MULTIPLE-GOAL ASSESSMENT FOR LAND RESOURCE DEVELOPMENT -- THE CASE OF

BRITISH COLUMBIA

by

Yongyuan Yin

B.Sc., East China Normal University, 1982

M.A., University of Guelph, 1985

THESIS SUBMITTED IN PARTIAL FULFILLMENT OF

THE REQUIREMENTS FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

in the Department

of

Geography

© Yongyuan Yin 1990

SIMON FRASER UNIVERSITY

December 1990

APPROVAL

Name: Yongyuan Yin

Degree: Doctor of Philosophy

Title of Thesis: Multiple -- Goal Assessment for Land Resource
Development -- The Case of British Columbia

Examining Committee:

Chairman: I. Hutchinson
Associate Professor

J.T. Pierce
Associate Professor
Senior Supervisor

D. Moon, Head, L.R.R.I.
Agriculture Canada

M. Jaccard
Assistant Professor
Natural Resources Management Program
Simon Fraser University

C.R. Cocklin
External Examiner
Department of Geography
University of Auckland
New Zealand

Date Approved: December 10, 1990

Title of Thesis/Project/Extended Essay

Multiple -- Goal Assessment for Land Resource Development -- The

Case of British Columbia

_____

_____

Author: _____   ____

(signature)

Yongyuan Yin

(name)

December 10, 1990

(date)

ABSTRACT

Decision makers in resource sectors recognize, in theory at least, the multiple use of land resources. Such recognition reflects the possible choices and options for society and the need to evaluate the economic, social and environmental implications of these choices. As such, integrated resource management is now a widely accepted concept in land resource management.

This study contributes to integrated resource management in four aspects. First, a systematic survey and evaluation of a range of methods has been undertaken to identify an appropriate approach for integrated land resource assessment which facilitates the evaluation of sustainability. Second, a data base for integrated land use assessment is established to provide a basis for incorporating biophysical and socio-economic information from various data sources. Third, an integrated analytical system is developed for assessing the implications of land use options or policies for achieving multiple development goals. This analytical system coordinates the land assessment made by three major resource sectors: agriculture, forestry, and wetlands. And finally, the integrated assessment system is employed to examine the implications of a wide range of land use problems, concerns, and policies for integrated land management in the Peace River Region of British Columbia. In particular, it deals with conflicts between many users and identifies the inevitable trade-offs among various land use goals. In addition, it provides information on the impacts of various

land use options or policies upon the achievement of multiple land use objectives with respect to sustainable resource production, environmental quality, habitat protection, and economic return, thereby assisting decision makers in the search for more sustainable land use options.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

1.1 Problem Statement and Objectives

Today the land resource base sustains the production of a large and growing number of goods and services -- from agricultural, mining, and forestry products to recreational services and space for built-up purposes. The growth in demand for land resources has been met by intensification of existing uses and by conversion of lands from one use to another. Implicit in the allocation process is a complex set of trade-offs reflecting different preferences or resource use goals and priorities of society which by necessity exclude some uses and intensify the use of land by others.

Traditionally this process has been viewed as a black box with only the outcomes clearly evident. However as conflicts have increased among competing uses, concern has arisen about the efficiency and equity of the process and outcomes. Particularly when there are weak markets for some of the services and when non-market effects are created in the production and consumption of these goods and services. Society is faced with numerous goals and objectives and ultimately choices relating to the further development of its land resource base. Land which may be suitable for forestry may also be suitable for urban development or agriculture. Land which is suitable for agriculture may

1

be able to sustain only a limited number of agricultural products before irreversible damage to the production potential of the resource takes place. These examples underline the joint suitability of land for many uses and the sensitivity of land to certain production practices and, in turn, the consequences of choosing one goal over another. They also illustrate the need to account explicitly for the potential for multiple uses of land and to develop improved means of integrating and reconciling these uses.

A variety of emerging global change issues has raised an unprecedented challenge to the whole world. Land use has played a crucial role in the challenge of global changes. Tropical deforestation, worldwide desertification, soil erosion, and salinization can cause global change by disturbing carbon storage, nutrient cycles, the hydrologic cycle, and albedo of the land surface (Malone and Corell, 1989; Daly and Cobb, 1989). Global changes such as climate change and acid rain deposition will cause important land use modifications by affecting soil nutrients, soil erosion and salinization, land productivity, and the suitability, availability, and distribution of land resources (Rosenzweig, 1985; Parry and Carter, 1987; Pierce and Stathers, 1988).

The threat of such consequences pertains to the need for the understanding of the processes and interactions among various biophysical and socio-economic systems. The complex and dynamic nature of these global change issues requires the development and application of comprehensive and integrated analytical methods to represent

functions and interactions of a wide range of components in land use systems, and to obtain a scientific understanding of the interactions between land use and global changes.

Facing the challenge of global changes, sustainable economic development has become a research focus of resource and environmental management. Many studies are attempting to clarify and operationalize this new concept (Clark and Munn, 1986; Barbier, 1987; WCED, 1987; Brklacich, 1989).

One response of geographers to global change and sustainable development has been a recognition of the need for the development of systematic and comprehensive analytical frameworks in resource and environmental management (Gelinas, Bond and Smit, 1986; IFIAS, 1988). Geographers have a long tradition of studying the environment, man's use of land resources, and of examining the spatial patterns of land uses. Berry and others (1987) indicated that one of the basic problems of economic geography is to understand and explain land use. However, geographers as well as other scientists have been working in the absence of effective and adequate analytical tools in dealing with issues related to sustainable economic development (Ilbery, 1985; Barbier, 1987; Cocklin, 1989a). Smit and Brklacich (1989) claim that analytical methods to investigate systematically the sustainability of rural land use systems are weak. They further suggest that one line of research which may contribute in this regard is to develop integrated land assessment frameworks. The need for broad and adequate information to plan efficiently for ensuring sustainable land resource development

3

has led to the replacement of traditional techniques by integrated land resource assessment techniques which can account for trade-offs among conflicting resource use goals (Manning, 1986).

An integrated land resource assessment takes an interdisciplinary and intersectoral approach which requires consideration of conflicting land uses and identification of trade-offs among alternative land development perspectives. Objectