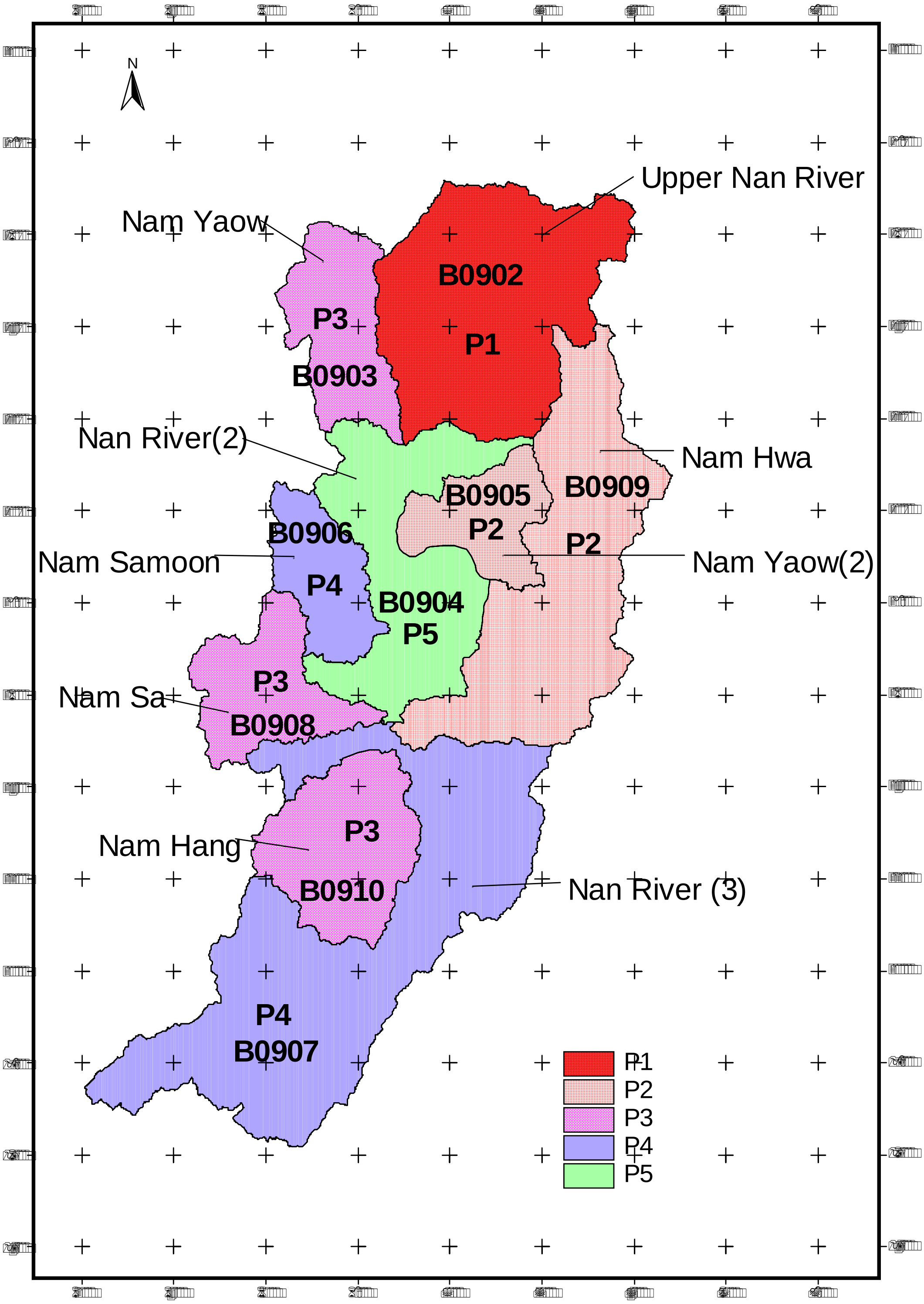


Figure 35 Sub-watershed conservation priority map of Upper Nan Basin

3. Optimal Sub-watershed Land-use Relocation SDSS:OSLUR:SDSS

3.1 The Derived Variable Coefficients for Optimization Model

Since a few of decision variable coefficients related to net income, soil loss, according to the land-use complex on the Upper Nan Basin, had been made available. The derived input data applied as decision variable coefficients in this study are thus based on the previous research finding, theoretical background, and surveying study particularly income.

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 can be described as follows:

3.1.1 Relationships between LUCC and Net Income, Soil Loss in Upper Nan Basin

The decision variable coefficients of the Upper Nan Basin in terms of net income, soil loss are different among land-uses. Since the topographic features in Upper Nan Basin does not much different between the upstream and downstream this study, therefore, assume that the topographic feature does not affect net income in the watershed scale. The derived decision variable coefficients are very important for the next step of LP for maximizing net income, and minimizing soil loss. Thus, it needs to make sure that all the finding decision variable coefficients scientific logic.

Based on the economic data from local government agencies in Upper Nan Basin, and Land Development Department, and Royal Forest Department, remaining land-use cover, the relationships between net income, soil loss and land-use/land cover change in Upper Nan Basin was analyzed. The derived decision coefficients can be described as follows:

3.1.1.1 Estimating Net Income in Upper Nan Basin

The estimated net income (Y_1, Baht) in Upper Nan Basin is derived by land-use parameters (Natural Forest (X_1, ha), Forest Plantation (X_2, ha), Upland Crops (X_3, ha), Tree (X_4, ha), Paddy Field (X_5, ha), Grasslands (X_6, ha), Urban (X_7, ha), and Water body (X_8, ha)).

Based on the economic data from local government agencies in Upper Nan Basin, for example, the benefit obtained from natural forest (X_1) at the Upper Nan Basin was approximately 16,250 Baht per ha per year, and 5,000 Baht per ha per year in forest plantation (X_2). In Upper Nan Basin, plantation forest just was planted in the beginning 2000's, therefore, net income from plantation forest in this watershed was still very low. The high net present income obtained from the Tree (X_4) (included fruit tree, longcon, coffee, tea….) is about 25,000 Baht per ha per year, and the Upland crops (X_3) (included corn, upland rice, ...) is about 18,750 Baht per ha per year, and paddy field (X_5) was 16,250 Baht per ha per year. The decision variable coefficients in term of X_1, X_2, X_3, X_4, X_5, X_6, X_7, X_8, are shown in Table 30 The prediction equation for net income derived from land-use/land cover change in Upper Nan Basin are:

$$\mathbf{Y_1 = 16{,}250\ X_1 + 5000\ X_2 + 19{,}750\ X_3 + 25{,}000\ X_4 + 16{,}250\ X_5 + 0\ X_6 + 0\ X_7 + 0\ X_8}$$

3.1.1.2 Relationship between Soil Loss and Land-use in Sub-watershed in Upper Nan Basin

1) In B 0902 Sub-watershed in Upper Nan Basin

The on-site impacts are focused on soil loss at the level of watershed scale that would affect on the way of living in downstream. The soil loss was estimated by using USLE and GIS technique. Based on the remaining land-uses as shown in Table 30 the decision variable coefficients of the B0902 Sub-watershed in Upper Nan Basin in term of soil loss (Y_2), and land-use/land cover change variables [Natural Forest (X_1, ha), Forest Plantation (X_2, ha), Upland Crops (X_3, ha), Tree (X_4, ha), Paddy Field (X_5, ha), Grasslands (X_6, ha), Urban (X_7, ha), and Water body (X_8, ha)] is shown in Table 30

The decision variable coefficients for X_1, X_2, X_3, X_4, X_5, X_6, X_7, X_8, are 9.28365; -51.5547; 9.43485; -1.81567; -1109.08; -1173.9; -23.5651; -80.1302 respectively. The relationship between soil loss (Y_2, tons) and land-use/land cover change (X_1, X_2, X_3, X_4, X_5, X_6, X_7, X_8, ha) are derived as:

$$\mathbf{Y_2} = 1.20258E7 + 9.28365*x1 - 51.5547*x2 + 9.43485*x3 -1.81567*x4 - 1109.08*x5 - 1173.9*x6 - 23.5651*x7 - 80.1302*x8$$

(R^2 = 99.0 percent; SEE = 232.002)

2) <u>In B0903 Sub-watershed in Upper Nan Basin</u>

In the same manner, the decision variable coefficients of the B0903 Sub-watershed in Upper Nan Basin in term of soil loss (Y_3), and land-use/land cover change variables [Natural Forest (X_1, ha), Forest Plantation (X_2, ha), Upland Crops (X_3, ha), Tree (X_4, ha), Paddy Field (X_5, ha), Grasslands (X_6, ha), Urban (X_7, ha), and Water body (X_8, ha)] is shown in Table 30

The decision variable coefficients for X_1, X_2, X_3, X_4, X_5, X_6, X_7, X_8, are -4.60793; -60.5056; -8.68038; 4021.54; -2.0167; 11.1698; 0.272232; 2018.99 respectively. The relationship between soil loss (Y_3, tons) and land-use/land cover change (X_1, X_2, X_3, X_4, X_5, X_6, X_7, X_8, ha) are derived as:

$$\mathbf{Y_3} = 438002.0 - 4.60793*x1 - 60.5056*x2 - 8.68038*x3 + 4021.54*x4 - 2.0167*x5 + 11.1698*x6 + 0.272232*x7 + 2018.99*x8$$

(R^2 = 0.99; SEE = 4.4076)

Table 30 The area of land-use types and soil loss in Upper Nan from 1977 to 2000

sub basin name	Year	Forest x1	Forest Plantation x2	Upland Crops x3	Tree x4	Paddy Fields x5	Grass land x6	Urban x7	Water Body x8	soil loss
	_1977_	**205,269**	**0**	**2,092**	**2,625**	**9,508**	**2,508**	**124**	**0**	**_454,098_**
	_1982_	201,734	0	3,680	675	9,566	2,427	298	3	_466,384_
	_1985_	199,642	0	5,163	299	9,601	2,379	504	5	_473,914_
	_1988_	197,573	0	7,245	132	9,637	2,332	853	10	_481,566_
	_1992_	194,846	0	11,381	45	9,684	2,272	1,722	24	_491,961_
B0902	**_1994_**	**193,497**	**0**	**14,265**	**26**	**9,708**	**2,242**	**2,446**	**37**	**_497,242_**
	_1997_	144,433	23	37,567	169	8,987	2,357	2,446	148	_915,921_
	_1998_	131,018	66	51,878	316	8,759	2,397	2,446	237	_1,122,763_
	_1999_	118,849	187	71,640	589	8,537	2,438	2,446	377	_1,376,315_
	_2000_	**107,811**	**534**	**98,931**	**1,100**	**8,320**	**2,479**	**2,446**	**601**	**_1,687,128_**
	_1977_	**72,616**	**0**	**4,001**	**0**	**441**	**1,751**	**1**	**0**	**_93,312_**
	_1982_	72,354	0	4,195	0	549	1,564	5	0	_90,528_
	_1985_	72,198	0	4,316	0	626	1,461	14	0	_88,898_
	_1988_	72,041	0	4,440	0	713	1,365	37	0	_87,298_
	_1992_	71,833	0	4,611	0	850	1,247	136	0	_85,208_
B0903	**_1994_**	**71,730**	**0**	**4,699**	**0**	**927**	**1,192**	**261**	**0**	**_84,182_**
	_1997_	53,341	50	12,656	7	511	1,481	261	10	_143,250_
	_1998_	48,326	185	17,608	15	419	1,593	261	21	_171,023_
	_1999_	43,782	684	24,499	28	344	1,713	261	45	_204,180_
	_2000_	**39,666**	**2,523**	**34,086**	**56**	**282**	**1,841**	**261**	**95**	**_243,765_**
	_1977_	**109,731**	**0**	**9,389**	**336**	**25,429**	**7,847**	**98**	**39**	**_127,418_**
	_1982_	101,622	0	13,785	905	20,755	7,708	287	39	_142,454_
	_1985_	97,048	0	17,357	1,639	18,374	7,626	547	39	_152,314_
	_1988_	92,679	0	21,855	2,969	16,266	7,544	1,042	39	_162,857_
	_1992_	87,158	0	29,715	6,558	13,827	7,437	2,462	39	_178,058_
B0904	**_1994_**	**84,522**	**0**	**34,649**	**9,746**	**12,748**	**7,384**	**3,785**	**39**	**_186,183_**
	_1997_	75,380	58	34,432	11,662	16,064	8,176	3,744	209	_230,850_
	_1998_	72,558	224	34,360	12,381	17,352	8,458	3,731	365	_248,005_
	_1999_	69,841	869	34,288	13,145	18,742	8,750	3,718	637	_266,434_
	_2000_	**67,226**	**3,364**	**34,216**	**13,955**	**20,244**	**9,053**	**3,704**	**1,113**	**_286,233_**

Note: Land-use Unit = Hectare Soil loss Unit = Ton/ha/Year

Table 30 (con't) The area of land-use types and soil loss in Upper Nan from 1977 to 2000

sub basin name	Year	Forest x1	Forest Plantation x2	Upland Crops x3	Tree x4	Paddy Fields x5	Grass Land x6	Urban x7	Water Body x8	soil loss
	1977	**56,032**	**0**	**373**	**0**	**2,396**	**330**	**0**	**0**	***64,734***
	1982	54,905	0	605	8	2,517	330	6	0	*65,902*
	1985	54,241	0	809	30	2,592	330	17	0	*66,612*
	1988	53,584	0	1,081	106	2,669	330	49	0	*67,331*
	1992	52,720	0	1,591	575	2,776	330	199	0	*68,301*
B0905	***1994***	**52,294**	**0**	**1,930**	**1,342**	**2,831**	**330**	**404**	**0**	***68,791***
	1997	40,003	0	6,642	1,616	2,745	397	404	14	*118,488*
	1998	36,586	0	10,027	1,719	2,717	423	404	32	*142,033*
	1999	33,460	0	15,138	1,829	2,689	450	404	77	*170,257*
	2000	**30,601**	**0**	**22,854**	**1,946**	**2,661**	**479**	**404**	**185**	***204,089***
	1977	**51,346**	**0**	**1,974**	**122**	**5,223**	**546**	**0**	**0**	***69,564***
	1982	48,650	0	3,137	300	4,321	546	8	0	*73,303*
	1985	47,102	0	4,143	516	3,856	546	25	0	*75,643*
	1988	45,602	0	5,470	886	3,441	546	86	0	*78,056*
	1992	43,677	0	7,925	1,823	2,957	546	434	0	*81,395*
B0906	***1994***	**42,745**	**0**	**9,538**	**2,615**	**2,740**	**546**	**975**	**0**	***83,118***
	1997	36,250	55	10,375	3,057	4,811	776	973	4	*100,494*
	1998	34,313	209	10,671	3,221	5,803	872	972	7	*107,059*
	1999	32,479	794	10,974	3,393	7,000	980	971	12	*114,053*
	2000	**30,743**	**3,019**	**11,287**	**3,574**	**8,444**	**1,102**	**971**	**19**	***121,503***
	1977	**303,637**	**0**	**3,414**	**421**	**3,860**	**1,101**	**6**	**25,424**	***540,112***
	1982	301,782	0	4,541	489	3,511	1,050	30	25,424	*548,438*
	1985	300,674	0	5,389	534	3,316	1,020	78	25,424	*553,495*
	1988	299,571	0	6,396	585	3,133	991	203	25,424	*558,598*
	1992	298,106	0	8,036	659	2,904	955	724	25,424	*565,476*
B0907	***1994***	**297,376**	**0**	**9,008**	**700**	**2,796**	**937**	**1,366**	**25,424**	***568,947***
	1997	269,743	70	22,739	1,104	2,916	1,015	1,402	24,336	*717,522*
	1998	261,115	288	30,960	1,286	2,957	1,043	1,414	23,984	*775,217*
	1999	252,763	1,186	42,155	1,498	2,999	1,071	1,426	23,637	*837,551*
	2000	**244,678**	**4,885**	**57,398**	**1,744**	**3,042**	**1,100**	**1,439**	**23,295**	***904,897***

Note: Land-use Unit = Hectare Soil loss Unit = Ton/ha/Year

Table30(con't) The area of land-use types and soil loss in Upper Nan from 1977 to 2000

sub basin name	Year	Forest x1	Forest Plantation x2	Upland Crops x3	Tree x4	Paddy Fields x5	GrassLand x6	Urban x7	Water Body x8	soil loss
	1977	72,834	0	237	1,258	1,641	1,875	0	0	123,714
	1982	70,054	0	721	745	1,466	1,871	6	0	138,032
	1985	68,436	0	1,408	544	1,371	1,869	16	0	147,406
	1988	66,857	0	2,750	397	1,282	1,867	46	0	157,417
	1992	64,807	0	6,708	261	1,172	1,864	183	0	171,830
B0908	1994	63,805	0	10,479	211	1,120	1,862	366	0	179,524
	1997	61,044	7	12,545	331	1,179	1,914	366	17	204,372
	1998	60,151	13	13,320	384	1,200	1,931	366	44	213,397
	1999	59,270	24	14,144	446	1,220	1,949	366	113	222,821
	2000	58,403	46	15,018	518	1,241	1,967	366	289	232,660
	1977	218,752	0	190	0	1,562	440	0	0	225,407
	1982	217,758	0	435	4	1,585	382	5	0	230,289
	1985	217,164	0	717	11	1,600	351	14	0	233,269
	1988	216,571	0	1,180	27	1,615	323	38	0	236,287
	1992	215,784	0	2,295	88	1,634	288	143	0	240,373
B0909	1994	215,391	0	3,200	160	1,644	273	276	0	242,442
	1997	178,160	13	14,966	229	1,574	346	276	30	424,821
	1998	167,239	30	25,029	259	1,552	375	276	91	512,160
	1999	156,987	69	41,857	292	1,530	406	276	282	617,454
	2000	147,364	161	69,999	330	1,508	440	276	873	744,396
	1977	96,647	0	2,687	0	4,005	1,043	0	0	123,378
	1982	90,290	0	4,944	2	4,113	824	7	6	152,501
	1985	86,678	0	7,128	3	4,179	716	25	19	173,179
	1988	83,211	0	10,277	5	4,246	621	84	58	196,660
	1992	78,803	0	16,739	9	4,338	515	420	251	232,994
B0910	1994	76,687	0	21,364	13	4,384	469	940	525	253,606
	1997	60,638	67	31,273	87	3,920	699	940	279	294,744
	1998	56,073	274	35,732	166	3,776	799	940	226	309,890
	1999	51,852	1,114	40,635	316	3,638	912	940	183	325,814
	2000	47,948	4,532	45,778	600	3,505	1,043	940	149	342,556

Note: Land-use Unit = Hectare Soil loss Unit = Ton/ha/Year

3) <u>In B0904 Sub-watershed in Upper Nan Basin</u>

The decision variable coefficients for X_1, X_2, X_3, X_4, X_5, X_6, X_7, X_8, are 12.5246; -1.34559; 18.697; -91.45; -27.4486; 547.693; 181.243; 19.1435 respectively. The relationship between soil loss (Y_4, tons) and land-use/land cover change (X_1, X_2, X_3, X_4, X_5, X_6, X_7, X_8, ha) are derived as:

$$\mathbf{Y_4} = -5.01001E6 + 12.5246*x1 - 1.34559*x2 + 18.697*x3 - 91.45*x4 - 27.4486*x5 + 547.693*x6 + 181.243*x7 + 19.1435*x8$$

(R^2 = 0.99; SEE = 125.373)

4) <u>In B0905 Sub-watershed in Upper Nan Basin</u>

The decision variable coefficients for X_1, X_2, X_3, X_4, X_5, X_6, X_7, X_8, are - 0.312173; 3.64547; 6.55382; -0.148966; 415.349; -28.6095; -74.0686 respectively. The relationship between soil loss (Y_5, tons) and land-use/land cover change (X_1, X_2, X_3, X_4, X_5, X_6, X_7, X_8, ha) are derived as:

$$\mathbf{Y_5} = -55719.2 - 0.312173*x1 + 3.64547*x3 + 6.55382*x4 - 0.148966*x5 + 415.349*x6 - 28.6095*x7 - 74.0686*x8$$

(R^2 = 0.99; SEE = 60.6245)

5) <u>In B0906 Sub-watershed in Upper Nan Basin</u>

The decision variable coefficients for X_1, X_2, X_3, X_4, X_5, X_6, X_7, X_8, are - 0.554977; -0.057742; 1.31728; -1.79714; -1.14136; 69.3637; 0.47578; - 40.9012 respectively. The relationship between soil loss (Y_6, tons) and land-use/land cover change (X_1, X_2, X_3, X_4, X_5, X_6, X_7, X_8, ha) are derived as:

$$\mathbf{Y_6} = 63807.7 - 0.554977*x1 - 0.057742*x2 + 1.31728*x3 - 1.79714*x4 - 1.14136*x5 + 69.3637*x6 + 0.47578*x7 - 40.9012*x8$$

(R^2 = 0.99; SEE = 4.29398)

6) <u>In B0907 Sub-watershed in Upper Nan Basin</u>

The decision variable coefficients for X_1, X_2, X_3, X_4, X_5, X_6, X_7, X_8, are 10.0686; 0.026482; -0.231121; 145.624; -47.5843; -16.2446; - 0.548; -347.562 respectively. The relationship between soil loss (Y_7, tons) and land-use/land cover change (X_1, X_2, X_3, X_4, X_5, X_6, X_7, X_8, ha) are derived as:

$$Y_7 = 6.46037E6 + 10.0686*x1 + 0.026482*x2 - 0.231121*x3 + 145.624*x4 - 47.5843*x5 - 16.2446*x6 - 0.548*x7 - 347.562*x8$$

(R^2 = 0.99; SEE = 91.5686)

7) <u>In B0908 Sub-watershed in Upper Nan Basin</u>

The decision variable coefficients for X_1, X_2, X_3, X_4, X_5, X_6, X_7, X_8, are - 7.3085; 377.989; 0.889424; 6.95743; 16.4288; -12.9888; - 9.90524; - 35.2427 respectively. The relationship between soil loss (Y_8, tons) and land-use/land cover change (X_1, X_2, X_3, X_4, X_5, X_6, X_7, X_8, ha) are derived as:

$$Y_8 = 644121.0 - 7.3085*x1 + 377.989*x2 + 0.889424*x3 + 6.95743*x4 + 16.4288*x5 - 12.9888*x6 - 9.90524*x7 - 35.2427*x8$$

(R^2 = 0.99; SEE = 26.5365)

8) <u>In B0909 Sub-watershed in Upper Nan Basin</u>

The decision variable coefficients for X_1, X_2, X_3, X_4, X_5, X_6, X_7, X_8, are - 4.85935; -23512.8; 42.2406; -3741.05; 518.754; 305.818; 1734.29; 2026.69 respectively. The relationship between soil loss (Y_9, tons) and land-use/land cover change (X_1, X_2, X_3, X_4, X_5, X_6, X_7, X_8, ha) are derived as:

$$Y_9 = 358989.0 - 4.85935*x1 - 23512.8*x2 + 42.2406*x3 - 3741.05*x4 + 518.754*x5 + 305.818*x6 + 1734.29*x7 + 2026.69*x8$$

(R^2 = 0.9996; SEE = 360.813)

9) <u>In B0910 Sub-watershed in Upper Nan Basin</u>

The decision variable coefficients for X_1, X_2, X_3, X_4, X_5, X_6, X_7, X_8, are - 3.95231; 0.3017; 2.36345; -9.57867; 174.975; 91.7972; 27.4614; -61.2759 respectively. The relationship between soil loss (Y_{10}, tons) and land-use/land cover change (X_1, X_2, X_3, X_4, X_5, X_6, X_7, X_8, ha) are derived as:

$$Y_{10} = -297469.0 - 3.95231*x1 + 0.3017*x2 + 2.36345*x3 - 9.57867*x4 + 174.975*x5 + 91.7972*x6 + 27.4614*x7 - 61.2759*x8$$

$(R^2 = 1;\ SEE = 96.5049)$

The summarized of the decision coefficients in each objective function as shown in Table 31 and the output details of Multiple Linear Model as shown in appendix A

Table 31 Summarized of the decision coefficients in each objective function

	Constant/ Intercept	Natural Forest (X_1)	Plantation forest (X_2)	Upland Crops (X_3)	Tree (X_4)	Paddy Field (X_5)	Grasslands (X_6)	Urban (X_7)	Water body (X_8).
Y_1	-	16,250	5,000	19,750	25,000	16,250	0	0	0
Y_2	12025800	9.28365	- 51.5547	9.43485	-1.81567	- 1109.08	- 1173.9	-23.5651	- 80.1302
Y_3	438002.0	- 4.60793	- 60.5056	- 8.68038	4021.54	- 2.0167	11.1698	0.272232	2018.99
Y_4	-5010010	12.5246	- 1.34559	18.697	-91.45	- 27.4486	547.693	181.243	19.1435
Y_5	-55719.2	- 0.312173	0	3.64547	6.55382	-0.148966	415.349	- 28.6095	- 74.0686
Y_6	63807.7	- 0.554977	- 0.057742	1.31728	-1.79714	- 1.14136	69.3637	0.47578	- 40.9012
Y_7	6460370	10.0686	0.026482	- 0.231121	145.624	- 47.5843	- 16.2446	- 0.548	- 347.562
Y_8	644121.0	- 7.3085	377.989	0.889424	6.95743	16.4288	- 12.9888	- 9.90524	- 35.2427
Y_9	358989.0	- 4.85935	- 23512.8	42.2406	- 3741.05	518.754	305.818	1734.29	2026.69
Y_{10}	-297469.0	- 3.95231	0.3017	2.36345	- 9.57867	174.975	91.7972	27.4614	- 61.2759

Where the two objectives considered in this analysis: Y_1 = the objective function of income (Baht) in B0902 to B0910

Y_2 –Y_{10} = the objective function of soil erosion (Ton/ha/year)

The objective function of soil erosion and income are defined as : Y_2 =B0902 Y_3 =B0903 Y_4 =B0904 Y_5 =B0905 Y_6 =B0906

Y_7 =B0907 Y_8 =B0908 Y_9 =B0909 Y_{10} =B0910

and the eight decision variables of land-use are defined as: X_1=Natural Forest X_2 = Plantation forest X_3 = Upland Crops

X_4 =Tree X_5=Paddy Field X_6=Grasslands X_7 = Urban

X_8=Water body

3.2 Solution based on LP and Goal Programming

The problems associated with managing land water and other resources have never been simple. The concept of watershed management which tries to compromise economic, and other impacts utilization in the system seems impossible to determine for the best management practice. Because of the desirable conflicts for the maximum or minimum value of each individual objective to achieve its own benefit, the objective in this model is thus manipulated separately corresponding to the same constraint set. However, the solution sets suggest that only two broad-based planning objectives-economic development (net income) and environmental quality (soil loss) need to be considered independently. The LP technique could not combine among objectives while the GP model can plays around with multi-objectives.

The previous objectives and their potential target values or aspiration were formulated in term of multiple objectives management functions. The achievement level of those objectives and land-uses allocation were evaluated using GP model. The model solutions of Upper Nan Basin can be described as follows:

1) GP model in B0902 Upper Nan River

The optimum land-use derived from GP model in B0902 Upper Nan River consists of 48.51% for natural forest (X_1) or 107,811 ha; 21.76% for plantation forest (X_2) or 48,354 ha; 6.42% for upland crops (X_3) or 14,265 ha; 17.44% for tree (X_4) or 38,776 ha; 3.37% for paddy field (X_5) or 7,488 ha; 1.11 % for Grasslands (X_6) or 2,479 ha; 1.10% for urban (X_7) or 2,446 ha; and 0.27% for water body or 601 ha.

2) GP model in B0903 Upper Nan River

The optimum land-use derived from GP model in B0903 Upper Nan River consists of 50.33% for natural forest (X_1) or 39,666ha; 3.20% for plantation forest (X_2) or 2,523 ha; 5.96% for upland crops (X_3) or 4,699 ha; 37.39% for tree (X_4) or

29,471 ha; 0.32 % for paddy field (X_5) or 254 ha; 2.34 % for Grasslands (X_6) or 1,841ha; 0.33 % for urban (X_7) or 261ha; and 0.12 % for water body or 95 ha.

3) GP model in B0904 Upper Nan River

The optimum land-use derived from GP model in B0904 Upper Nan River consists of 43.97 % for natural forest (X_1) or 67,226 ha; 2.20% for plantation forest (X_2) or 3,364 ha; 22.67% for upland crops (X_3) or 34,649 ha; 10.17% for tree (X_4) or 15,546 ha; 11.92 % for paddy field (X_5) or 18,219 ha; 5.92% for Grasslands (X_6) or 9,053 ha; 2.42% for urban (X_7) or 3,704 ha; and 0.73% for water body or 1,113 ha.

4) GP model in B0905 Upper Nan River

The optimum land-use derived from GP And model in B0905 Upper Nan Yaow(2) consists of 50.05% for natural forest (X_1) or 30,601 ha; 0 % for plantation forest (X_2) or 0 ha; 3.157% for upland crops (X_3) or 1,930 ha; 41.12% for tree (X_4) or 25,137 ha; 3.91% for paddy field (X_5) or 2,395 ha; 0.78 % for Grasslands (X_6) or 479 ha; 0.66% for urban (X_7) or 404 ha; and 0.30% for water body or 185 ha.

5) GP model in B0906 Upper Nan River

The optimum land-use derived from GP model in B0906 Upper Nan River consists of 51.97% for natural forest (X_1) or 30,743 ha; 5.10% for plantation forest (X_2) or 3,019ha; 16.12% for upland crops (X_3) or 9,538ha; 11.06% for tree (X_4) or 6,544ha; 12.21% for paddy field (X_5) or 7,223ha; 1.86% for Grasslands (X_6) or 1,102ha; 1.64% for urban (X_7) or 971ha; and 0.03% for water body or 19ha.

6) GP model in B0907 Upper Nan River

The optimum land-use derived from GP model in B0907 Upper Nan River consists of 72.05% for natural forest (X_1) or 244,678ha; 1.44% for plantation forest (X_2) or 4,885ha; 2.65% for upland crops (X_3) or 9,008ha; 15.44% for tree (X_4) or

52,438ha; 0.81% for paddy field (X_5) or 2,737ha; 0.32% for Grasslands (X_6) or 1,100ha; 0.42% for urban (X_7) or 1,439ha; and 6.86% for water body or 23,295ha.

7) GP model in B0908 Upper Nan River

The optimum land-use derived from GP model in B0908 Upper Nan River consists of 75.02% for natural forest (X_1) or 58,403ha; 0.06% for plantation forest (X_2) or 46ha; 13.46% for upland crops (X_3) or 10,479ha; 6.66% for tree (X_4) or 5,181ha; 1.43% for paddy field (X_5) or 1,117ha; 2.53% for Grasslands (X_6) or 1,967ha; 0.47% for urban (X_7) or 366ha; and 0.37% for water body or 289ha.

8) GP model in B0909 Upper Nan River

The optimum land-use derived from GP model in B0909 Upper Nan River consists of 66.70% for natural forest (X_1) or 147,364ha; 8.62% for plantation forest (X_2) or 19,052ha; 1.45% for upland crops (X_3) or 3,200ha; 21.90% for tree (X_4) or 48,388ha; 0.61% for paddy field (X_5) or 1,357ha; 0.20% for Grasslands (X_6) or 440ha; 0.12% for urban (X_7) or 276ha; and 0.40% for water body or 873ha.

9) GP model in B0910 Upper Nan River

The optimum land-use derived from GP model in B0910 Upper Nan River consists of 45.89% for natural forest (X_1) or 47,948ha; 4.34% for plantation forest (X_2) or 4,532ha; 20.45 for upland crops (X_3) or 21,364ha; 24.27% for tree (X_4) or 25,364ha; 3.02% for paddy field (X_5) or 3,154ha; 1.00% for Grasslands (X_6) or 1,043ha; 0.90% for urban (X_7) or 940ha; and 0.14% for water body or 149ha.

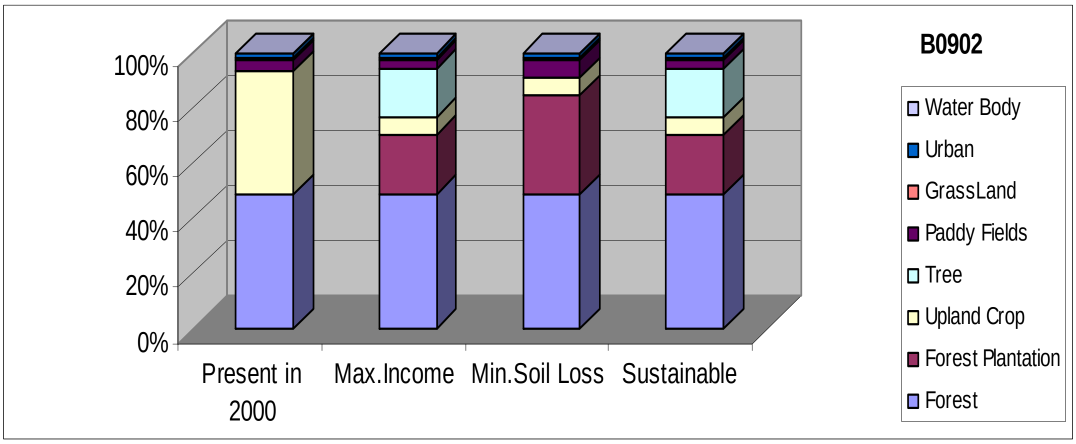
The output details of LP and GP model as shown in Table32 Figure 36 and Appendix B

Table 32 Solution for optimization of land-use and soil loss based on Goal Programming

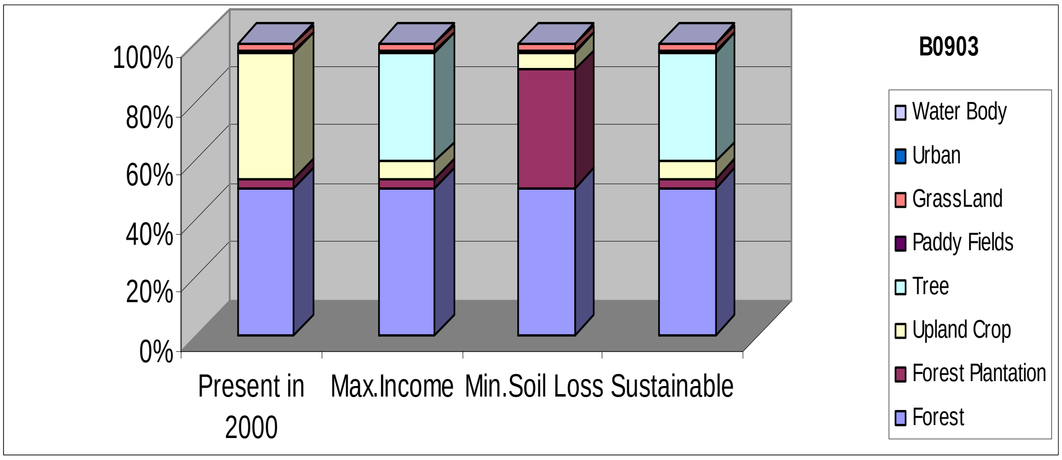
Sub-basin Code	Land-use Type	Present in 2000(%)	Solution from LP(%)		Solution from GP(%)	
			Max.Income	Min.Soil Loss	Sustainable	Difference
B0902	Forest	48.51	48.52	48.52	48.52	0.00
	Forest Plantation	0.24	21.76	36.02	21.76	21.52
	Upland Crop	44.52	6.42	6.42	6.42	-38.10
	Tree	0.50	17.45	0.50	17.45	16.95
	Paddy Fields	3.74	3.37	6.06	3.37	-0.37
	Grasslands	1.12	1.12	1.12	1.12	0.00
	Urban	1.10	1.10	1.10	1.10	0.00
	Water Body	0.27	0.27	0.27	0.27	0.00
B0903	Forest	50.33	50.33	50.33	50.33	0.00
	Forest Plantation	3.20	3.20	40.52	3.20	0.00
	Upland Crop	43.25	5.96	5.96	5.96	-37.29
	Tree	0.07	37.39	0.07	37.39	37.32
	Paddy Fields	0.36	0.32	0.32	0.32	-0.04
	Grasslands	2.34	2.34	2.34	2.34	0.00
	Urban	0.33	0.33	0.33	0.33	0.00
	Water Body	0.12	0.12	0.12	0.12	0.00
B0904	Forest	43.97	43.97	43.97	43.97	0.00
	Forest Plantation	2.20	2.20	2.20	2.20	0.00
	Upland Crop	22.38	22.67	22.67	22.67	0.28
	Tree	9.13	10.17	10.17	10.17	1.04
	Paddy Fields	13.24	11.92	11.92	11.92	-1.32
	Grasslands	5.92	5.92	5.92	5.92	0.00
	Urban	2.42	2.42	2.42	2.42	0.00
	Water Body	0.73	0.73	0.73	0.73	0.00
B0905	Forest	51.75	50.06	50.06	50.06	0.00
	Forest Plantation	0.00	0.00	37.52	0.00	0.00
	Upland Crop	38.65	3.16	3.16	3.16	-35.49
	Tree	3.29	41.12	3.18	41.12	37.83
	Paddy Fields	4.50	3.92	4.34	3.92	0.00
	Grasslands	0.81	0.78	0.78	0.78	0.00
	Urban	0.68	0.66	0.66	0.66	0.00
	Water Body	0.31	0.30	0.30	0.30	0.00

Table 32(con't) Solution for optimization of land-use and soil loss based on Goal Programming

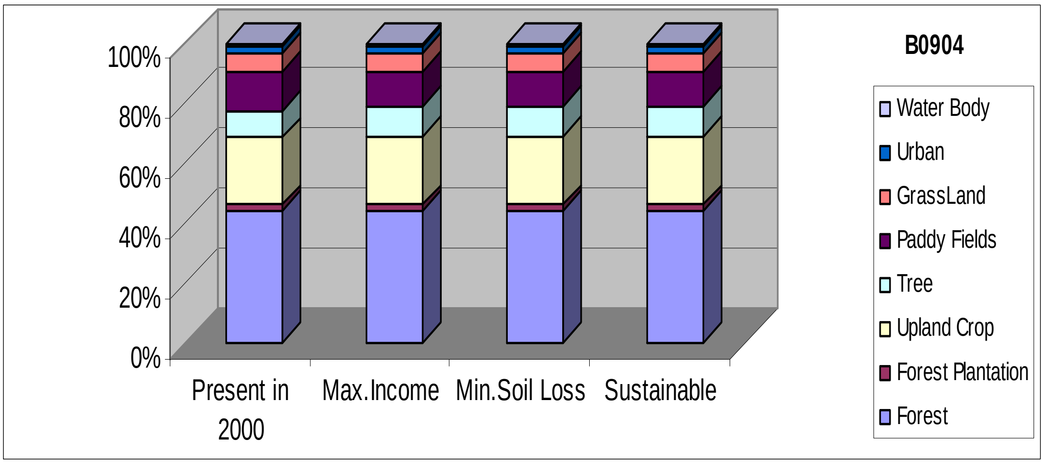
Sub-basin Code	Land-use Type	Present in 2000(%)	Solution from LP(%)		Solution from GP(%)	
			Max.Income	Min.Soil Loss	Sustainable	Difference
B0906	Forest	51.97	51.97	51.97	51.97	0.00
	Forest Plantation	5.10	5.10	5.10	5.10	0.00
	Upland Crop	19.08	16.12	16.12	16.12	-2.96
	Tree	6.04	11.06	11.06	11.06	5.02
	Paddy Fields	14.27	12.21	12.21	12.21	-2.06
	Grasslands	1.86	1.86	1.86	1.86	0.00
	Urban	1.64	1.64	1.64	1.64	0.00
	Water Body	0.03	0.03	0.03	0.03	0.00
B0907	Forest	72.48	72.05	72.05	72.05	0.00
	Forest Plantation	1.45	1.44	1.44	1.44	0.00
	Upland Crop	17.00	2.65	10.86	2.65	-14.35
	Tree	0.52	15.44	0.51	15.44	14.93
	Paddy Fields	0.90	0.81	7.53	0.81	-0.09
	Grasslands	0.33	0.32	0.32	0.32	0.00
	Urban	0.43	0.42	0.42	0.42	0.00
	Water Body	6.90	6.86	6.86	6.86	0.00
B0908	Forest	75.02	75.02	75.02	75.02	0.00
	Forest Plantation	0.06	0.06	0.06	0.06	0.00
	Upland Crop	19.29	13.46	19.45	13.46	-5.83
	Tree	0.67	6.66	0.67	6.66	5.99
	Paddy Fields	1.59	1.43	1.43	1.43	-0.16
	Grasslands	2.53	2.53	2.53	2.53	0.00
	Urban	0.47	0.47	0.47	0.47	0.00
	Water Body	0.37	0.37	0.37	0.37	0.00
B0909	Forest	66.70	66.70	66.70	66.70	0.00
	Forest Plantation	0.07	8.62	30.37	8.62	8.55
	Upland Crop	31.68	1.45	1.45	1.45	-30.23
	Tree	0.15	21.90	0.15	21.90	21.75
	Paddy Fields	0.68	0.61	0.61	0.61	-0.07
	Grasslands	0.20	0.20	0.20	0.20	0.00
	Urban	0.12	0.12	0.12	0.12	0.00
	Water Body	0.40	0.40	0.40	0.40	0.00
B0910	Forest	45.89	45.89	45.89	45.89	0.00
	Forest Plantation	4.34	4.34	4.34	4.34	0.00
	Upland Crop	43.81	20.45	20.45	20.45	-23.36
	Tree	0.57	24.27	24.27	24.27	23.70
	Paddy Fields	3.35	3.02	3.02	3.02	-0.34
	Grasslands	1.00	1.00	1.00	1.00	0.00
	Urban	0.90	0.90	0.90	0.90	0.00
	Water Body	0.14	0.14	0.14	0.14	0.00



(a) B0902

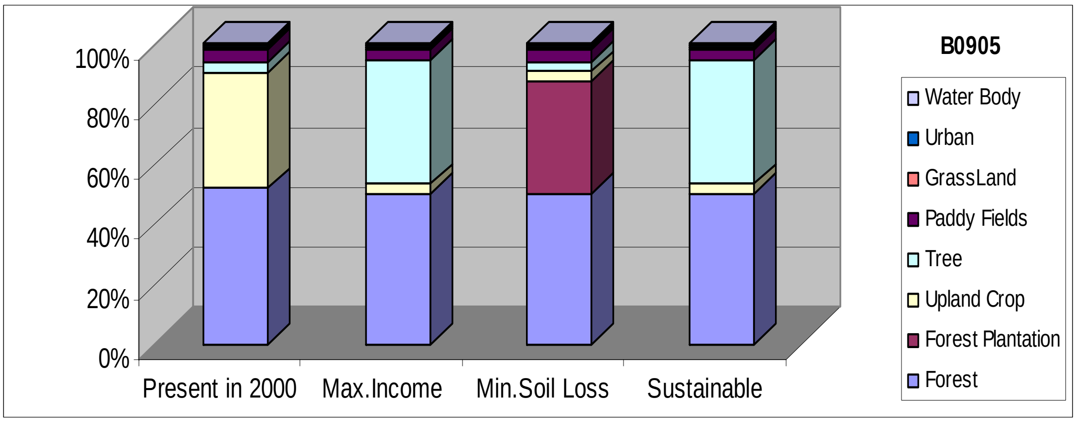


(b) B0903

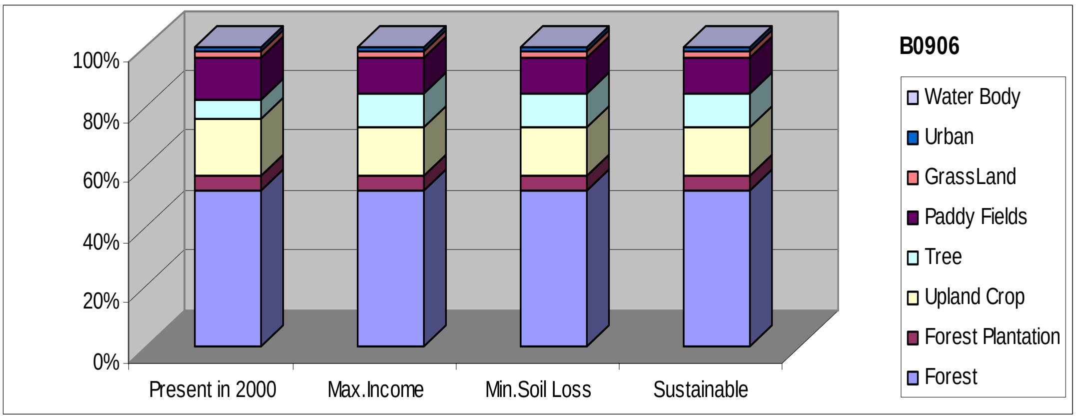


(c) B0904

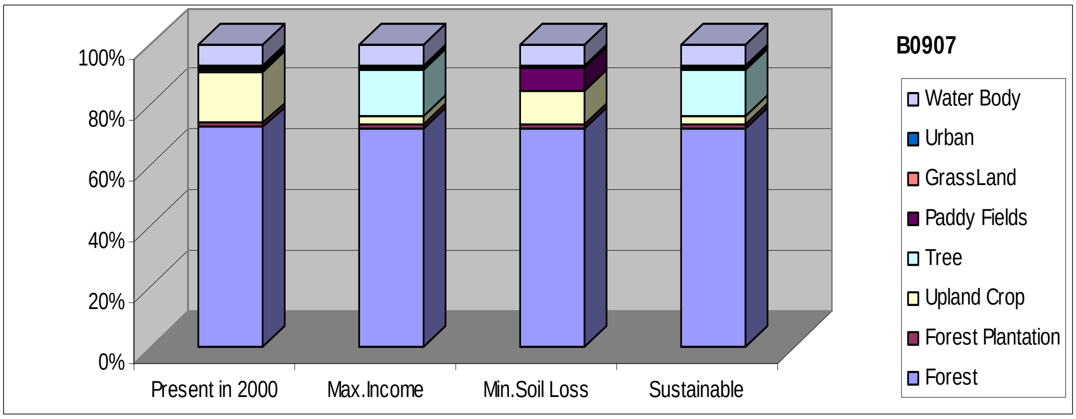
Figure 36 Chart showing the solution based on Goal Programming



(d) B0905

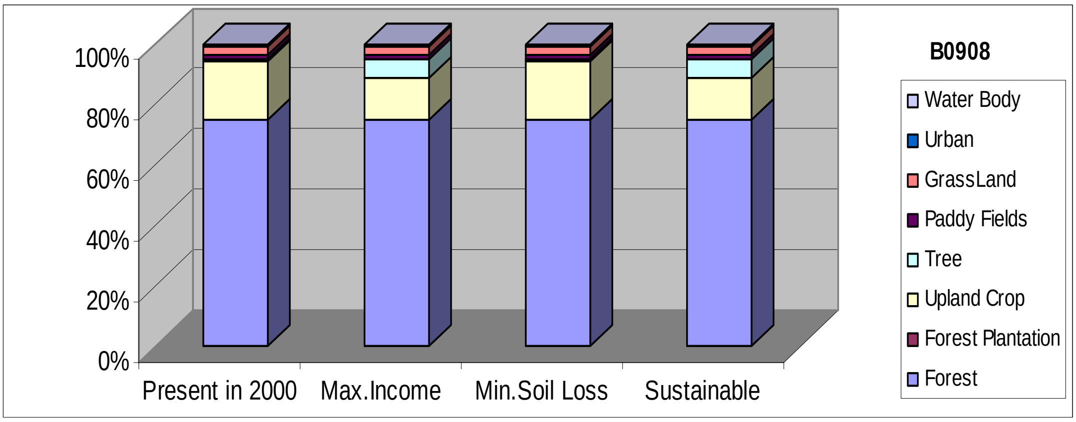


(e) B0906

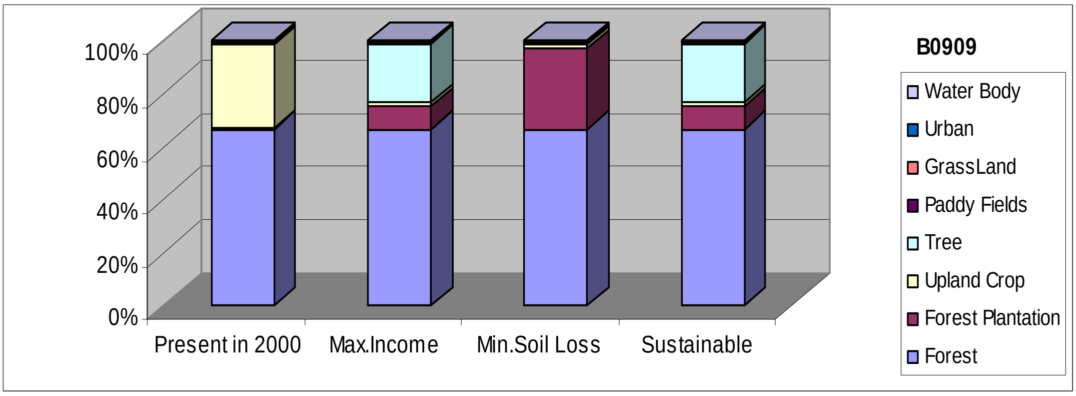


(f) B0907

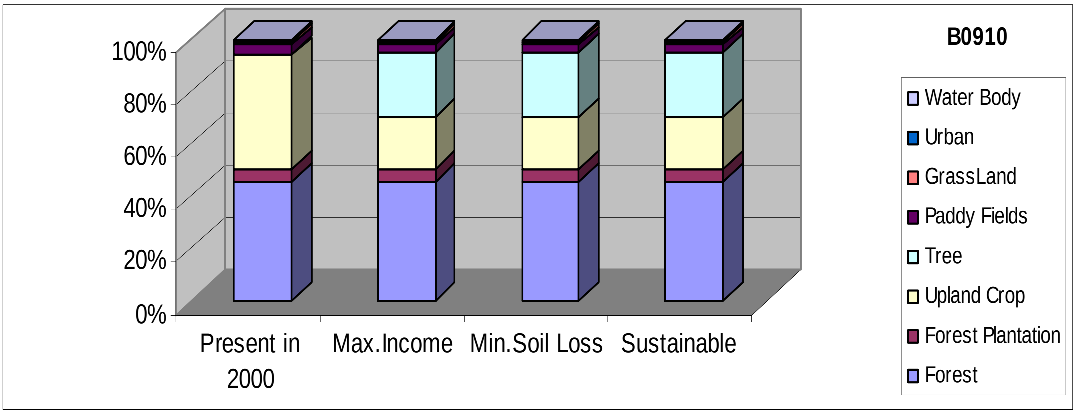
Figure 36(Con't) Chart showing the solution based on Goal Programming



(g) B0908



(h) B0909



(i) B0910

Figure 36(Con't) Chart showing the solution based on Goal Programming

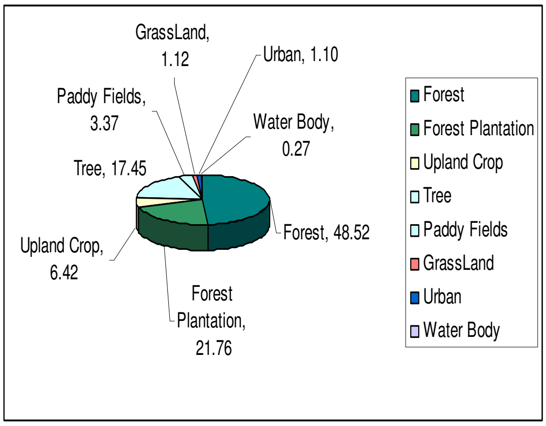
3.3 Mapping New Location of Land-use after Optimization and Conservation Prioritization

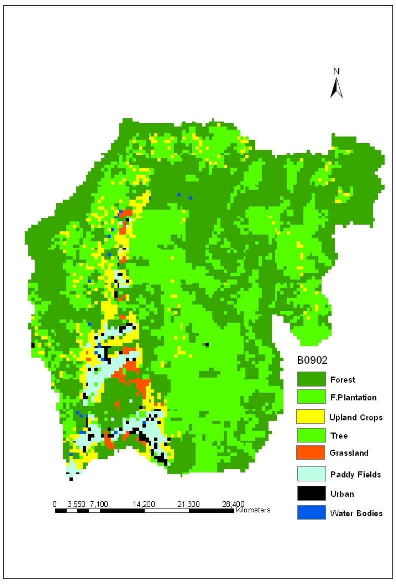
The final step of DSS involves with the geographical distribution of different land-uses allocation proportion derived from Table 32 and Conservation Prioritization of the Sub-watersheds from Table 29, Based on the methodology section 2.6.2 is needed for new land-use according to result of GP. Mapping new location of land-use after optimization and conservation prioritization as following;

3.3.1 Land-use Mapping for First Conservation Priority

Land-use mapping for first conservation priority namely ; B0902 Upper Nan River

The optimum land-use derived from GP model in B0902 Upper Nan River consists of 48.52% for natural forest (X_1) or 107,811 ha; 21.76% for plantation forest (X_2) or 48,354 ha; 6.42% for upland crops (X_3) or 14,265 ha; 17.44% for tree (X_4) or 38,776 ha; 3.37% for paddy field (X_5) or 7,488 ha; 1.11 % for grasslands (X_6) or 2,479 ha; 1.10% for urban (X_7) or 2,446 ha; and 0.27% for water body or 601 ha is shown in Figure 37a and the geographical distribution of different land-uses allocation proportion by GIS technique is shown in Figure 37b





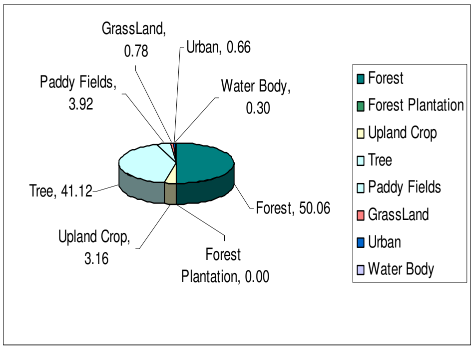
(a) proportion of land-use	(b)geographical distribution of land-uses

Figure 37 Pie chart showing land-use proportion(a) and geographical distribution mapping(b) based on goal programming solution for first conservation priority ; B0902 Upper Nan River sub-watershed

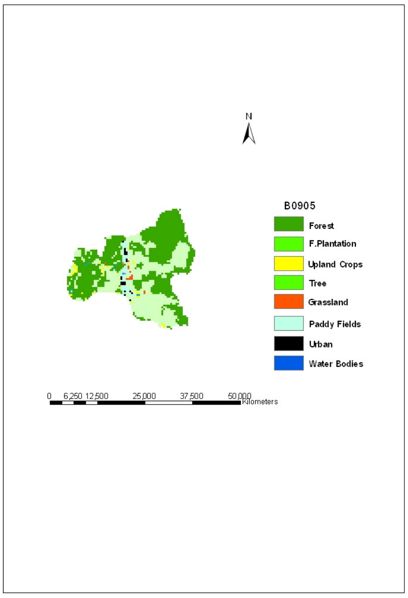
3.3.2 Land-use Mapping for Second Priority ; B0909

1) Optimization mapping for B0905 Nam Yaow(2)

The optimum land-use derived from GP and model in B0905 Nam Yaow(2) consists of 50.05% for natural forest (X_1) or 30,601 ha; 0 % for plantation forest (X_2) or 0 ha; 3.157% for upland crops (X_3) or 1,930 ha; 41.12% for tree (X_4) or 25,137 ha; 3.91% for paddy field (X_5) or 2,395 ha; 0.78 % for grasslands (X_6) or 479 ha; 0.66% for urban (X_7) or 404 ha; and 0.30% for water body or 185 ha. is shown in Figure 38a and the geographical distribution of different land-uses allocation proportion by GIS technique is shown in Figure 38b



(a) proportion of land-use

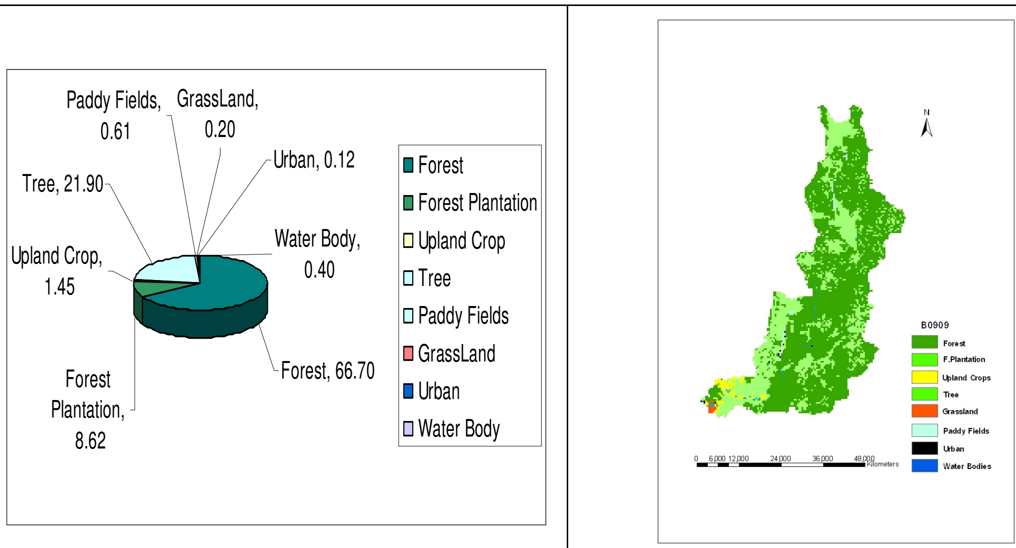


(b)geographical distribution of land-uses

<u>Figure 38</u> Pie chart showing land-use proportion(a) and geographical distribution mapping(b) based on goal programming solution for second conservation priority ; B0905 Nam Yaow(2) sub-watershed

2) Optimization mapping for B0909 Nam Hwa

The optimum land-use derived from GP model in B0909 Upper Nan River consists of 66.70% for natural forest (X_1) or 147,364ha; 8.62% for plantation forest (X_2) or 19,052ha; 1.45% for upland crops (X_3) or 3,200ha; 21.90% for tree (X_4) or 48,388ha; 0.61% for paddy field (X_5) or 1,357ha; 0.20% for grasslands (X_6) or 440ha; 0.12% for urban (X_7) or 276ha; and 0.40% for water body or 873ha. is shown in Figure 39a. and the geographical distribution of different land-uses allocation proportion by GIS technique is shown in Figure 39b.



(a) proportion of land-use	(b) geographical distribution of land-uses

Figure 39 Pie chart showing land-use proportion(a) and geographical distribution mapping(b) based on goal programming solution for second conservation priority ; B0909 Nam Hwa sub-watershed.

3.3.3 Land-use Mapping for Third, Fourth and Fifth Conservation Priority

In the same manner, land-use proportion and geographical distribution mapping based on goal programming solution for Third conservation priority ; B0903 Nam Yaow, B0908 Nam Sa and B0910 Nam Hang sub- watershed as shown in Figure 40 and for Fourth conservation priority; B0906 Nam Samoon and B0907 Nan River (3) sub-watershed as shown in Figure 41 and Fifth conservation Priority ; B0904 Nan River(2) sub-watershed as shown in Figure 42

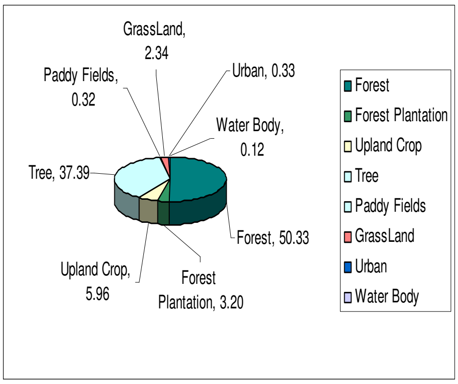
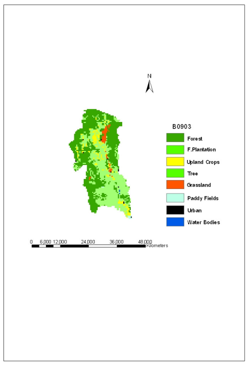
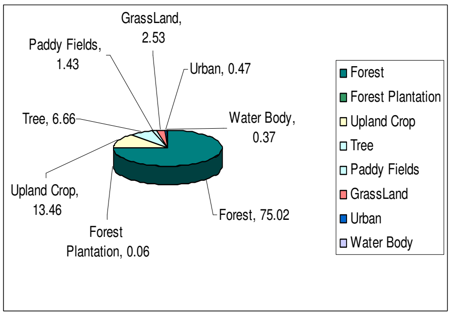
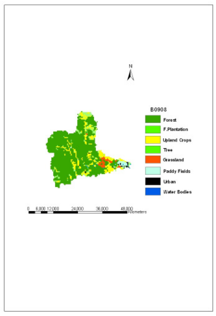
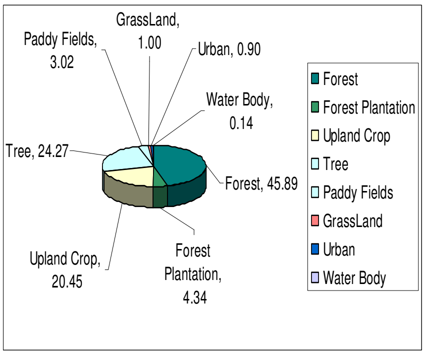
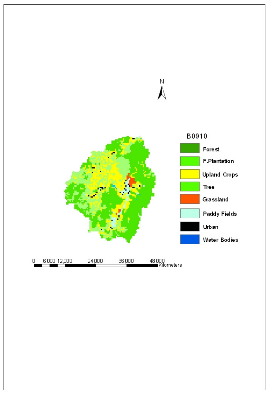
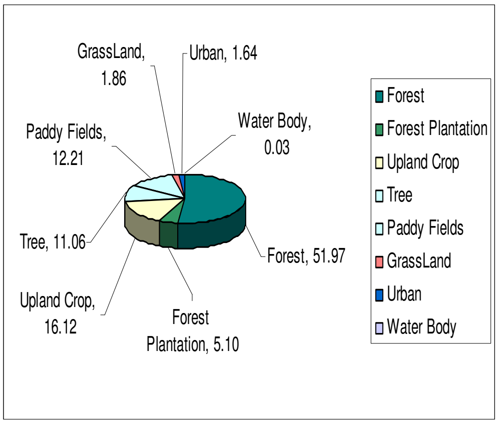
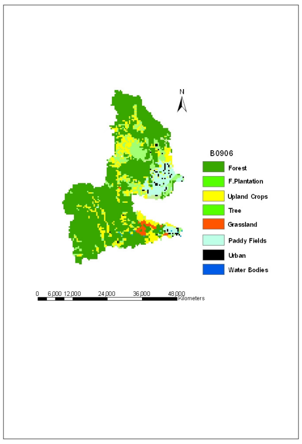
	
(a) proportion of land-use of B0903 Nam Yaow sub-watershed	(b) geographical distribution of land-uses of B0903 Nam Yaow sub-watershed
	
(c) proportion of land-use of B0908 Nam Sa sub-watershed	(d) geographical distribution of land-uses of B0908 Nam Sa sub-watershed
	
(e) proportion of land-use of B0910 Nam Hang sub-watershed	(f) geographical distribution of land-uses of B0910 Nam Hang sub-watershed

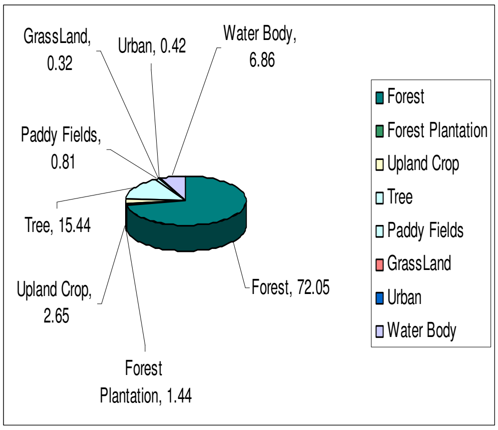
Figure 40 Pie chart showing land-use proportion and geographical distribution mapping based on goal programming solution for Third Conservation Priority; B0903 Nam Yaow, B0908 Nam Sa and B0910 Nam Hang sub-watershed



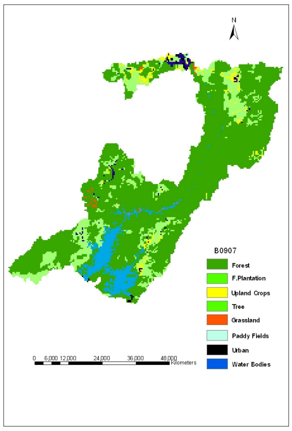
(a) proportion of land-use of B0906 Nam Samoon sub-watershed



(b) geographical distribution of land-uses of B0906 Nam Samoon sub-watershed



(c) proportion of land-use of B0907 Nan River (3) sub-watershed



(d) geographical distribution of land-use of B0907 Nan River (3) sub-watershed

Figure 41 Pie chart showing land-use proportion and geographical distribution mapping based on goal programming solution for Forth Conservation Priority; B0906 Nam Samoon and B0907 Nan River (3) sub-watershed

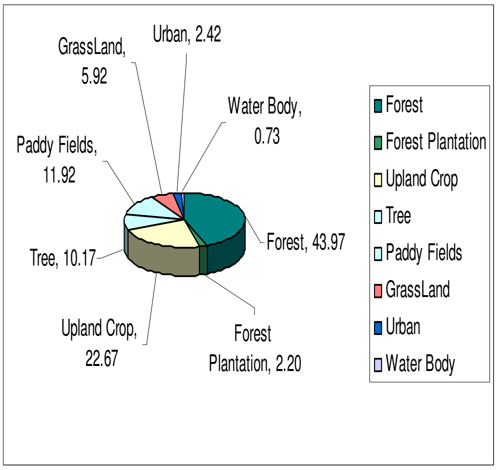
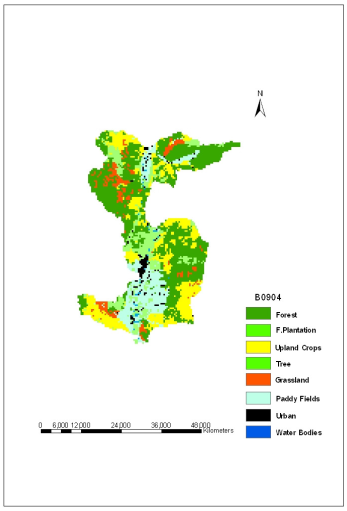
	
(a) proportion of land-use of B0904 Nan River(2)	(b)geographical distribution of land-use of B0904 Nan River(2)

Figure 42 Pie chart showing land-use proportion and geographical distribution mapping based on goal programming solution for Fifth Conservation Priority ; B0904 Nan River(2) sub-watershed

CONCLUSIONS AND RECOMMENDATIONS

1. Conclusions

The decision support system (DSS) herein is a typical SDSS (Spatial Decision Support System) developed for formulating the plans for highland Basin conservation and rehabilitation in Upper Nan Basin, Northern Thailand. It is a mathematical combination approach consisting of linear programming (LP), goal programming (GP), and Geographic Information System (GIS). The tools employed for deriving the in this study were Statgraphics Plus 5.0, LINDO software, and GIS system of Arc View program. Model generated are Overall Upper Nan Land-use Planning-DSS, Priority of Sub-watershed Degradation-SDSS and Optimal Sub-watershed Land-use Relocation-SDSS. Following the results described before under these three models, conclusions and recommendations can be drawn as follows:

1.1 Overall Upper Nan Land-use Planning DSS (Land-use and Land Cover Change from 1977 to 2000 and its trend up to 2012)

The result derived from land-use transformation coefficient and the remaining land-uses during 1977 to 1994 indicates a decrease of forest area at about 88,575 ha or about 6.75 percent of the study area, while the others land-use categories were increased. The largest increased category was upland crops, it was increased about 84,675 ha or 6.45 percent of the study area. In the same way, the result derived from land-use transformation coefficient and the remaining land-use between 1994 to 2000 indicates a decrease of forest area at about 325,150 ha or about 24.76 percent of the studied area, while the others classes were increased. The largest increased category was upland crops, It was increased about 281,950 ha or 21.47 percent of the study area more than change between 1977 to 1994

Trend of land-use types year by year from 2000 to 2012 as predicted by Markov Chain model and mathematical model indicate that a decrease of forest area will decrease continuously from year 2000 and will stand at about 559,131 ha (42.48

percent) or 16.35 percent decreased from 2000 to 2012, while Upland Crops will increase a little only 1.16 percent, but Tree/Fruit Tree/Forest Plantation in creasing about 12.16 percent. It means in the future Upland Crops will rather stable in change while Tree/Fruit/ Forest Plantation tree will replace the forest area.

1.2 Priority of Sub-watershed Degradation SDSS:PSD-SDSS

1.2.1 Overall land-use change and soil loss increment Upper Nan Basin

Analyzing overall land-use change and soil loss increment in Upper Nan Basin for the duration of 23 years, between 1977 and 2000 showed that the rate for forest loss of the study area was 1.48 percent per year, which was too high while considering the sustainability, along with 0.09 ton/ha./year increment in soil erosion rate . Because decrease in forest area was found continued due to agriculture area expansion that resulted increase in soil loss.

1.2.2 Conservation prioritization solutions and mapping of Sub-watersheds, Upper Nan Basin

Applying GIS technique, sub-watershed conservation prioritization solutions and mapping was made with three condition Indicators ; DSI:degradation speed of the sub-watersheds, SI :Sensitivity Index between forest Loss (%) and soil loss increment, PEI: Present Environment Impact Index (the soil erosion rate of the present year 2000) .By simple weighting method of three condition Indicators, 9 sub watersheds of Upper Nan Basin, the conservation prioritization solutions of Upper Nan Basin are as follows ;First Priority (P1): B0902 Upper Nan River ;Second Priority (P2)**:** B0905 Nam Yaow(2) and B0909 Nam Hwa ;Third Priority (P3): B0903 Nam Yaow, B0908 Nam Sa and B0910 Nam Hang ; Fourth Priority (P4): B0906 Nam Samoon and B0907 Nan River (3) and Fifth Priority (P5) :B0904 Nan River(2) . So, it can be recommended that conservation and rehabilitation work in the Upper Nan Basin area should be started according to the priority list. Slope stabilization, slope failure protection, gully control by check dam, reforestation, growing of horticultural crop along with some other intensive soil conservation activities are required for the first and second ranking sub-watersheds. Fifth ranking sub-watershed need little attention like maintaining the crown cover and protection of the existing forest along with managed agriculture. Other sub-watersheds should be treated by intermediate activities according to their ranks.

3. Mapping New Location of Land-use after Optimization and Conservation Prioritization

3.1 Relationship between soil loss and land-use/land cover change

The relationship between soil loss in tons (Y_2 = B0902, Y_3=B0903, Y_4 =B0904 Y_5 =B0905, Y_6 =B0906, Y_7 =B0907, Y_8 =B0908, Y_9 =B0909, Y_{10} =B0910) and land-use/land cover change in ha in each sub-watershed as derived by Statgraphics Plus 5.0 software and mathematic model are shown below. The decision variable coefficients are X_1 indicating Forest, X_2 indicating Forest plantation, X_3 indicating Upland crops, X_4 indicating Tree, X_5 indicating Paddy fields, X_6 indicating Grass land),X_7 indicating Urban, X_8 indicating Water body.

$$Y_2 \text{ (B0902)} = 1.20258E7 + 9.28365*x1 - 51.5547*x2 + 9.43485*x3 - 1.81567*x4 - 1109.08*x5 - 1173.9*x6 - 23.5651*x7 - 80.1302*x8$$

$$Y_3 \text{ (B0903)} = 438002.0 - 4.60793*x1 - 60.5056*x2 - 8.68038*x3 + 4021.54*x4 - 2.0167*x5 + 11.1698*x6 + 0.272232*x7 + 2018.99*x8$$

$$Y_4 \text{ (B0904)} = -5.01001E6 + 12.5246*x1 - 1.34559*x2 + 18.697*x3 -91.45*x4 - 27.4486*x5 + 547.693*x6 + 181.243*x7 + 19.1435*x8$$

$$Y_5 \text{ (B0905)} = -55719.2 - 0.312173*x1 + 3.64547*x3 + 6.55382*x4 - 0.148966*x5 + 415.349*x6 - 28.6095*x7 - 74.0686*x8$$

$$Y_6 \text{ (B0906)} = 63807.7 - 0.554977*x1 - 0.057742*x2 + 1.31728*x3 - 1.79714*x4 - 1.14136*x5 + 69.3637*x6 + 0.47578*x7 - 40.9012*x8$$

$$Y_7 \text{ (B0907)} = 6.46037E6 + 10.0686*x1 + 0.026482*x2 - 0.231121*x3 + 145.624*x4 - 47.5843*x5 - 16.2446*x6 - 0.548*x7 - 347.562*x8$$

$$Y_8 \text{ (B0908)} = 644121.0 - 7.3085*x1 + 377.989*x2 + 0.889424*x3 + 6.95743*x4 + 16.4288*x5 - 12.9888*x6 - 9.90524*x7 - 35.2427*x8$$

$$Y_9 \text{ (B0909)} = 358989.0 - 4.85935*x1 - 23512.8*x2 + 42.2406*x3 - 3741.05*x4 + 518.754*x5 + 305.818*x6 + 1734.29*x7 + 2026.69*x8$$

$$Y_{10} \text{ (B09010)} = -297469.0 - 3.95231*x1 + 0.3017*x2 + 2.36345*x3 - 9.57867*x4 + 174.975*x5 + 91.7972*x6 + 27.4614*x7 - 61.2759*x8$$

The decision variable coefficients as found in the above model have negative value (e.g. Y_2) in case of some sub-watersheds which imply increase in area of some land-use result decreasing soil loss, while that have positive value in case of some sub -watersheds which imply increase in area of some land-use result increasing soil loss. So soil loss vary with the land-use types and location in each of sub-watershed (e.g. % slope, soil erodibility properties, etc.)

2) **<u>Mapping the GP Results</u>**

Through optimization of land-use proportion, GP does not provide a spatial representation for the resulted land-use allocation. Two approaches were applied to solve this solution, i.e., GIS and GP based on criteria of watershed class, slope, rate of soil loss and local boundary for relocating suitable land-use. For First Conservation Priority; B0902 Upper Nan River Sub-watershed about 48,354 ha or 21.76 % of non-forest area are needed for mapping a new relocated forest plantation area according to the GP model (land-use proportion and geographical distribution mapping)

2. Recommendations

The study provided the useful recommendations for both improving the Upper Nan Basin Management Planning and for further studies as follows:

2.1 Resource Management

1) Concerning forestry policy, Thailand should have the forest land not less than 40% of the country area, but in order to reduce rate of soil erosion, based on land-use/ land cover change, especially in high land area or head forest watershed like Upper Nan Basin, the forest area were followed by Watershed Class Area especially WSC1 and WSC2 of the whole head forest watershed area in northern of Thailand.

2) The problems of catchments area of major rivers in Thailand which are being largely degraded by forest encroachment and agricultural exploitation are now the serious situation of the country. The effects have caused severe erosion and sediment transportation downstream as well as many other changes in hydrological characteristics. The crisis has become more serious in this decade from consequent effects of flash flood alternate with water shortage. Then the need of watershed management concept should be taken into consideration of watershed system.

3) Delineating the watershed area into sub-watershed for priority based conservation work is essential and appropriate for the developing region like northern Thailand. Remote sensing and GIS in combination with USLE model can be used as appropriate tools for sub-watershed prioritization.

4) Overall, final linear programming solutions suggest that increasing the forest plantation area including trees/fruit trees could be feasible for producing more net income and reducing rate of soil loss if Upper Nan Basin communities are considered for playing their role in conservation activities.

5) The suggested prediction equation containing forestland and soil loss parameters also implies management techniques in reducing rate of soil loss by means of land-use practices in Upper Nan Basin. Agriculture land in the Upper Nan Basin upland should be practices under soil conservation measures such as contour banking for cultivation so that on site soil erosion could be reduced while the farmers could gain more benefit from using the area as agricultural land.

6) In the future, if the government would like to make multi-dimensional plans for natural resource management to improve not only higher net income and environmental impact but also have to satisfy social needs; this SDSS could provide better planning predicting land allocation and revision until meeting the real needs of all the stakeholder before taking any action plans.

7) As Upper Nan Basin are mountainous with more than 85% of high land, all conservation and rehabilitation activities should include planting vetiver grass. The line of vetiver grass will reduce runoff as well, prolongs construction like road, dam and irrigation canal since it stabilizes the soil .

2.2 Technical Problems and Further Investigation

1) Land evaluation for changes in land-use is a more complex task, and at present the options are limited by the availability and scale of fundamental data. Information used in GIS such as aerial photographs came from the various sources and different in the year of taking and also in scale, some of them have not been rectified, this might give incorrect information. Thus, in order to obtain the correct output, the circumspection of digitize is needed.

2) The models used in this study are the lump model, which is very good to forecast land-use change and rate of soil loss, but could not explain spatial natural phenomena. For further study, the model as hydrological and mathematics could be established as a distributed model so that every pixels or grids (if enough data, computer random capacity available) can be accounted in phenomena .

3) In term of relocated land-use map in other watersheds, it should be processes. better if the current computer had high capacity and could select smaller pixel or grid size. The small pixel size can also reduce the error (in case of area)

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APPENDIX A

MULTIPLE REGRESSION ANALYSIS PART

Multiple Regression Analysis :Soil loss_B0902

X_1=Natural Forest X_2 = Plantation forest X_3 = Upland Crops X_4 =Tree
X_5=Paddy Field X_6=Grass land X_7 = Urban X_8=Water body

Dependent variable: soil loss_B0902

Parameter	Estimate	Standard Error	T Statistic	P-Value
CONSTANT	1.20258E7	1.61534E6	7.44478	0.0850
x1	9.28365	1.5481	5.99679	0.1052
x2	-51.5547	39.7291	-1.29766	0.4180
x3	9.43485	1.90984	4.94012	0.1271
x4	-1.81567	1.25885	-1.44232	0.3859
x5	-1109.08	149.954	-7.39614	0.0856
x6	-1173.9	199.503	-5.88415	0.1072
x7	-23.5651	2.10726	-11.1828	0.0568
x8	-80.1302	267.392	-0.299673	0.8146

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	1.86187E12	8	2.32734E11	4323901.92	0.0004
Residual	53825.0	1	53825.0		
Total (Corr.)	1.86187E12	9			

R-squared = 99.0 percent R-squared (adjusted for d.f.) = 100.0 percent
Standard Error of Est. = 232.002 Mean absolute error = 52.3772
Durbin-Watson statistic = 3.58803

THE EXPLAINING RESULTS :Soil loss_B0902

The output shows the results of fitting a multiple linear regression model to describe the relationship between soil loss_B0902 and 8 independent variables. The equation of the fitted model is

soil loss_B0902 = 1.20258E7 + 9.28365*x1 - 51.5547*x2 + 9.43485*x3 -1.81567*x4 - 1109.08*x5 - 1173.9*x6 - 23.5651*x7 - 80.1302*x8

Since the P-value in the ANOVA table is less than 0.01, there is a statistically significant relationship between the variables at the 99% confidence level.

The R-Squared statistic indicates that the model as fitted explains 100.0% of the variability in soil loss_B0902. The adjusted R-squared statistic, which is more suitable for comparing models with different numbers of independent variables, is 100.0%. The standard error of the estimate shows the standard deviation of the residuals to be 232.002. This value can be used to construct prediction limits for new observations by selecting the Reports option from the text menu. The mean absolute error (MAE) of 52.3772 is the average value of the residuals. The Durbin-Watson (DW) statistic tests the residuals to determine if there is any significant correlation based on the order in which they occur in your data file. Since the DW value is greater than 1.4, there is probably not any serious autocorrelation in the residuals.

In determining whether the model can be simplified, notice that the highest P-value on the independent variables is 0.8146, belonging to x8. Since the P-value is greater or equal to 0.10, that term is not statistically significant at the 90% or higher confidence level. Consequently, you should consider removing x8 from the model.

Multiple Regression Analysis :Soil loss_B0903

X_1=Natural Forest X_2 = Plantation forest X_3 = Upland Crops X_4 =Tree

X_5=Paddy Field X_6=Grass land X_7 = Urban X_8=Water body

Dependent variable: soil loss_B0903

Parameter	Estimate	Standard Error	T Statistic	P-Value
CONSTANT	438002.0	131868.0	3.32153	0.1862
x1	-4.60793	1.5298	-3.0121	0.2041
x2	-60.5056	24.4348	-2.47621	0.2443
x3	-8.68038	5.40655	-1.60553	0.3546
x4	4021.54	1565.66	2.56859	0.2364
x5	-2.0167	3.08717	-0.653253	0.6316
x6	11.1698	1.71268	6.52183	0.0969
x7	0.272232	0.1632	1.66809	0.3438
x8	2018.99	940.858	2.1459	0.2776

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	3.08191E10	8	3.85239E9	***********	0.0001
Residual	19.4269	1	19.4269		
Total (Corr.)	3.08191E10	9			

R-squared = 99.0 percent R-squared (adjusted for d.f.) = 100.0 percent

Standard Error of Est. = 4.4076 Mean absolute error = 0.854385

Durbin-Watson statistic = 3.5901

THE EXPLAINING RESULTS :Soil loss_B0903

The output shows the results of fitting a multiple linear regression model to describe the relationship between soil loss_B0903 and 8 independent variables. The equation of the fitted model is

soil loss_B0903 = 438002.0 - 4.60793*x1 - 60.5056*x2 - 8.68038*x3 + 4021.54*x4 - 2.0167*x5 + 11.1698*x6 + 0.272232*x7 + 2018.99*x8

Since the P-value in the ANOVA table is less than 0.01, there is a statistically significant relationship between the variables at the 99% confidence level.

The R-Squared statistic indicates that the model as fitted explains 100.0% of the variability in soil loss_B0903. The adjusted R-squared statistic, which is more suitable for comparing models with different numbers of independent variables, is 100.0%. The standard error of the estimate shows the standard deviation of the residuals to be 4.4076. This value can be used to construct prediction limits for new observations by selecting the Reports option from the text menu. The mean absolute error (MAE) of 0.854385 is the average value of the residuals. The Durbin-Watson (DW) statistic tests the residuals to determine if there is any significant correlation based on the order in which they occur in your data file. Since the DW value is greater than 1.4, there is probably not any serious autocorrelation in the residuals.

In determining whether the model can be simplified, notice that the highest P-value on the independent variables is 0.6316, belonging to x5. Since the P-value is greater or equal to 0.10, that term is not statistically significant at the 90% or higher confidence level. Consequently, you should consider removing x5 from the model.

Multiple Regression Analysis :Soil loss_B0904

X_1=Natural Forest X_2 = Plantation forest X_3 = Upland Crops X_4 =Tree
X_5=Paddy Field X_6=Grass land X_7 = Urban X_8=Water body

Dependent variable: soil loss_B0904

Parameter	Estimate	Standard Error	T Statistic	P-Value
CONSTANT	-5.01001E6	4.54831E6	-1.10151	0.4693
x1	12.5246	12.8603	0.973897	0.5084
x2	-1.34559	0.677489	-1.98615	0.2969
x3	18.697	15.4882	1.20718	0.4404
x4	-91.45	82.5085	-1.10837	0.4673
x5	-27.4486	24.8818	-1.10316	0.4688
x6	547.693	463.644	1.18128	0.4472
x7	181.243	164.981	1.09857	0.4701
x8	19.1435	5.6498	3.38835	0.1827

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	2.79746E10	8	3.49682E9	222465.07	0.0016
Residual	15718.5	1	15718.5		
Total (Corr.)	2.79746E10	9			

R-squared = 99.9999 percent R-squared (adjusted for d.f.) = 99.9995 percent

Standard Error of Est. = 125.373 Mean absolute error = 33.1224

Durbin-Watson statistic = 3.66117

THE EXPLAINING RESULTS : Soil loss_B0904

The output shows the results of fitting a multiple linear regression model to describe the relationship between soil loss_B0904 and 8 independent variables. The equation of the fitted model is

soil loss_B0904 = -5.01001E6 + 12.5246*x1 - 1.34559*x2 + 18.697*x3 -91.45*x4 - 27.4486*x5 + 547.693*x6 + 181.243*x7 + 19.1435*x8

Since the P-value in the ANOVA table is less than 0.01, there is a statistically significant relationship between the variables at the 99% confidence level.

The R-Squared statistic indicates that the model as fitted explains 99.9999% of the variability in soil loss_B0904. The adjusted R-squared statistic, which is more suitable for comparing models with different numbers of independent variables, is 99.9995%. The standard error of the estimate shows the standard deviation of the residuals to be 125.373. This value can be used to construct prediction limits for new observations by selecting the Reports option from the text menu. The mean absolute error (MAE) of 33.1224 is the average value of the residuals. The Durbin-Watson (DW) statistic tests the residuals to determine if there is any significant correlation based on the order in which they occur in your data file. Since the DW value is greater than 1.4, there is probably not any serious autocorrelation in the residuals.

In determining whether the model can be simplified, notice that the highest P-value on the independent variables is 0.5084, belonging to x1. Since the P-value is greater or equal to 0.10, that term is not statistically significant at the 90% or higher confidence level. Consequently, you should consider removing x1 from the model.

Multiple Regression Analysis :Soil loss_B0905

X_1=Natural Forest X_2 = Plantation forest X_3 = Upland Crops X_4 =Tree

X_5=Paddy Field X_6=Grass land X_7 = Urban X_8=Water body

Dependent variable: soil loss_B0905

Parameter	Estimate	Standard Error	T Statistic	P-Value
CONSTANT	-55719.2	73731.2	-0.755707	0.5287
x1	-0.312173	0.429159	-0.727407	0.5426
x3	3.64547	0.467533	7.79726	0.0161
x4	6.55382	1.41524	4.6309	0.0436
x5	-0.148966	4.9069	-0.0303586	0.9785
x6	415.349	115.771	3.58767	0.0697
x7	-28.6095	5.23432	-5.46575	0.0319
x8	-74.0686	15.9248	-4.65116	0.0432

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	2.43129E10	7	3.47326E9	945021.72	0.0000
Residual	7350.65	2	3675.33		
Total (Corr.)	2.43129E10	9			

R-squared = 99.0 percent R-squared (adjusted for d.f.) = 99.9999 percent

Standard Error of Est. = 60.6245 Mean absolute error = 18.0285

Durbin-Watson statistic = 2.73484

THE EXPLAINING RESULTS :Soil loss_B0905

The output shows the results of fitting a multiple linear regression model to describe the relationship between soil loss_B0905 and 7 independent variables. The equation of the fitted model is

soil loss_B0905 = -55719.2 - 0.312173*x1 + 3.64547*x3 + 6.55382*x4 - 0.148966*x5 + 415.349*x6 - 28.6095*x7 - 74.0686*x8

Since the P-value in the ANOVA table is less than 0.01, there is a statistically significant relationship between the variables at the 99% confidence level.

The R-Squared statistic indicates that the model as fitted explains 100.0% of the variability in soil loss_B0905. The adjusted R-squared statistic, which is more suitable for comparing models with different numbers of independent variables, is 99.9999%. The standard error of the estimate shows the standard deviation of the residuals to be 60.6245. This value can be used to construct prediction limits for new observations by selecting the Reports option from the text menu. The mean absolute error (MAE) of 18.0285 is the average value of the residuals. The Durbin-Watson (DW) statistic tests the residuals to determine if there is any significant correlation based on the order in which they occur in your data file. Since the DW value is greater than 1.4, there is probably not any serious autocorrelation in the residuals.

In determining whether the model can be simplified, notice that the highest P-value on the independent variables is 0.9785, belonging to x5. Since the P-value is greater or equal to 0.10, that term is not statistically significant at the 90% or higher confidence level. Consequently, you should consider removing x5 from the model.

Multiple Regression Analysis :Soil loss_B0906

X_1=Natural Forest X_2 = Plantation forest X_3 = Upland Crops X_4 =Tree
X_5=Paddy Field X_6=Grass land X_7 = Urban X_8=Water body

Dependent variable: soil loss_B0906

Parameter	Estimate	Standard Error	T Statistic	P-Value
CONSTANT	63807.7	5170.24	12.3413	0.0515
x1	-0.554977	0.0758887	-7.31304	0.0865
x2	-0.057742	0.0157795	-3.65931	0.1698
x3	1.31728	0.0831152	15.8489	0.0401
x4	-1.79714	0.209221	-8.58968	0.0738
x5	-1.14136	0.188156	-6.06601	0.1040
x6	69.3637	3.93634	17.6214	0.0361
x7	0.47578	0.117062	4.06434	0.1536
x8	-40.9012	17.6222	-2.321	0.2590

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	3.13698E9	8	3.92122E8	21266726.92	0.0002
Residual	18.4383	1	18.4383		
Total (Corr.)	3.13698E9	9			

R-squared = 99.0 percent R-squared (adjusted for d.f.) = 100.0 percent
Standard Error of Est. = 4.29398 Mean absolute error = 0.843443
Durbin-Watson statistic = 3.56194

THE EXPLAINING RESULTS :Soil loss_B0906

The output shows the results of fitting a multiple linear regression model to describe the relationship between soil loss_B0906 and 8 independent variables. The equation of the fitted model is

soil loss_B0906 = 63807.7 - 0.554977*x1 - 0.057742*x2 + 1.31728*x3 -1.79714*x4 - 1.14136*x5 + 69.3637*x6 + 0.47578*x7 - 40.9012*x8

Since the P-value in the ANOVA table is less than 0.01, there is a statistically significant relationship between the variables at the 99% confidence level.

The R-Squared statistic indicates that the model as fitted explains 100.0% of the variability in soil loss_B0906. The adjusted R-squared statistic, which is more suitable for comparing models with different numbers of independent variables, is 100.0%. The standard error of the estimate shows the standard deviation of the residuals to be 4.29398. This value can be used to construct prediction limits for new observations by selecting the Reports option from the text menu. The mean absolute error (MAE) of 0.843443 is the average value of the residuals. The Durbin-Watson (DW) statistic tests the residuals to determine if there is any significant correlation based on the order in which they occur in your data file. Since the DW value is greater than 1.4, there is probably not any serious autocorrelation in the residuals.

In determining whether the model can be simplified, notice that the highest P-value on the independent variables is 0.2590, belonging to x8. Since the P-value is greater or equal to 0.10, that term is not statistically significant at the 90% or higher confidence level. Consequently, you should consider removing x8 from the model.

Multiple Regression Analysis :Soil loss_B0907

X_1=Natural Forest X_2 = Plantation forest X_3 = Upland Crops X_4 =Tree

X_5=Paddy Field X_6=Grass land X_7 = Urban X_8=Water body

Dependent variable: soil loss_B0907

Parameter	Estimate	Standard Error	T Statistic	P-Value
CONSTANT	6.46037E6	1.34447E6	4.80513	0.1306
x1	10.0686	3.24637	3.10149	0.1986
x2	0.026482	0.481203	0.0550329	0.9650
x3	-0.231121	0.696805	-0.331687	0.7961
x4	145.624	38.1762	3.81452	0.1632
x5	-47.5843	12.0116	-3.96152	0.1574
x6	-16.2446	145.892	-0.111346	0.9294
x7	-0.548	0.406141	-1.34929	0.4060
x8	-347.562	86.8446	-4.00211	0.1559

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	1.73664E11	8	2.17081E10	2588974.81	0.0005
Residual	8384.81	1	8384.81		
Total (Corr.)	1.73664E11	9			

R-squared = 99.0 percent R-squared (adjusted for d.f.) = 100.0 percent

Standard Error of Est. = 91.5686 Mean absolute error = 20.0234

Durbin-Watson statistic = 3.49546

THE EXPLAINING RESULTS :Soil loss_B0907

The output shows the results of fitting a multiple linear regression model to describe the relationship between soil loss_B0907 and 8 independent variables. The equation of the fitted model is

soil loss_B0907 = 6.46037E6 + 10.0686*x1 + 0.026482*x2 - 0.231121*x3 + 145.624*x4 - 47.5843*x5 - 16.2446*x6 - 0.548*x7 - 347.562*x8

Since the P-value in the ANOVA table is less than 0.01, there is a statistically significant relationship between the variables at the 99% confidence level.

The R-Squared statistic indicates that the model as fitted explains 100.0% of the variability in soil loss_B0907. The adjusted R-squared statistic, which is more suitable for comparing models with different numbers of independent variables, is 100.0%. The standard error of the estimate shows the standard deviation of the residuals to be 91.5686. This value can be used to construct prediction limits for new observations by selecting the Reports option from the text menu. The mean absolute error (MAE) of 20.0234 is the average value of the residuals. The Durbin-Watson (DW) statistic tests the residuals to determine if there is any significant correlation based on the order in which they occur in your data file. Since the DW value is greater than 1.4, there is probably not any serious autocorrelation in the residuals.

In determining whether the model can be simplified, notice that the highest P-value on the independent variables is 0.9650, belonging to x2. Since the P-value is greater or equal to 0.10, that term is not statistically significant at the 90% or higher confidence level. Consequently, you should consider removing x2 from the model.

Multiple Regression Analysis :Soil loss_B0908

X_1=Natural Forest X_2 = Plantation forest X_3 = Upland Crops X_4 =Tree

X_5=Paddy Field X_6=Grass land X_7 = Urban X_8=Water body

Dependent variable: soil loss_B0908

Parameter	Estimate	Standard Error	T Statistic	P-Value
CONSTANT	644121.0	142040.0	4.53477	0.1382
x1	-7.3085	0.804323	-9.08652	0.0698
x2	377.989	23.0658	16.3874	0.0388
x3	0.889424	0.157099	5.66157	0.1113
x4	6.95743	1.12425	6.18851	0.1020
x5	16.4288	16.0801	1.02169	0.4932
x6	-12.9888	58.1531	-0.223355	0.8601
x7	-9.90524	2.61385	-3.78952	0.1643
x8	-35.2427	2.52218	-13.9731	0.0455

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	1.2877E10	8	1.60963E9	2285800.16	0.0005
Residual	704.187	1	704.187		
Total (Corr.)	1.2877E10	9			

R-squared = 99.0 percent R-squared (adjusted for d.f.) = 100.0 percent

Standard Error of Est. = 26.5365 Mean absolute error = 5.08743

Durbin-Watson statistic = 3.57126

THE EXPLAINING RESULTS :Soil loss_B0908

The output shows the results of fitting a multiple linear regression model to describe the relationship between soil loss_B0908 and 8 independent variables. The equation of the fitted model is

soil loss_B0908 = 644121.0 - 7.3085*x1 + 377.989*x2 + 0.889424*x3 + 6.95743*x4 + 16.4288*x5 - 12.9888*x6 - 9.90524*x7 - 35.2427*x8

Since the P-value in the ANOVA table is less than 0.01, there is a statistically significant relationship between the variables at the 99% confidence level.

The R-Squared statistic indicates that the model as fitted explains 100.0% of the variability in soil loss_B0908. The adjusted R-squared statistic, which is more suitable for comparing models with different numbers of independent variables, is 100.0%. The standard error of the estimate shows the standard deviation of the residuals to be 26.5365. This value can be used to construct prediction limits for new observations by selecting the Reports option from the text menu. The mean absolute error (MAE) of 5.08743 is the average value of the residuals. The Durbin-Watson (DW) statistic tests the residuals to determine if there is any significant correlation based on the order in which they occur in your data file. Since the DW value is greater than 1.4, there is probably not any serious autocorrelation in the residuals.

In determining whether the model can be simplified, notice that the highest P-value on the independent variables is 0.8601, belonging to x6. Since the P-value is greater or equal to 0.10, that term is not statistically significant at the 90% or higher confidence level. Consequently, you should consider removing x6 from the model.

Multiple Regression Analysis :Soil loss_B0909

X_1=Natural Forest X_2 = Plantation forest X_3 = Upland Crops X_4 =Tree
X_5=Paddy Field X_6=Grass land X_7 = Urban X_8=Water body

Dependent variable: soil loss_B0909

Parameter	Estimate	Standard Error	T Statistic	P-Value
CONSTANT	358989.0	473326.0	0.758439	0.5869
x1	-4.85935	1.03065	-4.71485	0.1331
x2	-23512.8	5276.98	-4.45573	0.1405
x3	42.2406	8.40717	5.02435	0.1251
x4	-3741.05	1028.26	-3.63822	0.1708
x5	518.754	391.843	1.32388	0.4118
x6	305.818	185.529	1.64836	0.3472
x7	1734.29	494.73	3.50552	0.1769
x8	2026.69	475.258	4.26441	0.1466

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	3.34691E11	8	4.18364E10	321357.40	0.0013
Residual	130186.0	1	130186.0		
Total (Corr.)	3.34691E11	9			

R-squared = 99.96 percent R-squared (adjusted for d.f.) = 99.9996 percent
Standard Error of Est. = 360.813 Mean absolute error = 72.797
Durbin-Watson statistic = 3.39552

THE EXPLAINING RESULTS :Soil loss_B0909

The output shows the results of fitting a multiple linear regression model to describe the relationship between soil loss_B0909 and 8 independent variables. The equation of the fitted model is

soil loss_B0909 = 358989.0 - 4.85935*x1 - 23512.8*x2 + 42.2406*x3 - 3741.05*x4 + 518.754*x5 + 305.818*x6 + 1734.29*x7 + 2026.69*x8

Since the P-value in the ANOVA table is less than 0.01, there is a statistically significant relationship between the variables at the 99% confidence level.

The R-Squared statistic indicates that the model as fitted explains 100.0% of the variability in soil loss_B0909. The adjusted R-squared statistic, which is more suitable for comparing models with different numbers of independent variables, is 99.9996%. The standard error of the estimate shows the standard deviation of the residuals to be 360.813. This value can be used to construct prediction limits for new observations by selecting the Reports option from the text menu. The mean absolute error (MAE) of 72.797 is the average value of the residuals. The Durbin-Watson (DW) statistic tests the residuals to determine if there is any significant correlation based on the order in which they occur in your data file. Since the DW value is greater than 1.4, there is probably not any serious autocorrelation in the residuals.

In determining whether the model can be simplified, notice that the highest P-value on the independent variables is 0.4118, belonging to x5. Since the P-value is greater or equal to 0.10, that term is not statistically significant at the 90% or higher confidence level. Consequently, you should consider removing x5 from the model.

Multiple Regression Analysis :Soil loss_B0910

X_1=Natural Forest X_2 = Plantation forest X_3 = Upland Crops X_4 =Tree

X_5=Paddy Field X_6=Grass land X_7 = Urban X_8=Water body

Dependent variable: soil loss_B0910

Parameter	Estimate	Standard Error	T Statistic	P-Value
CONSTANT	-297469.0	72001.2	-4.13145	0.1512
x1	-3.95231	1.24459	-3.1756	0.1942
x2	0.3017	0.464402	0.649653	0.6332
x3	2.36345	0.827206	2.85715	0.2143
x4	-9.57867	10.4755	-0.91439	0.5285
x5	174.975	23.2713	7.51891	0.0842
x6	91.7972	37.6068	2.44098	0.2475
x7	27.4614	23.9965	1.1444	0.4572
x8	-61.2759	52.8448	-1.15954	0.4531

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	5.35948E10	8	6.69935E9	719340.22	0.0009
Residual	9313.19	1	9313.19		
Total (Corr.)	5.35948E10	9			

R-squared = 100.0 percent R-squared (adjusted for d.f.) = 99.9998 percent

Standard Error of Est. = 96.5049 Mean absolute error = 22.0317

Durbin-Watson statistic = 3.61945

THE EXPLAINING RESULTS :Soil loss_B0910

The output shows the results of fitting a multiple linear regression model to describe the relationship between soil loss_B0910 and 8 independent variables. The equation of the fitted model is

soil loss_B0910 = -297469.0 - 3.95231*x1 + 0.3017*x2 + 2.36345*x3 - 9.57867*x4 + 174.975*x5 + 91.7972*x6 + 27.4614*x7 - 61.2759*x8

Since the P-value in the ANOVA table is less than 0.01, there is a statistically significant relationship between the variables at the 99% confidence level.

The R-Squared statistic indicates that the model as fitted explains 100.0% of the variability in soil loss_B0910. The adjusted R-squared statistic, which is more suitable for comparing models with different numbers of independent variables, is 99.9998%. The standard error of the estimate shows the standard deviation of the residuals to be 96.5049. This value can be used to construct prediction limits for new observations by selecting the Reports option from the text menu. The mean absolute error (MAE) of 22.0317 is the average value of the residuals. The Durbin-Watson (DW) statistic tests the residuals to determine if there is any significant correlation based on the order in which they occur in your data file. Since the DW value is greater than 1.4, there is probably not any serious autocorrelation in the residuals.

In determining whether the model can be simplified, notice that the highest P-value on the independent variables is 0.6332, belonging to x2. Since the P-value is greater or equal to 0.10, that term is not statistically significant at the 90% or higher confidence level. Consequently, you should consider removing x2 from the model.

APPENDIX B

LINEAR and Goal PROGRAMMING PART

Linear Programming for Maximize Economic :B0902

```
MAX 16250 X1 + 5000 X2 + 18750 X3  + 25000 X4  +
16250 X5 + 0 X6 + 0 X7 + 0 X8

ST
X1 + X2 + X3 + X4 + X5 + X6 + X7 + X8 = 222221
X1 = 107811
X2 >= 534
X3 >= 14265
X3 <= 72852
X3 + X4 + X5 <= 60530
X4 >= 1100
X5 >= 7488
X5 <= 13471
X6 = 2479
X7 = 2446
X8 = 601
X1 > 0
X2 > 0
X3 > 0
X4 > 0
X5 > 0
X6 > 0
X7 > 0
X8 > 0
END
LP OPTIMUM FOUND AT STEP      4

     OBJECTIVE FUNCTION VALUE

     1)     0.3352272E+10

 VARIABLE        VALUE          REDUCED COST
     X1    107811.000000          0.000000
     X2     48354.000000          0.000000
     X3     14265.000000          0.000000
     X4     38777.000000          0.000000
     X5      7488.000000          0.000000
     X6      2479.000000          0.000000
     X7      2446.000000          0.000000
     X8       601.000000          0.000000


    ROW   SLACK OR SURPLUS     DUAL PRICES
     2)         0.000000       5000.000000
     3)         0.000000      11250.000000
     4)     47820.000000          0.000000
     5)         0.000000      -6250.000000
     6)     58587.000000          0.000000
     7)         0.000000      20000.000000
     8)     37677.000000          0.000000
     9)         0.000000      -8750.000000
    10)      5983.000000          0.000000
    11)         0.000000      -5000.000000
    12)         0.000000      -5000.000000
    13)         0.000000      -5000.000000
    14)    107811.000000          0.000000
    15)     48354.000000          0.000000
    16)     14265.000000          0.000000
    17)     38777.000000          0.000000
    18)      7488.000000          0.000000
    19)      2479.000000          0.000000
    20)      2446.000000          0.000000
    21)       601.000000          0.000000

NO. ITERATIONS=       4


 RANGES IN WHICH THE BASIS IS UNCHANGED:

                      OBJ COEFFICIENT RANGES
 VARIABLE        CURRENT        ALLOWABLE
ALLOWABLE
                  COEF          INCREASE         DECREASE
      X1     16250.000000       INFINITY         INFINITY
      X2      5000.000000     20000.000000       INFINITY
      X3     18750.000000      6250.000000       INFINITY
      X4     25000.000000       INFINITY       6250.000000
      X5     16250.000000      8750.000000       INFINITY
      X6         0.000000       INFINITY         INFINITY
      X7         0.000000       INFINITY         INFINITY
      X8         0.000000       INFINITY         INFINITY

                      RIGHTHAND SIDE RANGES
     ROW        CURRENT        ALLOWABLE
ALLOWABLE
                   RHS          INCREASE         DECREASE
       2    222221.000000       INFINITY      47820.000000
       3    107811.000000    47820.000000    107811.000000
       4       534.000000    47820.000000       INFINITY
       5     14265.000000    37677.000000     14265.000000
       6     72852.000000       INFINITY      58587.000000
       7     60530.000000    47820.000000     37677.000000
       8      1100.000000    37677.000000       INFINITY
       9      7488.000000     5983.000000      7488.000000
      10     13471.000000       INFINITY       5983.000000
      11      2479.000000    47820.000000      2479.000000
      12      2446.000000    47820.000000      2446.000000
      13       601.000000    47820.000000       601.000000
      14         0.000000   107811.000000       INFINITY
      15         0.000000    48354.000000       INFINITY
      16         0.000000    14265.000000       INFINITY
      17         0.000000    38777.000000       INFINITY
      18         0.000000     7488.000000       INFINITY
      19         0.000000     2479.000000       INFINITY
      20         0.000000     2446.000000       INFINITY
      21         0.000000      601.000000       INFINITY
```

Linear Programming for Minimize Soil Loss :B0902

MIN 9.28365 x1 - 51.5547 x2 + 9.43485 x3 -1.81567 x4 - 1109.08 x5 - 1173.9 x6 - 23.5651 x7 - 80.1302 x8
ST
X1 + X2 + X3 + X4 + X5 + X6 + X7 + X8 = 222221
X1 = 107811
X2 >= 534
X3 >= 14265
X3 <= 72852
X3 + X4 + X5 <= 60530
X4 >= 1100
X5 >= 7488
X5 <= 13471
X6 = 2479
X7 = 2446
X8 = 601
X1 > 0
X2 > 0
X3 > 0
X4 > 0
X5 > 0
X6 > 0
X7 > 0
X8 > 0
END
LP OPTIMUM FOUND AT STEP 4

OBJECTIVE FUNCTION VALUE

1) -0.2094969E+08

VARIABLE	VALUE	REDUCED COST
X1	107811.000000	0.000000
X2	80048.000000	0.000000
X3	14265.000000	0.000000
X4	1100.000000	0.000000
X5	13471.000000	0.000000
X6	2479.000000	0.000000
X7	2446.000000	0.000000
X8	601.000000	0.000000

ROW	SLACK OR SURPLUS	DUAL PRICES
2)	0.000000	51.554699
3)	0.000000	-60.838348
4)	79514.000000	0.000000
5)	0.000000	-60.989548
6)	58587.000000	0.000000
7)	31694.000000	0.000000
8)	0.000000	-49.739029
9)	5983.000000	0.000000
10)	0.000000	1057.525269
11)	0.000000	1122.345337
12)	0.000000	-27.989599
13)	0.000000	28.575504
14)	107811.000000	0.000000
15)	80048.000000	0.000000
16)	14265.000000	0.000000
17)	1100.000000	0.000000
18)	13471.000000	0.000000
19)	2479.000000	0.000000
20)	2446.000000	0.000000
21)	601.000000	0.000000

NO. ITERATIONS= 4
RANGES IN WHICH THE BASIS IS UNCHANGED:

OBJ COEFFICIENT RANGES

VARIABLE	CURRENT COEF	ALLOWABLE INCREASE	ALLOWABLE DECREASE
X1	9.283650	INFINITY	INFINITY
X2	-51.554699	49.739029	1057.525269
X3	9.434850	INFINITY	60.989548
X4	-1.815670	INFINITY	49.739029
X5	-1109.079956	1057.525269	INFINITY
X6	-1173.900024	INFINITY	INFINITY
X7	-23.565100	INFINITY	INFINITY
X8	-80.130203	INFINITY	INFINITY

RIGHTHAND SIDE RANGES

ROW	CURRENT RHS	ALLOWABLE INCREASE	ALLOWABLE DECREASE
2	222221.000000	INFINITY	79514.000000
3	107811.000000	79514.000000	107811.000000
4	534.000000	79514.000000	INFINITY
5	14265.000000	31694.000000	14265.000000
6	72852.000000	INFINITY	58587.000000
7	60530.000000	INFINITY	31694.000000
8	1100.000000	31694.000000	1100.000000
9	7488.000000	5983.000000	INFINITY
10	13471.000000	31694.000000	5983.000000
11	2479.000000	79514.000000	2479.000000
12	2446.000000	79514.000000	2446.000000
13	601.000000	79514.000000	601.000000
14	0.000000	107811.000000	INFINITY
15	0.000000	80048.000000	INFINITY
16	0.000000	14265.000000	INFINITY
17	0.000000	1100.000000	INFINITY
18	0.000000	13471.000000	INFINITY
19	0.000000	2479.000000	INFINITY
20	0.000000	2446.000000	INFINITY
21	0.000000	601.000000	INFINITY

Goal Programming:B0902

```
MIN d1 + d3
ST
16250 X1 + 5000 X2 + 18750 X3  + 25000 X4  + 16250 X5 +
0 X6 + 0 X7 + 0 X8 +d1 - d2 = 3352272000
9.28365 x1 - 51.5547 x2 + 9.43485 x3 -1.81567 x4 - 1109.08
x5 - 1173.9 x6 - 23.5651 x7 - 80.1302 x8 + d3 - d4 = -
0.20949690

X1 + X2 + X3 + X4 + X5 + X6 + X7 + X8 = 222221
X1 = 107811
X2 >= 534
X3 >= 14265
X3 <= 72852
X3 + X4 + X5 <= 60530
X4 >= 1100
X5 >= 7488
X5 <= 13471
X6 = 2479
X7 = 2446
X8 = 601
X1 > 0
X2 > 0
X3 > 0
X4 > 0
X5 > 0
X6 > 0
X7 > 0
X8 > 0
END

LP OPTIMUM FOUND AT STEP      3

     OBJECTIVE FUNCTION VALUE

     1)     0.1274850E+08

 VARIABLE        VALUE          REDUCED COST
      D1         0.000000          0.998200
      D3  12748501.000000          0.000000
      X1    107811.000000          0.000000
      X2     48354.000000          0.000000
      X3     14265.100586          0.000000
      X4     38776.898438          0.000000
      X5      7488.000000          0.000000
      X6      2479.000000          0.000000
      X7      2446.000000          0.000000
      X8       601.000000          0.000000
      D2         0.000000          0.001800
      D4         0.000000          1.000000


     ROW   SLACK OR SURPLUS     DUAL PRICES
      2)         0.000000         -0.001800
      3)         0.000000         -1.000000
      4)         0.000000        -42.554283
      5)         0.000000         81.089287
      6)     47820.000000          0.000000
      7)         0.100480          0.000000
      8)     58586.898438          0.000000
      9)         0.000000         85.740692
     10)     37676.898438          0.000000
     11)         0.000000      -1123.015015
     12)      5983.000000          0.000000
     13)         0.000000      -1131.345703
     14)         0.000000         18.989183
     15)         0.000000        -37.575920
     16)    107811.000000          0.000000
     17)     48354.000000          0.000000
     18)     14265.100586          0.000000
     19)     38776.898438          0.000000
     20)      7488.000000          0.000000
     21)      2479.000000          0.000000
     22)      2446.000000          0.000000
     23)       601.000000          0.000000

 NO. ITERATIONS=       3


 RANGES IN WHICH THE BASIS IS UNCHANGED:

                   OBJ COEFFICIENT RANGES
 VARIABLE        CURRENT        ALLOWABLE
ALLOWABLE
                  COEF          INCREASE        DECREASE
      D1        1.000000        INFINITY        0.998200
      D3        1.000000      554.529907        1.000000
      X1        0.000000        INFINITY        INFINITY
      X2        0.000000        INFINITY       85.740692
      X3        0.000000       11.250521     6238.750000
      X4        0.000000     6238.750000       11.250521
      X5        0.000000        INFINITY     1123.015015
      X6        0.000000        INFINITY        INFINITY
      X7        0.000000        INFINITY        INFINITY
      X8        0.000000        INFINITY        INFINITY
      D2        0.000000        INFINITY        0.001800
      D4        0.000000        INFINITY        1.000000

                   RIGHTHAND SIDE RANGES
     ROW         CURRENT        ALLOWABLE
ALLOWABLE
                   RHS          INCREASE        DECREASE
       2****************      628.000000
235480624.000000
       3       -0.209497        INFINITY  12748501.000000
       4   222221.000000     47096.121094        0.125600
       5   107811.000000     20931.611328        0.055822
       6      534.000000     47820.000000        INFINITY
       7    14265.000000        0.100480        INFINITY
       8    72852.000000        INFINITY     58586.898438
       9    60530.000000     17125.863281        0.031400
      10     1100.000000     37676.898438        INFINITY
      11     7488.000000        0.071771      7488.000000
      12    13471.000000        INFINITY      5983.000000
      13     2479.000000        0.125600      2479.000000
      14     2446.000000        0.125600      2446.000000
      15      601.000000        0.125600       601.000000
      16        0.000000    107811.000000        INFINITY
      17        0.000000     48354.000000        INFINITY
      18        0.000000     14265.100586        INFINITY
      19        0.000000     38776.898438        INFINITY
      20        0.000000      7488.000000        INFINITY
      21        0.000000      2479.000000        INFINITY
      22        0.000000      2446.000000        INFINITY
      23        0.000000       601.000000        INFINITY
```

Linear Programming for Maximize Economic :B0903

```
MAX 16250 X1 + 5000 X2 + 18750 X3  + 25000 X4  + 16250
X5 + 0 X6 + 0 X7 + 0 X8
ST
X1 + X2 + X3 + X4 + X5 + X6 + X7 + X8 = 78810
X1 = 39666
X2 >= 2523
X3 >= 4699
X3 <= 54694
X3 + X4 + X5 <= 50014
X4 >= 56
X5 >= 254
X5 <= 2147
X6 = 1841
X7 = 261
X8 = 95
X1 > 0
X2 > 0
X3 > 0
X4 > 0
X5 > 0
X6 > 0
X7 > 0
X8 > 0
END
LP OPTIMUM FOUND AT STEP      6

      OBJECTIVE FUNCTION VALUE

      1)     0.1486196E+10

 VARIABLE        VALUE          REDUCED COST
      X1     39666.000000          0.000000
      X2      2523.000000          0.000000
      X3      4699.000000          0.000000
      X4     29471.000000          0.000000
      X5       254.000000          0.000000
      X6      1841.000000          0.000000
      X7       261.000000          0.000000
      X8        95.000000          0.000000


     ROW   SLACK OR SURPLUS     DUAL PRICES
      2)         0.000000      25000.000000
      3)         0.000000      -8750.000000
      4)         0.000000     -20000.000000
      5)         0.000000      -6250.000000
      6)     49995.000000          0.000000
      7)     15590.000000          0.000000
      8)     29415.000000          0.000000
      9)         0.000000      -8750.000000
     10)      1893.000000          0.000000
     11)         0.000000     -25000.000000
     12)         0.000000     -25000.000000
     13)         0.000000     -25000.000000
     14)     39666.000000          0.000000
     15)      2523.000000          0.000000
     16)      4699.000000          0.000000
     17)     29471.000000          0.000000
     18)       254.000000          0.000000
     19)      1841.000000          0.000000
     20)       261.000000          0.000000
     21)        95.000000          0.000000
```

```
RANGES IN WHICH THE BASIS IS UNCHANGED:

                       OBJ COEFFICIENT RANGES
 VARIABLE        CURRENT        ALLOWABLE
ALLOWABLE
                  COEF          INCREASE        DECREASE
      X1     16250.000000        INFINITY        INFINITY
      X2      5000.000000    20000.000000        INFINITY
      X3     18750.000000     6250.000000        INFINITY
      X4     25000.000000        INFINITY     6250.000000
      X5     16250.000000     8750.000000        INFINITY
      X6         0.000000        INFINITY        INFINITY
      X7         0.000000        INFINITY        INFINITY
      X8         0.000000        INFINITY        INFINITY

                       RIGHTHAND SIDE RANGES
     ROW        CURRENT        ALLOWABLE
ALLOWABLE
                  RHS          INCREASE        DECREASE
       2     78810.000000    15590.000000    29415.000000
       3     39666.000000    29415.000000    15590.000000
       4      2523.000000    29415.000000     2523.000000
       5      4699.000000    29415.000000     4699.000000
       6     54694.000000        INFINITY    49995.000000
       7     50014.000000        INFINITY    15590.000000
       8        56.000000    29415.000000        INFINITY
       9       254.000000     1893.000000      254.000000
      10      2147.000000        INFINITY     1893.000000
      11      1841.000000    29415.000000     1841.000000
      12       261.000000    29415.000000      261.000000
      13        95.000000    29415.000000       95.000000
      14         0.000000    39666.000000        INFINITY
      15         0.000000     2523.000000        INFINITY
      16         0.000000     4699.000000        INFINITY
      17         0.000000    29471.000000        INFINITY
      18         0.000000      254.000000        INFINITY
      19         0.000000     1841.000000        INFINITY
      20         0.000000      261.000000        INFINITY
      21         0.000000       95.000000        INFINITY
```

Linear Programming for Minimize Soil Loss :B0903

```
MIN - 4.60793 x1 - 60.5056 x2 - 8.68038 x3 + 4021.54 x4 -
2.0167 x5 + 11.1698 x6 + 0.272232 x7 + 2018.99 x8
ST
X1 + X2 + X3 + X4 + X5 + X6 + X7 + X8 = 78810
X1 = 39666
X2 >= 2523
X3 >= 4699
X3 <= 54694
X3 + X4 + X5 <= 50014
X4 >= 56
X5 >= 254
X5 <= 2147
X6 = 1841
X7 = 261
X8 = 95
X1 > 0
X2 > 0
X3 > 0
X4 > 0
X5 > 0
X6 > 0
X7 > 0
X8 > 0
END
LP OPTIMUM FOUND AT STEP     1

     OBJECTIVE FUNCTION VALUE

     1)    0.2377914E+09

 VARIABLE        VALUE          REDUCED COST
     X1     39666.000000          0.000000
     X2      2523.000000          0.000000
     X3      4699.000000          0.000000
     X4     29471.000000          0.000000
     X5       254.000000          0.000000
     X6      1841.000000          0.000000
     X7       261.000000          0.000000
     X8        95.000000          0.000000


    ROW   SLACK OR SURPLUS     DUAL PRICES
     2)         0.000000       4000.000000
     3)         0.000000      -1400.000000
     4)         0.000000      -3200.000000
     5)         0.000000      -1000.000000
     6)     49995.000000          0.000000
     7)     15590.000000          0.000000
     8)     29415.000000          0.000000
     9)         0.000000      -1400.000000
    10)      1893.000000          0.000000
    11)         0.000000      -4000.000000
    12)         0.000000      -4000.000000
    13)         0.000000      -4000.000000
    14)     39666.000000          0.000000
    15)      2523.000000          0.000000
    16)      4699.000000          0.000000
    17)     29471.000000          0.000000
    18)       254.000000          0.000000
    19)      1841.000000          0.000000
    20)       261.000000          0.000000
    21)        95.000000          0.000000
```

```
NO. ITERATIONS=      1


 RANGES IN WHICH THE BASIS IS UNCHANGED:

                    OBJ COEFFICIENT RANGES
 VARIABLE        CURRENT        ALLOWABLE
ALLOWABLE
                  COEF          INCREASE        DECREASE
      X1     2600.000000        INFINITY        INFINITY
      X2      800.000000     3200.000000        INFINITY
      X3     3000.000000     1000.000000        INFINITY
      X4     4000.000000        INFINITY     1000.000000
      X5     2600.000000     1400.000000        INFINITY
      X6        0.000000        INFINITY        INFINITY
      X7        0.000000        INFINITY        INFINITY
      X8        0.000000        INFINITY        INFINITY

                    RIGHTHAND SIDE RANGES
     ROW         CURRENT        ALLOWABLE
ALLOWABLE
                   RHS          INCREASE        DECREASE
       2    78810.000000    15590.000000    29415.000000
       3    39666.000000    29415.000000    15590.000000
       4     2523.000000    29415.000000     2523.000000
       5     4699.000000    29415.000000     4699.000000
       6    54694.000000        INFINITY    49995.000000
       7    50014.000000        INFINITY    15590.000000
       8       56.000000    29415.000000        INFINITY
       9      254.000000     1893.000000      254.000000
      10     2147.000000        INFINITY     1893.000000
      11     1841.000000    29415.000000     1841.000000
      12      261.000000    29415.000000      261.000000
      13       95.000000    29415.000000       95.000000
      14        0.000000    39666.000000        INFINITY
      15        0.000000     2523.000000        INFINITY
      16        0.000000     4699.000000        INFINITY
      17        0.000000    29471.000000        INFINITY
      18        0.000000      254.000000        INFINITY
      19        0.000000     1841.000000        INFINITY
      20        0.000000      261.000000        INFINITY
      21        0.000000       95.000000        INFINITY
```

Goal Programming :B0903

```
MIN d1 + d3

16250 X1 + 5000 X2 + 18750 X3  + 25000 X4  + 16250 X5 +
0 X6 + 0 X7 + 0 X8 +d1 - d2 = 1486196000
- 4.60793 x1 - 60.5056 x2 - 8.68038 x3 + 4021.54 x4 - 2.0167
x5 + 11.1698 x6 + 0.272232 x7 + 2018.99 x8 + d3 - d4 = -
1718862
ST
X1 + X2 + X3 + X4 + X5 + X6 + X7 + X8 = 78810
X1 = 39666
X2 >= 2523
X3 >= 4699
X3 <= 54694
X3 + X4 + X5 <= 50014
X4 >= 56
X5 >= 254
X5 <= 2147
X6 = 1841
X7 = 261
X8 = 95
X1 > 0
X2 > 0
X3 > 0
X4 > 0
X5 > 0
X6 > 0
X7 > 0
X8 > 0
END
LP OPTIMUM FOUND AT STEP      4

     OBJECTIVE FUNCTION VALUE

     1)     0.0000000E+00

 VARIABLE        VALUE          REDUCED COST
     D1         0.000000         1.000000
     D3         0.000000         1.000000
     X1     39666.000000         0.000000
     X2      2523.000000         0.000000
     X3      4699.000000         0.000000
     X4     29471.000000         0.000000
     X5       254.000000         0.000000
     X6      1841.000000         0.000000
     X7       261.000000         0.000000
     X8        95.000000         0.000000
     D2       282.000000         0.000000
     D4 120073368.000000         0.000000


    ROW   SLACK OR SURPLUS     DUAL PRICES
     2)         0.000000          0.000000
     3)         0.000000          0.000000
     4)         0.000000          0.000000
     5)         0.000000          0.000000
     6)         0.000000          0.000000
     7)         0.000000          0.000000
     8)     49995.000000          0.000000
     9)     15590.000000          0.000000
    10)     29415.000000          0.000000
    11)         0.000000          0.000000
    12)      1893.000000          0.000000
    13)         0.000000          0.000000
    14)         0.000000          0.000000
    15)         0.000000          0.000000
    16)     39666.000000          0.000000
    17)      2523.000000          0.000000
    18)      4699.000000          0.000000
    19)     29471.000000          0.000000
    20)       254.000000          0.000000
    21)      1841.000000          0.000000

    22)       261.000000          0.000000
    23)        95.000000          0.000000
 NO. ITERATIONS=       4

RANGES IN WHICH THE BASIS IS UNCHANGED:

                    OBJ COEFFICIENT RANGES
 VARIABLE        CURRENT        ALLOWABLE
ALLOWABLE
                  COEF          INCREASE        DECREASE
     D1        1.000000        INFINITY        1.000000
     D3        1.000000        INFINITY        1.000000
     X1        0.000000        INFINITY        INFINITY
     X2        0.000000        INFINITY        0.000000
     X3        0.000000        INFINITY        0.000000
     X4        0.000000        0.000000        INFINITY
     X5        0.000000        INFINITY        0.000000
     X6        0.000000        INFINITY        INFINITY
     X7        0.000000        INFINITY        INFINITY
     X8        0.000000        INFINITY        INFINITY
     D2        0.000000        0.000000        1.000000
     D4        0.000000        0.000000        1.000000

                    RIGHTHAND SIDE RANGES
    ROW        CURRENT        ALLOWABLE
ALLOWABLE
                 RHS          INCREASE        DECREASE
      2****************      282.000000        INFINITY
      3 -1718862.000000 120073368.000000       INFINITY
      4   78810.000000     15590.000000        0.011280
      5   39666.000000         0.032229    15590.000000
      6    2523.000000         0.014100     2523.000000
      7    4699.000000         0.045120     4699.000000
      8   54694.000000         INFINITY    49995.000000
      9   50014.000000         INFINITY    15590.000000
     10      56.000000     29415.000000        INFINITY
     11     254.000000         0.032229      254.000000
     12    2147.000000         INFINITY     1893.000000
     13    1841.000000         0.011280     1841.000000
     14     261.000000         0.011280      261.000000
     15      95.000000         0.011280       95.000000
     16       0.000000     39666.000000        INFINITY
     17       0.000000      2523.000000        INFINITY
     18       0.000000      4699.000000        INFINITY
     19       0.000000     29471.000000        INFINITY
     20       0.000000       254.000000        INFINITY
     21       0.000000      1841.000000        INFINITY
     22       0.000000       261.000000        INFINITY
     23       0.000000        95.000000        INFIN
```

Linear Programming for Maximize Economic :B0904

MAX 16250 X1 + 5000 X2 + 18750 X3 + 25000 X4 + 16250 X5 + 0 X6 + 0 X7 + 0 X8
ST
X1 + X2 + X3 + X4 + X5 + X6 + X7 + X8 = 152874
X1 = 67226
X2 >= 3364
X3 >= 34649
X3 <= 122787
X3 + X4 + X5 <= 93376
X4 >= 13955
X5 >= 18219
X5 <= 33965
X6 = 9053
X7 = 3704
X8 = 1113
X1 > 0
X2 > 0
X3 > 0
X4 > 0
X5 > 0
X6 > 0
X7 > 0
X8 > 0
END
LP OPTIMUM FOUND AT STEP 7

OBJECTIVE FUNCTION VALUE

1) 0.2443620E+10

VARIABLE	VALUE	REDUCED COST
X1	67226.000000	0.000000
X2	3364.000000	0.000000
X3	34649.000000	0.000000
X4	15546.000000	0.000000
X5	18219.000000	0.000000
X6	9053.000000	0.000000
X7	3704.000000	0.000000
X8	1113.000000	0.000000

ROW	SLACK OR SURPLUS	DUAL PRICES
2)	0.000000	25000.000000
3)	0.000000	-8750.000000
4)	0.000000	-20000.000000
5)	0.000000	-6250.000000
6)	88138.000000	0.000000
7)	24962.000000	0.000000
8)	1591.000000	0.000000
9)	0.000000	-8750.000000
10)	15746.000000	0.000000
11)	0.000000	-25000.000000
12)	0.000000	-25000.000000
13)	0.000000	-25000.000000
14)	67226.000000	0.000000
15)	3364.000000	0.000000
16)	34649.000000	0.000000
17)	15546.000000	0.000000
18)	18219.000000	0.000000
19)	9053.000000	0.000000
20)	3704.000000	0.000000
21)	1113.000000	0.000000

NO. ITERATIONS= 7

RANGES IN WHICH THE BASIS IS UNCHANGED:

OBJ COEFFICIENT RANGES

VARIABLE	CURRENT COEF	ALLOWABLE INCREASE	ALLOWABLE DECREASE
X1	16250.000000	INFINITY	INFINITY
X2	5000.000000	20000.000000	INFINITY
X3	18750.000000	6250.000000	INFINITY
X4	25000.000000	INFINITY	6250.000000
X5	16250.000000	8750.000000	INFINITY
X6	0.000000	INFINITY	INFINITY
X7	0.000000	INFINITY	INFINITY
X8	0.000000	INFINITY	INFINITY

RIGHTHAND SIDE RANGES

ROW	CURRENT RHS	ALLOWABLE INCREASE	ALLOWABLE DECREASE
2	152874.000000	24962.000000	1591.000000
3	67226.000000	1591.000000	24962.000000
4	3364.000000	1591.000000	3364.000000
5	34649.000000	1591.000000	34649.000000
6	122787.000000	INFINITY	88138.000000
7	93376.000000	INFINITY	24962.000000
8	13955.000000	1591.000000	INFINITY
9	18219.000000	1591.000000	18219.000000
10	33965.000000	INFINITY	15746.000000
11	9053.000000	1591.000000	9053.000000
12	3704.000000	1591.000000	3704.000000
13	1113.000000	1591.000000	1113.000000
14	0.000000	67226.000000	INFINITY
15	0.000000	3364.000000	INFINITY
16	0.000000	34649.000000	INFINITY
17	0.000000	15546.000000	INFINITY
18	0.000000	18219.000000	INFINITY
19	0.000000	9053.000000	INFINITY
20	0.000000	3704.000000	INFINITY
21	0.000000	1113.000000	INFINITY

Linear Programming for Minimize Soil Loss :B0904

MIN 12.5246x1 - 1.34559x2 + 18.697x3 -91.45x4 - 27.4486x5 + 547.693x6 + 181.243x7 + 19.1435x8
ST
X1 + X2 + X3 + X4 + X5 + X6 + X7 + X8 = 152874
X1 = 67226
X2 >= 3364
X3 >= 34649
X3 <= 122787
X3 + X4 + X5 <= 93376
X4 >= 13955
X5 >= 18219
X5 <= 33965
X6 = 9053
X7 = 3704
X8 = 1113
X1 > 0
X2 > 0
X3 > 0
X4 > 0
X5 > 0
X6 > 0
X7 > 0
X8 > 0
END

LP OPTIMUM FOUND AT STEP 7

OBJECTIVE FUNCTION VALUE

1) 0.3909792E+09

VARIABLE	VALUE	REDUCED COST
X1	67226.000000	0.000000
X2	3364.000000	0.000000
X3	34649.000000	0.000000
X4	15546.000000	0.000000
X5	18219.000000	0.000000
X6	9053.000000	0.000000
X7	3704.000000	0.000000
X8	1113.000000	0.000000

ROW	SLACK OR SURPLUS	DUAL PRICES
2)	0.000000	4000.000000
3)	0.000000	-1400.000000
4)	0.000000	-3200.000000
5)	0.000000	-1000.000000
6)	88138.000000	0.000000
7)	24962.000000	0.000000
8)	1591.000000	0.000000
9)	0.000000	-1400.000000
10)	15746.000000	0.000000
11)	0.000000	-4000.000000
12)	0.000000	-4000.000000
13)	0.000000	-4000.000000
14)	67226.000000	0.000000
15)	3364.000000	0.000000
16)	34649.000000	0.000000
17)	15546.000000	0.000000
18)	18219.000000	0.000000
19)	9053.000000	0.000000
20)	3704.000000	0.000000
21)	1113.000000	0.000000

NO. ITERATIONS= 7

RANGES IN WHICH THE BASIS IS UNCHANGED:

OBJ COEFFICIENT RANGES

VARIABLE	CURRENT COEF	ALLOWABLE INCREASE	ALLOWABLE DECREASE
X1	2600.000000	INFINITY	INFINITY
X2	800.000000	3200.000000	INFINITY
X3	3000.000000	1000.000000	INFINITY
X4	4000.000000	INFINITY	1000.00000
X5	2600.000000	1400.000000	INFINITY
X6	0.000000	INFINITY	INFINITY
X7	0.000000	INFINITY	INFINITY
X8	0.000000	INFINITY	INFINITY

RIGHTHAND SIDE RANGES

ROW	CURRENT RHS	ALLOWABLE INCREASE	ALLOWABLE DECREASE
2	152874.000000	24962.000000	1591.00000
3	67226.000000	1591.000000	24962.00000
4	3364.000000	1591.000000	3364.00000
5	34649.000000	1591.000000	34649.00000
6	122787.000000	INFINITY	88138.00000
7	93376.000000	INFINITY	24962.00000
8	13955.000000	1591.000000	INFINITY
9	18219.000000	1591.000000	18219.00000
10	33965.000000	INFINITY	15746.00000
11	9053.000000	1591.000000	9053.00000
12	3704.000000	1591.000000	3704.00000
13	1113.000000	1591.000000	1113.00000
14	0.000000	67226.000000	INFINITY
15	0.000000	3364.000000	INFINITY
16	0.000000	34649.000000	INFINITY
17	0.000000	15546.000000	INFINITY
18	0.000000	18219.000000	INFINITY
19	0.000000	9053.000000	INFINITY
20	0.000000	3704.000000	INFINITY
21	0.000000	1113.000000	INFINITY

Goal Programming :B0904

```
MIN d1 + d3
ST
16250 X1 + 5000 X2 + 18750 X3  + 25000 X4  + 16250 X5 +
0 X6 + 0 X7 + 0 X8 +d1 - d2 = 2443620000
12.5246x1 - 1.34559x2 + 18.697x3 -91.45x4 - 27.4486x5 +
547.693x6 + 181.243x7 + 19.1435x8 + d3 - d4 = 5214412
X1 + X2 + X3 + X4 + X5 + X6 + X7 + X8 = 152874
X1 = 67226
X2 >= 3364
X3 >= 34649
X3 <= 122787
X3 + X4 + X5 <= 93376
X4 >= 13955
X5 >= 18219
X5 <= 33965
X6 = 9053
X7 = 3704
X8 = 1113
X1 > 0
X2 > 0
X3 > 0
X4 > 0
X5 > 0
X6 > 0
X7 > 0
X8 > 0
END
LP OPTIMUM FOUND AT STEP      6

     OBJECTIVE FUNCTION VALUE

     1)      96.00000

 VARIABLE        VALUE          REDUCED COST
     D1        96.000000         0.000000
     D3         0.000000         1.000000
     X1     67226.000000         0.000000
     X2      3364.000000         0.000000
     X3     34649.000000         0.000000
     X4     15546.000000         0.000000
     X5     18219.000000         0.000000
     X6      9053.000000         0.000000
     X7      3704.000000         0.000000
     X8      1113.000000         0.000000
     D2         0.000000         1.000000
     D4         0.249742         0.000000


    ROW   SLACK OR SURPLUS     DUAL PRICES
     2)         0.000000        -1.000000
     3)         0.000000         0.000000
     4)         0.000000     25000.000000
     5)         0.000000     -8750.000000
     6)         0.000000    -20000.000000
     7)         0.000000     -6250.000000
     8)     88138.000000         0.000000
     9)     24962.000000         0.000000
    10)      1591.000000         0.000000
    11)         0.000000     -8750.000000
    12)     15746.000000         0.000000
    13)         0.000000    -25000.000000
    14)         0.000000    -25000.000000
    15)         0.000000    -25000.000000
    16)     67226.000000         0.000000
    17)      3364.000000         0.000000
    18)     34649.000000         0.000000
    19)     15546.000000         0.000000
    20)     18219.000000         0.000000
    21)      9053.000000         0.000000
    22)      3704.000000         0.000000
    23)      1113.000000         0.000000

NO. ITERATIONS=       6


 RANGES IN WHICH THE BASIS IS UNCHANGED:

                    OBJ COEFFICIENT RANGES
 VARIABLE        CURRENT        ALLOWABLE
ALLOWABLE
                  COEF        INCREASE        DECREASE
     D1        1.000000        INFINITY        1.000000
     D3        1.000000        INFINITY        1.000000
     X1        0.000000        INFINITY        INFINITY
     X2        0.000000        INFINITY     20000.000000
     X3        0.000000        INFINITY      6250.000000
     X4        0.000000     6250.000000      INFINITY
     X5        0.000000        INFINITY      8750.000000
     X6        0.000000        INFINITY        INFINITY
     X7        0.000000        INFINITY        INFINITY
     X8        0.000000        INFINITY        INFINITY
     D2        0.000000        INFINITY        1.000000
     D4        0.000000        INFINITY        1.000000

                    RIGHTHAND SIDE RANGES
     ROW        CURRENT        ALLOWABLE
ALLOWABLE
                  RHS        INCREASE        DECREASE
     2****************         INFINITY       96.000000
     3  5214412.000000        0.249742        INFINITY
     4   152874.000000        0.002731     1591.000000
     5    67226.000000     1591.000000        0.002402
     6     3364.000000     1591.000000        0.002772
     7    34649.000000     1591.000000        0.002267
     8   122787.000000        INFINITY    88138.000000
     9    93376.000000        INFINITY    24962.000000
    10    13955.000000     1591.000000        INFINITY
    11    18219.000000     1591.000000        0.003902
    12    33965.000000        INFINITY    15746.000000
    13     9053.000000     1591.000000        0.000391
    14     3704.000000     1591.000000        0.000916
    15     1113.000000     1591.000000        0.002258
    16        0.000000    67226.000000        INFINITY
    17        0.000000     3364.000000        INFINITY
    18        0.000000    34649.000000        INFINITY
    19        0.000000    15546.000000        INFINITY
    20        0.000000    18219.000000        INFINITY
    21        0.000000     9053.000000        INFINITY
    22        0.000000     3704.000000        INFINITY
    23        0.000000     1113.000000        INFINITY
```

Linear Programming for Maximize Economic :B0905

```
MAX 16250 X1 + 5000 X2 + 18750 X3  + 25000 X4  + 16250
X5 + 0 X6 + 0 X7 + 0 X8
ST
X1 + X2 + X3 + X4 + X5 + X6 + X7 + X8 = 61131
X1 = 30601
X2 >= 0
X3 >= 1930
X3 <= 38653
X3 + X4 + X5 <= 36591
X4 >= 1946
X5 >= 2395
X5 <= 2651
X6 = 479
X7 = 404
X8 = 185
X1 > 0
X2 > 0
X3 > 0
X4 > 0
X5 > 0
X6 > 0
X7 > 0
X8 > 0
END
LP OPTIMUM FOUND AT STEP      5

     OBJECTIVE FUNCTION VALUE

     1)     0.1200797E+10

 VARIABLE        VALUE          REDUCED COST
     X1     30601.000000          0.000000
     X2         0.000000      20000.000000
     X3      1930.000000          0.000000
     X4     25137.000000          0.000000
     X5      2395.000000          0.000000
     X6       479.000000          0.000000
     X7       404.000000          0.000000
     X8       185.000000          0.000000


     ROW   SLACK OR SURPLUS     DUAL PRICES
      2)         0.000000      25000.000000
      3)         0.000000      -8750.000000
      4)         0.000000          0.000000
      5)         0.000000      -6250.000000
      6)     36723.000000          0.000000
      7)      7129.000000          0.000000
      8)     23191.000000          0.000000
      9)         0.000000      -8750.000000
     10)       256.000000          0.000000
     11)         0.000000     -25000.000000
     12)         0.000000     -25000.000000
     13)         0.000000     -25000.000000
     14)     30601.000000          0.000000
     15)         0.000000          0.000000
     16)      1930.000000          0.000000
     17)     25137.000000          0.000000
     18)      2395.000000          0.000000
     19)       479.000000          0.000000
     20)       404.000000          0.000000
     21)       185.000000          0.000000
```

```
 NO. ITERATIONS=       5


 RANGES IN WHICH THE BASIS IS UNCHANGED:

                      OBJ COEFFICIENT RANGES
 VARIABLE         CURRENT        ALLOWABLE
ALLOWABLE
                    COEF          INCREASE          DECREASE
       X1     16250.000000        INFINITY          INFINITY
       X2      5000.000000    20000.000000          INFINITY
       X3     18750.000000     6250.000000          INFINITY
       X4     25000.000000        INFINITY       6250.000000
       X5     16250.000000     8750.000000          INFINITY
       X6         0.000000        INFINITY          INFINITY
       X7         0.000000        INFINITY          INFINITY
       X8         0.000000        INFINITY          INFINITY

                      RIGHTHAND SIDE RANGES
      ROW         CURRENT        ALLOWABLE
ALLOWABLE
                     RHS          INCREASE          DECREASE
        2     61131.000000     7129.000000      23191.000000
        3     30601.000000    23191.000000       7129.000000
        4         0.000000        0.000000          INFINITY
        5      1930.000000    23191.000000       1930.000000
        6     38653.000000        INFINITY      36723.000000
        7     36591.000000        INFINITY       7129.000000
        8      1946.000000    23191.000000          INFINITY
        9      2395.000000      256.000000       2395.000000
       10      2651.000000        INFINITY        256.000000
       11       479.000000    23191.000000        479.000000
       12       404.000000    23191.000000        404.000000
       13       185.000000    23191.000000        185.000000
       14         0.000000    30601.000000          INFINITY
       15         0.000000        0.000000          INFINITY
       16         0.000000     1930.000000          INFINITY
       17         0.000000    25137.000000          INFINITY
       18         0.000000     2395.000000          INFINITY
       19         0.000000      479.000000          INFINITY
       20         0.000000      404.000000          INFINITY
       21         0.000000      185.000000          INFINITY
```

Linear Programming for Minimize Soil Loss :B0905

MIN - 0.312173x1 + 3.64547x3 + 6.55382x4 -0.148966x5 + 415.349x6 - 28.6095x7 - 74.0686x8
ST
X1 + X2 + X3 + X4 + X5 + X6 + X7 + X8 = 61131
X1 = 30601
X2 >= 0
X3 >= 1930
X3 <= 38653
X3 + X4 + X5 <= 36591
X4 >= 1946
X5 >= 2395
X5 <= 2651
X6 = 479
X7 = 404
X8 = 185
X1 > 0
X2 > 0
X3 > 0
X4 > 0
X5 > 0
X6 > 0
X7 > 0
X8 > 0
END
LP OPTIMUM FOUND AT STEP 3

OBJECTIVE FUNCTION VALUE

1) 183533.0

VARIABLE	VALUE	REDUCED COST
X1	30601.000000	0.000000
X3	1930.000000	0.000000
X4	1946.000000	0.000000
X5	2651.000000	0.000000
X6	479.000000	0.000000
X7	404.000000	0.000000
X8	185.000000	0.000000
X2	22935.000000	0.000000

ROW	SLACK OR SURPLUS	DUAL PRICES
2)	0.000000	0.000000
3)	0.000000	0.312173
4)	22935.000000	0.000000
5)	0.000000	-3.645470
6)	36723.000000	0.000000
7)	30064.000000	0.000000
8)	0.000000	-6.553820
9)	256.000000	0.000000
10)	0.000000	0.148966
11)	0.000000	-415.348999
12)	0.000000	28.609501
13)	0.000000	74.068604
14)	30601.000000	0.000000
15)	22935.000000	0.000000
16)	1930.000000	0.000000
17)	1946.000000	0.000000
18)	2651.000000	0.000000
19)	479.000000	0.000000
20)	404.000000	0.000000
21)	185.000000	0.000000

NO. ITERATIONS= 3

RANGES IN WHICH THE BASIS IS UNCHANGED:

OBJ COEFFICIENT RANGES

VARIABLE	CURRENT COEF	ALLOWABLE INCREASE	ALLOWABLE DECREASE
X1	-0.312173	INFINITY	INFINITY
X3	3.645470	INFINITY	3.645470
X4	6.553820	INFINITY	6.553820
X5	-0.148966	0.148966	INFINITY
X6	415.348999	INFINITY	INFINITY
X7	-28.609501	INFINITY	INFINITY
X8	-74.068604	INFINITY	INFINITY
X2	0.000000	3.645470	0.148966

RIGHTHAND SIDE RANGES

ROW	CURRENT RHS	ALLOWABLE INCREASE	ALLOWABLE DECREASE
2	61131.000000	INFINITY	22935.000000
3	30601.000000	22935.000000	30601.000000
4	0.000000	22935.000000	INFINITY
5	1930.000000	22935.000000	1930.000000
6	38653.000000	INFINITY	36723.000000
7	36591.000000	INFINITY	30064.000000
8	1946.000000	22935.000000	1946.000000
9	2395.000000	256.000000	INFINITY
10	2651.000000	22935.000000	256.000000
11	479.000000	22935.000000	479.000000
12	404.000000	22935.000000	404.000000
13	185.000000	22935.000000	185.000000
14	0.000000	30601.000000	INFINITY
15	0.000000	22935.000000	INFINITY
16	0.000000	1930.000000	INFINITY
17	0.000000	1946.000000	INFINITY
18	0.000000	2651.000000	INFINITY
19	0.000000	479.000000	INFINITY
20	0.000000	404.000000	INFINITY
21	0.000000	185.000000	INFINITY

Goal Programming :B0905

MIN d1 + d3

ST
16250 X1 + 5000 X2 + 18750 X3 + 25000 X4 + 16250 X5 + 0 X6 + 0 X7 + 0 X8 + d1 - d2 = 1200797000
- 0.312173x1 + 3.64547x3 + 6.55382x4 -0.148966x5 + 415.349x6 - 28.6095x7 - 74.0686x8 + d3 - d4 = 183533.0
X1 + X2 + X3 + X4 + X5 + X6 + X7 + X8 = 61131
X1 = 30601
X2 >= 0
X3 >= 1930
X3 <= 38653
X3 + X4 + X5 <= 36591
X4 >= 1946
X5 >= 2395
X5 <= 2651
X6 = 479
X7 = 404
X8 = 185
X1 > 0
X2 > 0
X3 > 0
X4 > 0
X5 > 0
X6 > 0
X7 > 0
X8 > 0
END

LP OPTIMUM FOUND AT STEP 3

OBJECTIVE FUNCTION VALUE

1) 0.0000000E+00

VARIABLE	VALUE	REDUCED COST
D1	0.000000	1.000000
D3	0.000000	1.000000
X1	30601.000000	0.000000
X2	0.000000	0.000000
X3	1930.000000	0.000000
X4	25137.000000	0.000000
X5	2395.000000	0.000000
X6	479.000000	0.000000
X7	404.000000	0.000000
X8	185.000000	0.000000
D2	444.000000	0.000000
D4	152027.796875	0.000000

ROW	SLACK OR SURPLUS	DUAL PRICES
2)	0.000000	0.000000
3)	0.000000	0.000000
4)	0.000000	0.000000
5)	0.000000	0.000000
6)	0.000000	0.000000
7)	0.000000	0.000000
8)	36723.000000	0.000000
9)	7129.000000	0.000000
10)	23191.000000	0.000000
11)	0.000000	0.000000
12)	256.000000	0.000000
13)	0.000000	0.000000
14)	0.000000	0.000000
15)	0.000000	0.000000
16)	30601.000000	0.000000
17)	0.000000	0.000000
18)	1930.000000	0.000000
19)	25137.000000	0.000000
20)	2395.000000	0.000000
21)	479.000000	0.000000
22)	404.000000	0.000000
23)	185.000000	0.000000

NO. ITERATIONS= 3

RANGES IN WHICH THE BASIS IS UNCHANGED:

OBJ COEFFICIENT RANGES

VARIABLE	CURRENT COEF	ALLOWABLE INCREASE	ALLOWABLE DECREASE
D1	1.000000	INFINITY	1.000000
D3	1.000000	INFINITY	1.000000
X1	0.000000	INFINITY	INFINITY
X2	0.000000	INFINITY	0.000000
X3	0.000000	INFINITY	0.000000
X4	0.000000	0.000000	INFINITY
X5	0.000000	INFINITY	0.000000
X6	0.000000	INFINITY	INFINITY
X7	0.000000	INFINITY	INFINITY
X8	0.000000	INFINITY	INFINITY
D2	0.000000	0.000000	1.000000
D4	0.000000	0.000000	1.000000

RIGHTHAND SIDE RANGES

ROW	CURRENT RHS	ALLOWABLE INCREASE	ALLOWABLE DECREASE
2	****************	444.000000	INFINITY
3	183533.000000	152027.796875	INFINITY
4	61131.000000	7129.000000	0.017760
5	30601.000000	0.050743	7129.000000
6	0.000000	0.000000	INFINITY
7	1930.000000	0.071040	1930.000000
8	38653.000000	INFINITY	36723.000000
9	36591.000000	INFINITY	7129.000000
10	1946.000000	23191.000000	INFINITY
11	2395.000000	0.050743	2395.000000
12	2651.000000	INFINITY	256.000000
13	479.000000	0.017760	371.892365
14	404.000000	0.017760	404.000000
15	185.000000	0.017760	185.000000
16	0.000000	30601.000000	INFINITY
17	0.000000	0.000000	INFINITY
18	0.000000	1930.000000	INFINITY
19	0.000000	25137.000000	INFINITY
20	0.000000	2395.000000	INFINITY
21	0.000000	479.000000	INFINITY
22	0.000000	404.000000	INFINITY
23	0.000000	185.000000	INFINITY

Linear Programming for Maximize Economic :B0906

MAX 16250 X1 + 5000 X2 + 18750 X3 + 25000 X4 + 16250 X5 + 0 X6 + 0 X7 + 0 X8
ST
X1 + X2 + X3 + X4 + X5 + X6 + X7 + X8 = 59159
X1 = 30743
X2 >= 3019
X3 >= 9538
X3 <= 46735
X3 + X4 + X5 <= 37029
X4 >= 3574
X5 >= 7223
X5 <= 7600
X6 = 1102
X7 = 971
X8 = 19
X1 > 0
X2 > 0
X3 > 0
X4 > 0
X5 > 0
X6 > 0
X7 > 0
X8 > 0
END
LP OPTIMUM FOUND AT STEP 6

OBJECTIVE FUNCTION VALUE

1) 0.9744800E+09

VARIABLE	VALUE	REDUCED COST
X1	30743.000000	0.000000
X2	3019.000000	0.000000
X3	9538.000000	0.000000
X4	6544.000000	0.000000
X5	7223.000000	0.000000
X6	1102.000000	0.000000
X7	971.000000	0.000000
X8	19.000000	0.000000

ROW	SLACK OR SURPLUS	DUAL PRICES
2)	0.000000	25000.000000
3)	0.000000	-8750.000000
4)	0.000000	-20000.000000
5)	0.000000	-6250.000000
6)	37197.000000	0.000000
7)	13724.000000	0.000000
8)	2970.000000	0.000000
9)	0.000000	-8750.000000
10)	377.000000	0.000000
11)	0.000000	-25000.000000
12)	0.000000	-25000.000000
13)	0.000000	-25000.000000
14)	30743.000000	0.000000
15)	3019.000000	0.000000
16)	9538.000000	0.000000
17)	6544.000000	0.000000
18)	7223.000000	0.000000
19)	1102.000000	0.000000
20)	971.000000	0.000000
21)	19.000000	0.000000

NO. ITERATIONS= 6

RANGES IN WHICH THE BASIS IS UNCHANGED:

OBJ COEFFICIENT RANGES

VARIABLE	CURRENT COEF	ALLOWABLE INCREASE	ALLOWABLE DECREASE
X1	16250.000000	INFINITY	INFINITY
X2	5000.000000	20000.000000	INFINITY
X3	18750.000000	6250.000000	INFINITY
X4	25000.000000	INFINITY	6250.000000
X5	16250.000000	8750.000000	INFINITY
X6	0.000000	INFINITY	INFINITY
X7	0.000000	INFINITY	INFINITY
X8	0.000000	INFINITY	INFINITY

RIGHTHAND SIDE RANGES

ROW	CURRENT RHS	ALLOWABLE INCREASE	ALLOWABLE DECREASE
2	59159.000000	13724.000000	2970.000000
3	30743.000000	2970.000000	13724.000000
4	3019.000000	2970.000000	3019.000000
5	9538.000000	2970.000000	9538.000000
6	46735.000000	INFINITY	37197.000000
7	37029.000000	INFINITY	13724.000000
8	3574.000000	2970.000000	INFINITY
9	7223.000000	377.000000	7223.000000
10	7600.000000	INFINITY	377.000000
11	1102.000000	2970.000000	1102.000000
12	971.000000	2970.000000	971.000000
13	19.000000	2970.000000	19.000000
14	0.000000	30743.000000	INFINITY
15	0.000000	3019.000000	INFINITY
16	0.000000	9538.000000	INFINITY
17	0.000000	6544.000000	INFINITY
18	0.000000	7223.000000	INFINITY
19	0.000000	1102.000000	INFINITY
20	0.000000	971.000000	INFINITY
21	0.000000	19.000000	INFINITY

Linear Programming for Minimize Soil Loss :B0906

MIN - 0.554977x1 - 0.057742 x2 + 1.31728 x3 -1.79714 x4 - 1.14136 x5 + 69.3637 x6 + 0.47578 x7 - 40.9012 x8
ST
X1 + X2 + X3 + X4 + X5 + X6 + X7 + X8 = 59159
X1 = 30743
X2 >= 3019
X3 >= 9538
X3 <= 46735
X3 + X4 + X5 <= 37029
X4 >= 3574
X5 >= 7223
X5 <= 7600
X6 = 1102
X7 = 971
X8 = 19
X1 > 0
X2 > 0
X3 > 0
X4 > 0
X5 > 0
X6 > 0
X7 > 0
X8 > 0
END
LP OPTIMUM FOUND AT STEP 0

OBJECTIVE FUNCTION VALUE

1) 51447.37

VARIABLE	VALUE	REDUCED COST
X1	30743.000000	0.000000
X2	3019.000000	0.000000
X3	953 8.000000	0.000000
X4	6544.000000	0.000000
X5	7223.000000	0.000000
X6	1102.000000	0.000000
X7	971.000000	0.000000
X8	19.000000	0.000000

ROW	SLACK OR SURPLUS	DUAL PRICES
2)	0.000000	1.797140
3)	0.000000	-1.242163
4)	0.000000	-1.739398
5)	0.000000	-3.114420
6)	37197.000000	0.000000
7)	13724.000000	0.000000
8)	2970.000000	0.000000
9)	0.000000	-0.655780
10)	377.000000	0.000000
11)	0.000000	-71.160843
12)	0.000000	-2.272920
13)	0.000000	39.104061
14)	30743.000000	0.000000
15)	3019.000000	0.000000
16)	9538.000000	0.000000
17)	6544.000000	0.000000
18)	7223.000000	0.000000
19)	1102.000000	0.000000
20)	971.000000	0.000000
21)	19.000000	0.000000

NO. ITERATIONS= 0

RANGES IN WHICH THE BASIS IS UNCHANGED:

OBJ COEFFICIENT RANGES

VARIABLE	CURRENT COEF	ALLOWABLE INCREASE	ALLOWABLE DECREASE
X1	-0.554977	INFINITY	INFINITY
X2	-0.057742	INFINITY	1.739398
X3	1.317280	INFINITY	3.114420
X4	-1.797140	0.655780	INFINITY
X5	-1.141360	INFINITY	0.655780
X6	69.363701	INFINITY	INFINITY
X7	0.475780	INFINITY	INFINITY
X8	-40.901199	INFINITY	INFINITY

RIGHTHAND SIDE RANGES

ROW	CURRENT RHS	ALLOWABLE INCREASE	ALLOWABLE DECREASE
2	59159.000000	13724.000000	2970.000000
3	30743.000000	2970.000000	13724.000000
4	3019.000000	2970.000000	3019.000000
5	9538.000000	2970.000000	9538.000000
6	46735.000000	INFINITY	37197.000000
7	37029.000000	INFINITY	13724.000000
8	3574.000000	2970.000000	INFINITY
9	7223.000000	377.000000	7223.000000
10	7600.000000	INFINITY	377.000000
11	1102.000000	2970.000000	1102.000000
12	971.000000	2970.000000	971.000000
13	19.000000	2970.000000	19.000000
14	0.000000	30743.000000	INFINITY
15	0.000000	3019.000000	INFINITY
16	0.000000	9538.000000	INFINITY
17	0.000000	6544.000000	INFINITY
18	0.000000	7223.000000	INFINITY
19	0.000000	1102.000000	INFINITY
20	0.000000	971.000000	INFINITY
21	0.000000	19.000000	INFINITY

Goal Programming:B0906

MIN d1 + d3
ST
16250 X1 + 5000 X2 + 18750 X3 + 25000 X4 + 16250 X5 + 0 X6 + 0 X7 + 0 X8 +d1 - d2 = 974480000
- 0.554977x1 - 0.057742 x2 + 1.31728 x3 -1.79714 x4 - 1.14136 x5 + 69.3637 x6 + 0.47578 x7 - 40.9012 x8 + d3 - d4 = 51447.37
X1 + X2 + X3 + X4 + X5 + X6 + X7 + X8 = 59159
X1 = 30743
X2 >= 3019
X3 >= 9538
X3 <= 46735
X3 + X4 + X5 <= 37029
X4 >= 3574
X5 >= 7223
X5 <= 7600
X6 = 1102
X7 = 971
X8 = 19
X1 > 0
X2 > 0
X3 > 0
X4 > 0
X5 > 0
X6 > 0
X7 > 0
X8 > 0
END
LP OPTIMUM FOUND AT STEP 7

OBJECTIVE FUNCTION VALUE

1) 0.3662999E-02

VARIABLE	VALUE	REDUCED COST
D1	0.000000	0.999502
D3	0.003663	0.000000
X1	30743.000000	0.000000
X2	3019.000000	0.000000
X3	9538.000000	0.000000
X4	6544.000000	0.000000
X5	7223.000000	0.000000
X6	1102.000000	0.000000
X7	971.000000	0.000000
X8	19.000000	0.000000
D2	0.000000	0.000498
D4	0.000000	1.000000

ROW	SLACK OR SURPLUS	DUAL PRICES
2)	0.000000	-0.000498
3)	0.000000	-1.000000
4)	0.000000	10.660541
5)	0.000000	-3.118025
6)	0.000000	-8.226747
7)	0.000000	0.000000
8)	37197.000000	0.000000
9)	13724.000000	0.000000
10)	2970.000000	0.000000
11)	0.000000	-3.704408
12)	377.000000	0.000000
13)	0.000000	58.703159
14)	0.000000	-10.184760
15)	0.000000	-51.561741
16)	30743.000000	0.000000
17)	3019.000000	0.000000
18)	9538.000000	0.000000
19)	6544.000000	0.000000
20)	7223.000000	0.000000
21)	1102.000000	0.000000
22)	971.000000	0.000000
23)	19.000000	0.000000

NO. ITERATIONS= 7

RANGES IN WHICH THE BASIS IS UNCHANGED:

OBJ COEFFICIENT RANGES

VARIABLE	CURRENT COEF	ALLOWABLE INCREASE	ALLOWABLE DECREASE
D1	1.000000	INFINITY	0.999502
D3	1.000000	2005.794067	1.000000
X1	0.000000	INFINITY	INFINITY
X2	0.000000	INFINITY	8.226747
X3	0.000000	2.570858	6246.885742
X4	0.000000	6246.885742	3.114420
X5	0.000000	INFINITY	3.704408
X6	0.000000	INFINITY	INFINITY
X7	0.000000	INFINITY	INFINITY
X8	0.000000	INFINITY	INFINITY
D2	0.000000	INFINITY	0.000498
D4	0.000000	INFINITY	1.000000

RIGHTHAND SIDE RANGES

ROW	CURRENT RHS	ALLOWABLE INCREASE	ALLOWABLE DECREASE
2	974480000.000000	0.000000	7.350884
3	51447.371094	INFINITY	0.003663
4	59159.000000	0.000344	0.000000
5	30743.000000	0.000000	0.001175
6	3019.000000	0.000000	0.000445
7	9538.000000	0.000000	INFINITY
8	46735.000000	INFINITY	37197.000000
9	37029.000000	INFINITY	13724.000000
10	3574.000000	2970.000000	INFINITY
11	7223.000000	0.000000	0.000989
12	7600.000000	INFINITY	377.000000
13	1102.000000	0.000000	990.000000
14	971.000000	0.000000	0.000360
15	19.000000	0.000000	0.000071
16	0.000000	30743.000000	INFINITY
17	0.000000	3019.000000	INFINITY
18	0.000000	9538.000000	INFINITY
19	0.000000	6544.000000	INFINITY
20	0.000000	7223.000000	INFINITY
21	0.000000	1102.000000	INFINITY
22	0.000000	971.000000	INFINITY
23	0.000000	19.000000	INFINITY

Linear Programming for Maximize Economic :B0907

```
MAX 16250 X1 + 5000 X2 + 18750 X3  + 25000 X4  + 16250
X5 + 0 X6 + 0 X7 + 0 X8
ST
X1 + X2 + X3 + X4 + X5 + X6 + X7 + X8 = 339580
X1 = 244678
X2 >= 4885
X3 >= 9008
X3 <= 178093
X3 + X4 + X5 <= 175755
X4 >= 1744
X5 >= 2737
X5 <= 25572
X6 = 1100
X7 = 1439
X8 = 23295
X1 > 0
X2 > 0
X3 > 0
X4 > 0
X5 > 0
X6 > 0
X7 > 0
X8 > 0
END
LP OPTIMUM FOUND AT STEP      6

      OBJECTIVE FUNCTION VALUE

      1)     0.5524769E+10

  VARIABLE        VALUE          REDUCED COST
      X1    244678.000000          0.000000
      X2      4885.000000          0.000000
      X3      9008.000000          0.000000
      X4     52438.000000          0.000000
      X5      2737.000000          0.000000
      X6      1100.000000          0.000000
      X7      1439.000000          0.000000
      X8     23295.000000          0.000000


     ROW   SLACK OR SURPLUS     DUAL PRICES
      2)         0.000000      25000.000000
      3)         0.000000      -8750.000000
      4)         0.000000     -20000.000000
      5)         0.000000      -6250.000000
      6)    169085.000000          0.000000
      7)    111572.000000          0.000000
      8)     50694.000000          0.000000
      9)         0.000000      -8750.000000
     10)     22835.000000          0.000000
     11)         0.000000     -25000.000000
     12)         0.000000     -25000.000000
     13)         0.000000     -25000.000000
     14)    244678.000000          0.000000
     15)      4885.000000          0.000000
     16)      9008.000000          0.000000
     17)     52438.000000          0.000000
     18)      2737.000000          0.000000
     19)      1100.000000          0.000000
     20)      1439.000000          0.000000
     21)     23295.000000          0.000000
```

```
NO. ITERATIONS=       6


 RANGES IN WHICH THE BASIS IS UNCHANGED:

                     OBJ COEFFICIENT RANGES
 VARIABLE        CURRENT        ALLOWABLE
ALLOWABLE
                   COEF         INCREASE        DECREASE
      X1    16250.000000        INFINITY        INFINITY
      X2     5000.000000    20000.000000        INFINITY
      X3    18750.000000     6250.000000        INFINITY
      X4    25000.000000        INFINITY     6250.000000
      X5    16250.000000     8750.000000        INFINITY
      X6        0.000000        INFINITY        INFINITY
      X7        0.000000        INFINITY        INFINITY
      X8        0.000000        INFINITY        INFINITY

                     RIGHTHAND SIDE RANGES
     ROW         CURRENT        ALLOWABLE
ALLOWABLE
                    RHS         INCREASE        DECREASE
       2   339580.000000   111572.000000    50694.000000
       3   244678.000000    50694.000000   111572.000000
       4     4885.000000    50694.000000     4885.000000
       5     9008.000000    50694.000000     9008.000000
       6   178093.000000        INFINITY   169085.000000
       7   175755.000000        INFINITY   111572.000000
       8     1744.000000    50694.000000        INFINITY
       9     2737.000000    22835.000000     2737.000000
      10    25572.000000        INFINITY    22835.000000
      11     1100.000000    50694.000000     1100.000000
      12     1439.000000    50694.000000     1439.000000
      13    23295.000000    50694.000000    23295.000000
      14        0.000000   244678.000000        INFINITY
      15        0.000000     4885.000000        INFINITY
      16        0.000000     9008.000000        INFINITY
      17        0.000000    52438.000000        INFINITY
      18        0.000000     2737.000000        INFINITY
      19        0.000000     1100.000000        INFINITY
      20        0.000000     1439.000000        INFINITY
      21        0.000000    23295.000000        INFINITY
```

Linear Programming for Minimize Soil Loss :B0907

```
MIN 10.0686x1 + 0.026482x2 - 0.231121x3 + 145.624x4 -
47.5843x5 - 16.2446x6 - 0.548x7 - 347.562x8
ST
X1 + X2 + X3 + X4 + X5 + X6 + X7 + X8 = 339580
X1 = 244678
X2 >= 4885
X3 >= 9008
X3 <= 178093
X3 + X4 + X5 <= 175755
X4 >= 1744
X5 >= 2737
X5 <= 25572
X6 = 1100
X7 = 1439
X8 = 23295
X1 > 0
X2 > 0
X3 > 0
X4 > 0
X5 > 0
X6 > 0
X7 > 0
X8 > 0
END
LP OPTIMUM FOUND AT STEP      2

     OBJECTIVE FUNCTION VALUE

     1)     -6622798.

 VARIABLE        VALUE          REDUCED COST
     X1    244678.000000           0.000000
     X2      4885.000000           0.000000
     X3     36867.000000           0.000000
     X4      1744.000000           0.000000
     X5     25572.000000           0.000000
     X6      1100.000000           0.000000
     X7      1439.000000           0.000000
     X8     23295.000000           0.000000


     ROW   SLACK OR SURPLUS     DUAL PRICES
      2)         0.000000           0.231121
      3)         0.000000         -10.299721
      4)         0.000000          -0.257603
      5)     27859.000000           0.000000
      6)    141226.000000           0.000000
      7)    111572.000000           0.000000
      8)         0.000000        -145.855118
      9)     22835.000000           0.000000
     10)         0.000000          47.353180
     11)         0.000000          16.013479
     12)         0.000000           0.316879
     13)         0.000000         347.330902
     14)    244678.000000           0.000000
     15)      4885.000000           0.000000
     16)     36867.000000           0.000000
     17)      1744.000000           0.000000
     18)     25572.000000           0.000000
     19)      1100.000000           0.000000
     20)      1439.000000           0.000000
     21)     23295.000000           0.000000
```

```
NO. ITERATIONS=      2


 RANGES IN WHICH THE BASIS IS UNCHANGED:

                    OBJ COEFFICIENT RANGES
VARIABLE       CURRENT       ALLOWABLE
ALLOWABLE
                  COEF          INCREASE        DECREASE
     X1        10.068600       INFINITY        INFINITY
     X2         0.026482       INFINITY        0.257603
     X3        -0.231121       0.257603       47.353180
     X4       145.623993       INFINITY      145.855118
     X5       -47.584301      47.353180        INFINITY
     X6       -16.244600       INFINITY        INFINITY
     X7        -0.548000       INFINITY        INFINITY
     X8      -347.562012       INFINITY        INFINITY

                    RIGHTHAND SIDE RANGES
    ROW       CURRENT       ALLOWABLE
ALLOWABLE
                  RHS          INCREASE        DECREASE
      2   339580.000000   111572.000000      27859.0000
      3   244678.000000    27859.000000     111572.0000
      4     4885.000000    27859.000000     4885.000000
      5     9008.000000    27859.000000        INFINITY
      6   178093.000000        INFINITY     141226.0000
      7   175755.000000        INFINITY     111572.0000
      8     1744.000000    27859.000000      1744.00000
      9     2737.000000    22835.000000        INFINITY
     10    25572.000000    27859.000000     22835.00000
     11     1100.000000    27859.000000     1100.000000
     12     1439.000000    27859.000000     1439.000000
     13    23295.000000    27859.000000     23295.00000
     14        0.000000   244678.00000         INFINITY
     15        0.000000     4885.000000        INFINITY
     16        0.000000    36867.000000        INFINITY
     17        0.000000     1744.000000        INFINITY
     18        0.000000    25572.000000        INFINITY
     19        0.000000     1100.000000        INFINITY
     20        0.000000     1439.000000        INFINITY
     21        0.000000    23295.000000        INFINITY
```

Goal Programming :B0907

```
MIN d1 + d3
ST
16250 X1 + 5000 X2 + 18750 X3  + 25000 X4  + 16250 X5 +
0 X6 + 0 X7 + 0 X8 +d1 - d2 = 5524769000
10.0686x1 + 0.026482x2 - 0.231121x3 + 145.624x4 -
47.5843x5 - 16.2446x6 - 0.548x7 - 347.562x8  + d3 - d4 = -
6622798.
X1 + X2 + X3 + X4 + X5 + X6 + X7 + X8 = 339580
X1 = 244678
X2 >= 4885
X3 >= 9008
X3 <= 178093
X3 + X4 + X5 <= 175755
X4 >= 1744
X5 >= 2737
X5 <= 25572
X6 = 1100
X7 = 1439
X8 = 23295
X1 > 0
X2 > 0
X3 > 0
X4 > 0
X5 > 0
X6 > 0
X7 > 0
X8 > 0
END
LP OPTIMUM FOUND AT STEP      5

      OBJECTIVE FUNCTION VALUE

      1)      18.00000

  VARIABLE        VALUE          REDUCED COST
      D1        18.000000          0.000000
      D3         0.000000          1.000000
      X1    244678.000000          0.000000
      X2      4885.000000          0.000000
      X3      9008.000000          0.000000
      X4     52438.000000          0.000000
      X5      2737.000000          0.000000
      X6      1100.000000          0.000000
      X7      1439.000000          0.000000
      X8     23295.000000          0.000000
      D2         0.000000          1.000000
      D4   8475288.000000          0.000000


     ROW   SLACK OR SURPLUS     DUAL PRICES
      2)         0.000000         -1.000000
      3)         0.000000          0.000000
      4)         0.000000      25000.000000
      5)         0.000000      -8750.000000
      6)         0.000000     -20000.000000
      7)         0.000000      -6250.000000
      8)    169085.000000          0.000000
      9)    111572.000000          0.000000
     10)     50694.000000          0.000000
     11)         0.000000      -8750.000000
     12)     22835.000000          0.000000
     13)         0.000000     -25000.000000
     14)         0.000000     -25000.000000
     15)         0.000000     -25000.000000
     16)    244678.000000          0.000000
     17)      4885.000000          0.000000
     18)      9008.000000          0.000000
     19)     52438.000000          0.000000
     20)      2737.000000          0.000000
     21)      1100.000000          0.000000
     22)      1439.000000          0.000000
     23)     23295.000000          0.000000

 NO. ITERATIONS=       5


 RANGES IN WHICH THE BASIS IS UNCHANGED:

                           OBJ COEFFICIENT RANGES
 VARIABLE         CURRENT        ALLOWABLE
ALLOWABLE
                   COEF          INCREASE         DECREASE
       D1        1.000000        INFINITY         1.000000
       D3        1.000000        INFINITY         1.000000
       X1        0.000000        INFINITY         INFINITY
       X2        0.000000        INFINITY     20000.000000
       X3        0.000000        INFINITY      6250.000000
       X4        0.000000     6250.000000         INFINITY
       X5        0.000000        INFINITY      8750.000000
       X6        0.000000        INFINITY         INFINITY
       X7        0.000000        INFINITY         INFINITY
       X8        0.000000        INFINITY         INFINITY
       D2        0.000000        INFINITY         1.000000
       D4        0.000000       42.850742         1.000000

                           RIGHTHAND SIDE RANGES
      ROW         CURRENT        ALLOWABLE
ALLOWABLE
                    RHS          INCREASE         DECREASE
        2****************         INFINITY        18.000000
        3 -6622798.000000   8475288.000000         INFINITY
        4   339580.000000         0.000720     50694.000000
        5   244678.000000     50694.000000         0.002057
        6     4885.000000     50694.000000         0.000900
        7     9008.000000     50694.000000         0.002880
        8   178093.000000         INFINITY    169085.000000
        9   175755.000000         INFINITY    111572.000000
       10     1744.000000     50694.000000         INFINITY
       11     2737.000000     22835.000000         0.002057
       12    25572.000000         INFINITY     22835.000000
       13     1100.000000     50694.000000         0.000720
       14     1439.000000     50694.000000         0.000720
       15    23295.000000     17184.769531         0.000720
       16        0.000000    244678.000000         INFINITY
       17        0.000000      4885.000000         INFINITY
       18        0.000000      9008.000000         INFINITY
       19        0.000000     52438.000000         INFINITY
       20        0.000000      2737.000000         INFINITY
       21        0.000000      1100.000000         INFINITY
       22        0.000000      1439.000000         INFINITY
       23        0.000000     23295.000000         INFINITY
```

Linear Programming for Maximize Economic :B0908

MAX 16250 X1 + 5000 X2 + 18750 X3 + 25000 X4 + 16250 X5 + 0 X6 + 0 X7 + 0 X8
ST
X1 + X2 + X3 + X4 + X5 + X6 + X7 + X8 = 77848
X1 = 58403
X2 >= 46
X3 >= 10479
X3 <= 50649
X3 + X4 + X5 <= 47539
X4 >= 518
X5 >= 1117
X5 <= 3416
X6 = 1967
X7 = 366
X8 = 289
X1 > 0
X2 > 0
X3 > 0
X4 > 0
X5 > 0
X6 > 0
X7 > 0
X8 > 0
END
LP OPTIMUM FOUND AT STEP 6

OBJECTIVE FUNCTION VALUE

1) 0.1293436E+10

VARIABLE	VALUE	REDUCED COST
X1	58403.000000	0.000000
X2	46.000000	0.000000
X3	10479.000000	0.000000
X4	5181.000000	0.000000
X5	1117.000000	0.000000
X6	1967.000000	0.000000
X7	366.000000	0.000000
X8	289.000000	0.000000

ROW	SLACK OR SURPLUS	DUAL PRICES
2)	0.000000	25000.000000
3)	0.000000	-8750.000000
4)	0.000000	-20000.000000
5)	0.000000	-6250.000000
6)	40170.000000	0.000000
7)	30762.000000	0.000000
8)	4663.000000	0.000000
9)	0.000000	-8750.000000
10)	2299.000000	0.000000
11)	0.000000	-25000.000000
12)	0.000000	-25000.000000
13)	0.000000	-25000.000000
14)	58403.000000	0.000000
15)	46.000000	0.000000
16)	10479.000000	0.000000
17)	5181.000000	0.000000
18)	1117.000000	0.000000
19)	1967.000000	0.000000
20)	366.000000	0.000000
21)	289.000000	0.000000

NO. ITERATIONS= 6

RANGES IN WHICH THE BASIS IS UNCHANGED:

OBJ COEFFICIENT RANGES

VARIABLE	CURRENT COEF	ALLOWABLE INCREASE	ALLOWABLE DECREASE
X1	16250.000000	INFINITY	INFINITY
X2	5000.000000	20000.000000	INFINITY
X3	18750.000000	6250.000000	INFINITY
X4	25000.000000	INFINITY	6250.000000
X5	16250.000000	8750.000000	INFINITY
X6	0.000000	INFINITY	INFINITY
X7	0.000000	INFINITY	INFINITY
X8	0.000000	INFINITY	INFINITY

RIGHTHAND SIDE RANGES

ROW	CURRENT RHS	ALLOWABLE INCREASE	ALLOWABLE DECREASE
2	77848.000000	30762.000000	4663.000000
3	58403.000000	4663.000000	30762.000000
4	46.000000	4663.000000	46.000000
5	10479.000000	4663.000000	10479.000000
6	50649.000000	INFINITY	40170.000000
7	47539.000000	INFINITY	30762.000000
8	518.000000	4663.000000	INFINITY
9	1117.000000	2299.000000	1117.000000
10	3416.000000	INFINITY	2299.000000
11	1967.000000	4663.000000	1967.000000
12	366.000000	4663.000000	366.000000
13	289.000000	4663.000000	289.000000
14	0.000000	58403.000000	INFINITY
15	0.000000	46.000000	INFINITY
16	0.000000	10479.000000	INFINITY
17	0.000000	5181.000000	INFINITY
18	0.000000	1117.000000	INFINITY
19	0.000000	1967.000000	INFINITY
20	0.000000	366.000000	INFINITY
21	0.000000	289.000000	INFINITY

Linear Programming for Minimize Soil Loss :B0908

MIN - 7.3085x1 + 377.989x2 + 0.889424x3 + 6.95743x4 + 16.4288x5 - 12.9888x6 - 9.90524x7 - 35.2427x8
ST
X1 + X2 + X3 + X4 + X5 + X6 + X7 + X8 = 77848
X1 = 58403
X2 >= 46
X3 >= 10479
X3 <= 50649
X3 + X4 + X5 <= 47539
X4 >= 518
X5 >= 1117
X5 <= 3416
X6 = 1967
X7 = 366
X8 = 289
X1 > 0
X2 > 0
X3 > 0
X4 > 0
X5 > 0
X6 > 0
X7 > 0
X8 > 0
END
LP OPTIMUM FOUND AT STEP 1

OBJECTIVE FUNCTION VALUE

1) -413387.7

VARIABLE	VALUE	REDUCED COST
X1	58403.000000	0.000000
X2	46.000000	0.000000
X3	15142.000000	0.000000
X4	518.000000	0.000000
X5	1117.000000	0.000000
X6	1967.000000	0.000000
X7	366.000000	0.000000
X8	289.000000	0.000000

ROW	SLACK OR SURPLUS	DUAL PRICES
2)	0.000000	-0.889424
3)	0.000000	8.197924
4)	0.000000	-377.099579
5)	4663.000000	0.000000
6)	35507.000000	0.000000
7)	30762.000000	0.000000
8)	0.000000	-6.068006
9)	0.000000	-15.539376
10)	2299.000000	0.000000
11)	0.000000	13.878224
12)	0.000000	10.794664
13)	0.000000	36.132122
14)	58403.000000	0.000000
15)	46.000000	0.000000
16)	15142.000000	0.000000
17)	518.000000	0.000000
18)	1117.000000	0.000000
19)	1967.000000	0.000000
20)	366.000000	0.000000
21)	289.000000	0.000000

NO. ITERATIONS= 1

RANGES IN WHICH THE BASIS IS UNCHANGED:

OBJ COEFFICIENT RANGES

VARIABLE	CURRENT COEF	ALLOWABLE INCREASE	ALLOWABLE DECREASE
X1	-7.308500	I NFINITY	INFINITY
X2	377.989014	INFINITY	377.099579
X3	0.889424	6.068006	INFINITY
X4	6.957430	INFINITY	6.068006
X5	16.428801	INFINITY	15.539376
X6	-12.988800	INFINITY	INFINITY
X7	-9.905240	INFINITY	INFINITY
X8	-35.242699	INFINITY	INFINITY

RIGHTHAND SIDE RANGES

ROW	CURRENT RHS	ALLOWABLE INCREASE	ALLOWABLE DECREASE
2	77848.000000	30762.000000	4663.000000
3	58403.000000	4663.000000	30762.000000
4	46.000000	4663.000000	46.000000
5	10479.000000	4663.000000	INFINITY
6	50649.000000	INFINITY	35507.000000
7	47539.000000	INFINITY	30762.000000
8	518.000000	4663.000000	518.000000
9	1117.000000	2299.000000	1117.000000
10	3416.000000	INFINITY	2299.000000
11	1967.000000	4663.000000	1967.000000
12	366.000000	4663.000000	366.000000
13	289.000000	4663.000000	289.000000
14	0.000000	58403.000000	INFINITY
15	0.000000	46.000000	INFINITY
16	0.000000	15142.000000	INFINITY
17	0.000000	518.000000	INFINITY
18	0.000000	1117.000000	INFINITY
19	0.000000	1967.000000	INFINITY
20	0.000000	366.000000	INFINITY
21	0.000000	289.000000	INFINITY

Goal Programming :B0908

```
MIN d1 + d3
ST
16250 X1 + 5000 X2 + 18750 X3  + 25000 X4  + 16250 X5 +
0 X6 + 0 X7 + 0 X8 +d1 - d2 = 1293436000
- 7.3085x1 + 377.989x2 + 0.889424x3 + 6.95743x4 +
16.4288x5 - 12.9888x6 - 9.90524x7 - 35.2427x8  + d3 - d4 = -
413387.7
X1 + X2 + X3 + X4 + X5 + X6 + X7 + X8 = 77848
X1 = 58403
X2 >= 46
X3 >= 10479
X3 <= 50649
X3 + X4 + X5 <= 47539
X4 >= 518
X5 >= 1117
X5 <= 3416
X6 = 1967
X7 = 366
X8 = 289
X1 > 0
X2 > 0
X3 > 0
X4 > 0
X5 > 0
X6 > 0
X7 > 0
X8 > 0
END
LP OPTIMUM FOUND AT STEP      4

      OBJECTIVE FUNCTION VALUE

      1)     0.0000000E+00

  VARIABLE        VALUE          REDUCED COST
       D1         0.000000          1.000000
       D3         0.000000          1.000000
       X1     58403.000000          0.000000
       X2        46.000000          0.000000
       X3     10479.000000          0.000000
       X4      5181.000000          0.000000
       X5      1117.000000          0.000000
       X6      1967.000000          0.000000
       X7       366.000000          0.000000
       X8       289.000000          0.000000
       D2       218.000000          0.000000
       D4     28295.130859          0.000000


      ROW   SLACK OR SURPLUS     DUAL PRICES
       2)         0.000000          0.000000
       3)         0.000000          0.000000
       4)         0.000000          0.000000
       5)         0.000000          0.000000
       6)         0.000000          0.000000
       7)         0.000000          0.000000
       8)     40170.000000          0.000000
       9)     30762.000000          0.000000
      10)      4663.000000          0.000000
      11)         0.000000          0.000000
      12)      2299.000000          0.000000
      13)         0.000000          0.000000
      14)         0.000000          0.000000
      15)         0.000000          0.000000
```

```
      16)     58403.000000          0.000000
      17)        46.000000          0.000000
      18)     10479.000000          0.000000
      19)      5181.000000          0.000000
      20)      1117.000000          0.000000
      21)      1967.000000          0.000000
      22)       366.000000          0.000000
      23)       289.000000          0.000000

 NO. ITERATIONS=       4


 RANGES IN WHICH THE BASIS IS UNCHANGED:

                           OBJ COEFFICIENT RANGES
 VARIABLE         CURRENT        ALLOWABLE
ALLOWABLE
                   COEF          INCREASE         DECREASE
       D1        1.000000        INFINITY         1.000000
       D3        1.000000        INFINITY         1.000000
       X1        0.000000        INFINITY         INFINITY
       X2        0.000000        INFINITY         0.000000
       X3        0.000000        INFINITY         0.000000
       X4        0.000000        0.000000         INFINITY
       X5        0.000000        INFINITY         0.000000
       X6        0.000000        INFINITY         INFINITY
       X7        0.000000        INFINITY         INFINITY
       X8        0.000000        INFINITY         INFINITY
       D2        0.000000        0.000000         1.000000
       D4        0.000000        0.000000         0.000000

                           RIGHTHAND SIDE RANGES
      ROW         CURRENT        ALLOWABLE
ALLOWABLE
                    RHS          INCREASE         DECREASE
        2****************        218.000000         INFINITY
        3  -413387.687500     28295.130859         INFINITY
        4    77848.000000     30762.000000         0.008720
        5    58403.000000         0.024914     30762.000000
        6       46.000000         0.010900        46.000000
        7    10479.000000         0.034880     10479.000000
        8    50649.000000         INFINITY     40170.000000
        9    47539.000000         INFINITY     30762.000000
       10      518.000000      4663.000000         INFINITY
       11     1117.000000         0.024914      1117.000000
       12     3416.000000         INFINITY      2299.000000
       13     1967.000000         0.008720      1967.000000
       14      366.000000         0.008720       366.000000
       15      289.000000         0.008720       289.000000
       16        0.000000     58403.000000         INFINITY
       17        0.000000        46.000000         INFINITY
       18        0.000000     10479.000000         INFINITY
       19        0.000000      5181.000000         INFINITY
       20        0.000000      1117.000000         INFINITY
       21        0.000000      1967.000000         INFINITY
       22        0.000000       366.000000         INFINITY
       23        0.000000       289.000000         INFINITY
```

Linear Programming for Maximize Economic :B0909

```
MAX 16250 X1 + 5000 X2 + 18750 X3  + 25000 X4  + 16250
X5 + 0 X6 + 0 X7 + 0 X8
ST
X1 + X2 + X3 + X4 + X5 + X6 + X7 + X8 = 220950
X1 = 147364
X2 >= 161
X3 >= 3200
X3 <= 52837
X3 + X4 + X5 <= 52945
X4 >= 330
X5 >= 1357
X5 <= 8104
X6 = 440
X7 = 276
X8 = 873
X1 > 0
X2 > 0
X3 > 0
X4 > 0
X5 > 0
X6 > 0
X7 > 0
X8 > 0
END
LP OPTIMUM FOUND AT STEP      6

      OBJECTIVE FUNCTION VALUE

      1)     0.3781676E+10

 VARIABLE        VALUE          REDUCED COST
      X1    147364.000000          0.000000
      X2     19052.000000          0.000000
      X3      3200.000000          0.000000
      X4     48388.000000          0.000000
      X5      1357.000000          0.000000
      X6       440.000000          0.000000
      X7       276.000000          0.000000
      X8       873.000000          0.000000


     ROW   SLACK OR SURPLUS     DUAL PRICES
      2)         0.000000       5000.000000
      3)         0.000000      11250.000000
      4)     18891.000000          0.000000
      5)         0.000000      -6250.000000
      6)     49637.000000          0.000000
      7)         0.000000      20000.000000
      8)     48058.000000          0.000000
      9)         0.000000      -8750.000000
     10)      6747.000000          0.000000
     11)         0.000000      -5000.000000
     12)         0.000000      -5000.000000
     13)         0.000000      -5000.000000
     14)    147364.000000          0.000000
     15)     19052.000000          0.000000
     16)      3200.000000          0.000000
     17)     48388.000000          0.000000
     18)      1357.000000          0.000000
     19)       440.000000          0.000000
     20)       276.000000          0.000000
     21)       873.000000          0.000000
```

```
 NO. ITERATIONS=       6


 RANGES IN WHICH THE BASIS IS UNCHANGED:

                           OBJ COEFFICIENT RANGES
 VARIABLE        CURRENT        ALLOWABLE
ALLOWABLE
                   COEF          INCREASE         DECREASE
       X1     16250.000000        INFINITY         INFINITY
       X2      5000.000000     20000.000000        INFINITY
       X3     18750.000000      6250.000000        INFINITY
       X4     25000.000000        INFINITY      6250.000000
       X5     16250.000000      8750.000000        INFINITY
       X6         0.000000        INFINITY         INFINITY
       X7         0.000000        INFINITY         INFINITY
       X8         0.000000        INFINITY         INFINITY

                           RIGHTHAND SIDE RANGES
      ROW        CURRENT        ALLOWABLE
ALLOWABLE
                    RHS          INCREASE         DECREASE
        2   220950.000000        INFINITY     18891.000000
        3   147364.000000     18891.000000   147364.000000
        4      161.000000     18891.000000        INFINITY
        5     3200.000000     48058.000000     3200.000000
        6    52837.000000        INFINITY     49637.000000
        7    52945.000000     18891.000000    48058.000000
        8      330.000000     48058.000000        INFINITY
        9     1357.000000      6747.000000     1357.000000
       10     8104.000000        INFINITY      6747.000000
       11      440.000000     18891.000000      440.000000
       12      276.000000     18891.000000      276.000000
       13      873.000000     18891.000000      873.000000
       14        0.000000    147364.000000        INFINITY
       15        0.000000     19052.000000        INFINITY
       16        0.000000      3200.000000        INFINITY
       17        0.000000     48388.000000        INFINITY
       18        0.000000      1357.000000        INFINITY
       19        0.000000       440.000000        INFINITY
       20        0.000000       276.000000        INFINITY
       21        0.000000       873.000000        INFINITY
```

Linear Programming for Minimize Soil Loss :B0909

```
MIN - 4.85935x1 - 23512.8x2 + 42.2406x3 - 3741.05x4 +
518.754x5 + 305.818x6 + 1734.29x7 + 2026.69x8
ST
X1 + X2 + X3 + X4 + X5 + X6 + X7 + X8 = 220950
X1 = 147364
X2 >= 161
X3 >= 3200
X3 <= 52837
X3 + X4 + X5 <= 52945
X4 >= 330
X5 >= 1357
X5 <= 8104
X6 = 440
X7 = 276
X8 = 873
X1 > 0
X2 > 0
X3 > 0
X4 > 0
X5 > 0
X6 > 0
X7 > 0
X8 > 0
END
LP OPTIMUM FOUND AT STEP      1
```

OBJECTIVE FUNCTION VALUE

1) -0.1576673E+10

VARIABLE	VALUE	REDUCED COST
X1	147364.000000	0.000000
X2	67110.000000	0.000000
X3	3200.000000	0.000000
X4	330.000000	0.000000
X5	1357.000000	0.000000
X6	440.000000	0.000000
X7	276.000000	0.000000
X8	873.000000	0.000000

ROW	SLACK OR SURPLUS	DUAL PRICES
2)	0.000000	23512.800781
3)	0.000000	-23507.941406
4)	66949.000000	0.000000
5)	0.000000	-23555.041016
6)	49637.000000	0.000000
7)	48058.000000	0.000000
8)	0.000000	-19771.750000
9)	0.000000	-24031.554688
10)	6747.000000	0.000000
11)	0.000000	-23818.617188
12)	0.000000	-25247.089844
13)	0.000000	-25539.490234
14)	147364.000000	0.000000
15)	67110.000000	0.000000
16)	3200.000000	0.000000
17)	330.000000	0.000000
18)	1357.000000	0.000000
19)	440.000000	0.000000
20)	276.000000	0.000000
21)	873.000000	0.000000

NO. ITERATIONS= 1

RANGES IN WHICH THE BASIS IS UNCHANGED:

OBJ COEFFICIENT RANGES

VARIABLE	CURRENT COEF	ALLOWABLE INCREASE	ALLOWABLE DECREASE
X1	-4.859350	INFINITY	INFINITY
X2	-23512.800781	19771.750000	INFINITY
X3	42.240601	INFINITY	23555.041016
X4	-3741.050049	INFINITY	19771.750000
X5	518.754028	INFINITY	24031.554688
X6	305.817993	INFINITY	INFINITY
X7	1734.290039	INFINITY	INFINITY
X8	2026.689941	INFINITY	INFINITY

RIGHTHAND SIDE RANGES

ROW	CURRENT RHS	ALLOWABLE INCREASE	ALLOWABLE DECREASE
2	220950.000000	INFINITY	66949.00000
3	147364.000000	66949.000000	147364.00000
4	161.000000	66949.000000	INFINITY
5	3200.000000	48058.000000	3200.000000
6	52837.000000	INFINITY	49637.00000
7	52945.000000	INFINITY	48058.00000
8	330.000000	48058.000000	330.000000
9	1357.000000	6747.000000	1357.000000
10	8104.000000	INFINITY	6747.000000
11	440.000000	66949.000000	440.000000
12	276.000000	66949.000000	276.000000
13	873.000000	66949.000000	873.000000
14	0.000000	147364.000000	INFINITY
15	0.000000	67110.000000	INFINITY
16	0.000000	3200.000000	INFINITY
17	0.000000	330.000000	INFINITY
18	0.000000	1357.000000	INFINITY
19	0.000000	440.000000	INFINITY
20	0.000000	276.000000	INFINITY
21	0.000000	873.000000	INFINITY

Goal Programming :B0909

```
MIN d1 + d3
ST
16250 X1 + 5000 X2 + 18750 X3  + 25000 X4  + 16250 X5 +
0 X6 + 0 X7 + 0 X8 +d1 - d2 = 3781676000
- 4.85935x1 - 23512.8x2 + 42.2406x3 - 3741.05x4 +
518.754x5 + 305.818x6 + 1734.29x7 + 2026.69x8  + d3 - d4 =
-1576673000
X1 + X2 + X3 + X4 + X5 + X6 + X7 + X8 = 220950
X1 = 147364
X2 >= 161
X3 >= 3200
X3 <= 52837
X3 + X4 + X5 <= 52945
X4 >= 330
X5 >= 1357
X5 <= 8104
X6 = 440
X7 = 276
X8 = 873
X1 > 0
X2 > 0
X3 > 0
X4 > 0
X5 > 0
X6 > 0
X7 > 0
X8 > 0
END
 LP OPTIMUM FOUND AT STEP      8

      OBJECTIVE FUNCTION VALUE

      1)     0.0000000E+00

 VARIABLE        VALUE          REDUCED COST
      D1         0.000000          1.000000
      D3         0.000000          1.000000
      X1    147364.000000          0.000000
      X2     19052.000000          0.000000
      X3      3200.034912          0.000000
      X4     48387.964844          0.000000
      X5      1357.000000          0.000000
      X6       440.000000          0.000000
      X7       276.000000          0.000000
      X8       873.000000          0.000000
      D2         0.000000          0.000000
      D4 950190912.000000          0.000000


     ROW   SLACK OR SURPLUS     DUAL PRICES
      2)         0.000000          0.000000
      3)         0.000000          0.000000
      4)         0.000000          0.000000
      5)         0.000000          0.000000
      6)     18891.000000          0.000000
      7)         0.034880          0.000000
      8)     49636.964844          0.000000
      9)         0.000000          0.000000
     10)     48057.964844          0.000000
     11)         0.000000          0.000000
     12)      6747.000000          0.000000
     13)         0.000000          0.000000
     14)         0.000000          0.000000
     15)         0.000000          0.000000
     16)    147364.000000          0.000000
     17)     19052.000000          0.000000
     18)      3200.034912          0.000000
     19)     48387.964844          0.000000
     20)      1357.000000          0.000000
     21)       440.000000          0.000000
     22)       276.000000          0.000000
     23)       873.000000          0.000000

 NO. ITERATIONS=       8


 RANGES IN WHICH THE BASIS IS UNCHANGED:

                           OBJ COEFFICIENT RANGES
 VARIABLE         CURRENT        ALLOWABLE
ALLOWABLE
                   COEF          INCREASE         DECREASE
       D1         1.000000        INFINITY         1.000000
       D3         1.000000        INFINITY         1.000000
       X1         0.000000        INFINITY         INFINITY
       X2         0.000000        INFINITY         0.000000
       X3         0.000000        0.000000      6250.000000
       X4         0.000000     6250.000000         0.000000
       X5         0.000000        INFINITY         0.000000
       X6         0.000000        INFINITY         INFINITY
       X7         0.000000        INFINITY         INFINITY
       X8         0.000000        INFINITY         INFINITY
       D2         0.000000        INFINITY         0.000000
       D4         0.000000        0.000000         1.000000

                           RIGHTHAND SIDE RANGES
      ROW         CURRENT        ALLOWABLE
ALLOWABLE
                    RHS          INCREASE         DECREASE
        2****************        218.000015
300362272.000000
        3**************** 950190912.000000
INFINITY
        4   220950.000000     46382.070312         0.043600
        5   147364.000000     18891.000000         0.019378
        6      161.000000     18891.000000         INFINITY
        7     3200.000000         0.034880         INFINITY
        8    52837.000000         INFINITY     49636.964844
        9    52945.000000     15511.551758         0.010900
       10      330.000000     48057.964844         INFINITY
       11     1357.000000         0.024914      1357.000000
       12     8104.000000         INFINITY      6747.000000
       13      440.000000         0.043600       440.000000
       14      276.000000         0.043600       276.000000
       15      873.000000         0.043600       873.000000
       16        0.000000    147364.000000         INFINITY
       17        0.000000     19052.000000         INFINITY
       18        0.000000      3200.034912         INFINITY
       19        0.000000     48387.964844         INFINITY
       20        0.000000      1357.000000         INFINITY
       21        0.000000       440.000000         INFINITY
       22        0.000000       276.000000         INFINITY
       23        0.000000       873.000000         INFINITY
```

Linear Programming for Maximize Economic :B0910

```
MAX 16250 X1 + 5000 X2 + 18750 X3  + 25000 X4  + 16250
X5 + 0 X6 + 0 X7 + 0 X8
ST
X1 + X2 + X3 + X4 + X5 + X6 + X7 + X8 = 104494
X1 = 47948
X2 >= 4532
X3 >= 21364
X3 <= 80219
X3 + X4 + X5 <= 76420
X4 >= 600
X5 >= 3154
X5 <= 4748
X6 = 1043
X7 = 940
X8 = 149
X1 > 0
X2 > 0
X3 > 0
X4 > 0
X5 > 0
X6 > 0
X7 > 0
X8 > 0
END
LP OPTIMUM FOUND AT STEP      6

      OBJECTIVE FUNCTION VALUE

      1)     0.1887742E+10

  VARIABLE        VALUE          REDUCED COST
       X1     47948.000000          0.000000
       X2      4532.000000          0.000000
       X3     21364.000000          0.000000
       X4     25364.000000          0.000000
       X5      3154.000000          0.000000
       X6      1043.000000          0.000000
       X7       940.000000          0.000000
       X8       149.000000          0.000000


      ROW   SLACK OR SURPLUS     DUAL PRICES
       2)         0.000000      25000.000000
       3)         0.000000      -8750.000000
       4)         0.000000     -20000.000000
       5)         0.000000      -6250.000000
       6)     58855.000000          0.000000
       7)     26538.000000          0.000000
       8)     24764.000000          0.000000
       9)         0.000000      -8750.000000
      10)      1594.000000          0.000000
      11)         0.000000     -25000.000000
      12)         0.000000     -25000.000000
      13)         0.000000     -25000.000000
      14)     47948.000000          0.000000
      15)      4532.000000          0.000000
      16)     21364.000000          0.000000
      17)     25364.000000          0.000000
      18)      3154.000000          0.000000
      19)      1043.000000          0.000000
      20)       940.000000          0.000000
      21)       149.000000          0.000000

 NO. ITERATIONS=       6


 RANGES IN WHICH THE BASIS IS UNCHANGED:

                           OBJ COEFFICIENT RANGES
 VARIABLE         CURRENT        ALLOWABLE
ALLOWABLE
                   COEF          INCREASE          DECREASE
       X1     16250.000000        INFINITY          INFINITY
       X2      5000.000000    20000.000000          INFINITY
       X3     18750.000000     6250.000000          INFINITY
       X4     25000.000000        INFINITY       6250.000000
       X5     16250.000000     8750.000000          INFINITY
       X6         0.000000        INFINITY          INFINITY
       X7         0.000000        INFINITY          INFINITY
       X8         0.000000        INFINITY          INFINITY

                           RIGHTHAND SIDE RANGES
      ROW         CURRENT        ALLOWABLE
ALLOWABLE
                    RHS          INCREASE          DECREASE
        2   104494.000000    26538.000000      24764.000000
        3    47948.000000    24764.000000      26538.000000
        4     4532.000000    24764.000000       4532.000000
        5    21364.000000    24764.000000      21364.000000
        6    80219.000000        INFINITY      58855.000000
        7    76420.000000        INFINITY      26538.000000
        8      600.000000    24764.000000          INFINITY
        9     3154.000000     1594.000000       3154.000000
       10     4748.000000        INFINITY       1594.000000
       11     1043.000000    24764.000000       1043.000000
       12      940.000000    24764.000000        940.000000
       13      149.000000    24764.000000        149.000000
       14        0.000000    47948.000000          INFINITY
       15        0.000000     4532.000000          INFINITY
       16        0.000000    21364.000000          INFINITY
       17        0.000000    25364.000000          INFINITY
       18        0.000000     3154.000000          INFINITY
       19        0.000000     1043.000000          INFINITY
       20        0.000000      940.000000          INFINITY
       21        0.000000      149.000000          INFINITY
```

Linear Programming for Minimize Soil Loss :B0910

MIN - 3.95231x1 + 0.3017x2 + 2.36345x3 - 9.57867x4 + 174.975x5 + 91.7972x6 + 27.4614x7 - 61.2759x8
ST
X1 + X2 + X3 + X4 + X5 + X6 + X7 + X8 = 104494
X1 = 47948
X2 >= 4532
X3 >= 21364
X3 <= 80219
X3 + X4 + X5 <= 76420
X4 >= 600
X5 >= 3154
X5 <= 4748
X6 = 1043
X7 = 940
X8 = 149
X1 > 0
X2 > 0
X3 > 0
X4 > 0
X5 > 0
X6 > 0
X7 > 0
X8 > 0
END
LP OPTIMUM FOUND AT STEP 5

OBJECTIVE FUNCTION VALUE

1) 283700.6

VARIABLE	VALUE	REDUCED COST
X1	47948.000000	0.000000
X2	4532.000000	0.000000
X3	21364.000000	0.000000
X4	25364.000000	0.000000
X5	3154.000000	0.000000
X6	1043.000000	0.000000
X7	940.000000	0.000000
X8	149.000000	0.000000

ROW	SLACK OR SURPLUS	DUAL PRICES
2)	0.000000	9.578670
3)	0.000000	-5.626359
4)	0.000000	-9.880369
5)	0.000000	-11.942120
6)	58855.000000	0.000000
7)	26538.000000	0.000000
8)	24764.000000	0.000000
9)	0.000000	-184.553680
10)	1594.000000	0.000000
11)	0.000000	-101.375870
12)	0.000000	-37.040070
13)	0.000000	51.697231
14)	47948.000000	0.000000
15)	4532.000000	0.000000
16)	21364.000000	0.000000
17)	25364.000000	0.000000
18)	3154.000000	0.000000
19)	1043.000000	0.000000
20)	940.000000	0.000000
21)	149.000000	0.000000

NO. ITERATIONS= 5

RANGES IN WHICH THE BASIS IS UNCHANGED:

OBJ COEFFICIENT RANGES

VARIABLE	CURRENT COEF	ALLOWABLE INCREASE	ALLOWABLE DECREASE
X1	-3.952310	INFINITY	INFINITY
X2	0.301700	INFINITY	9.880369
X3	2.363450	INFINITY	11.942120
X4	-9.578670	9.880369	INFINITY
X5	174.975006	INFINITY	184.553680
X6	91.797203	INFINITY	INFINITY
X7	27.461399	INFINITY	INFINITY
X8	-61.275902	INFINITY	INFINITY

RIGHTHAND SIDE RANGES

ROW	CURRENT RHS	ALLOWABLE INCREASE	ALLOWABLE DECREASE
2	104494.000000	26538.000000	24764.000000
3	47948.000000	24764.000000	26538.000000
4	4532.000000	24764.000000	4532.000000
5	21364.000000	24764.000000	21364.000000
6	80219.000000	INFINITY	58855.000000
7	76420.000000	INFINITY	26538.000000
8	600.000000	24764.000000	INFINITY
9	3154.000000	1594.000000	3154.000000
10	4748.000000	INFINITY	1594.000000
11	1043.000000	24764.000000	1043.000000
12	940.000000	24764.000000	940.000000
13	149.000000	24764.000000	49.000000
14	0.000000	47948.000000	INFINITY
15	0.000000	4532.000000	INFINITY
16	0.000000	21364.000000	INFINITY
17	0.000000	25364.000000	INFINITY
18	0.000000	3154.000000	INFINITY
19	0.000000	1043.000000	INFINITY
20	0.000000	940.000000	INFINITY
21	0.000000	149.000000	INFINITY

Goal Programming :B0910

MIN d1 + d3
ST
16250 X1 + 5000 X2 + 18750 X3 + 25000 X4 + 16250 X5 + 0 X6 + 0 X7 + 0 X8 +d1 - d2 = 1887742000
- 3.95231x1 + 0.3017x2 + 2.36345x3 - 9.57867x4 + 174.975x5 + 91.7972x6 + 27.4614x7 - 61.2759x8 + d3 - d4 = 283700.6
X1 + X2 + X3 + X4 + X5 + X6 + X7 + X8 = 104494
X1 = 47948
X2 >= 4532
X3 >= 21364
X3 <= 80219
X3 + X4 + X5 <= 76420
X4 >= 600
X5 >= 3154
X5 <= 4748
X6 = 1043
X7 = 940
X8 = 149
X1 > 0
X2 > 0
X3 > 0
X4 > 0
X5 > 0
X6 > 0
X7 > 0
X8 > 0
End

LP OPTIMUM FOUND AT STEP 9

OBJECTIVE FUNCTION VALUE

1) 0.0000000E+00

VARIABLE	VALUE	REDUCED COST
D1	0.000000	1.000000
D3	0.000000	1.000000
X1	47948.000000	0.000000
X2	4532.027344	0.000000
X3	21364.000000	0.000000
X4	25363.972656	0.000000
X5	3154.000000	0.000000
X6	1043.000000	0.000000
X7	940.000000	0.000000
X8	149.000000	0.000000
D2	0.000000	0.000000
D4	0.251406	0.000000

ROW	SLACK OR SURPLUS	DUAL PRICES
2)	0.000000	0.000000
3)	0.000000	0.000000
4)	0.000000	0.000000
5)	0.000000	0.000000
6)	0.027400	0.000000
7)	0.000000	0.000000
8)	58855.000000	0.000000
9)	26538.027344	0.000000
10)	24763.972656	0.000000
11)	0.000000	0.000000
12)	1594.000000	0.000000
13)	0.000000	0.000000
14)	0.000000	0.000000
15)	0.000000	0.000000
16)	47948.000000	0.000000
17)	4532.027344	0.000000
18)	21364.000000	0.000000
19)	25363.972656	0.000000
20)	3154.000000	0.000000
21)	1043.000000	0.000000
22)	940.000000	0.000000
23)	149.000000	0.000000

NO. ITERATIONS= 9

RANGES IN WHICH THE BASIS IS UNCHANGED:

OBJ COEFFICIENT RANGES

VARIABLE	CURRENT COEF	ALLOWABLE INCREASE	ALLOWABLE DECREASE
D1	1.000000	INFINITY	1.000000
D3	1.000000	INFINITY	1.000000
X1	0.000000	INFINITY	INFINITY
X2	0.000000	0.000000	20000.000000
X3	0.000000	INFINITY	0.000000
X4	0.000000	0.000000	0.000000
X5	0.000000	INFINITY	0.000000
X6	0.000000	INFINITY	INFINITY
X7	0.000000	INFINITY	INFINITY
X8	0.000000	INFINITY	INFINITY
D2	0.000000	INFINITY	0.000000
D4	0.000000	0.000000	0.000000

RIGHTHAND SIDE RANGES

ROW	CURRENT RHS	ALLOWABLE INCREASE	ALLOWABLE DECREASE
2	****************	508.900146	495279456.000000
3	283700.593750	0.251406	INFINITY
4	104494.000000	99055.890625	0.021920
5	47948.000000	0.062629	0.192841
6	4532.000000	0.027400	INFINITY
7	21364.000000	0.087680	0.028393
8	80219.000000	INFINITY	58855.000000
9	76420.000000	INFINITY	26538.027344
10	600.000000	24763.972656	INFINITY
11	3154.000000	0.062629	0.001395
12	4748.000000	INFINITY	1594.000000
13	1043.000000	0.021920	0.002824
14	940.000000	0.021920	0.010183
15	149.000000	0.003925	149.000000
16	0.000000	47948.000000	INFINITY
17	0.000000	4532.027344	INFINITY
18	0.000000	21364.000000	INFINITY
19	0.000000	25363.972656	INFINITY
20	0.000000	3154.000000	INFINITY
21	0.000000	1043.000000	INFINITY
22	0.000000	940.000000	INFINITY
23	0.000000	149.000000	INFINITY

CURRICULUM VITAE

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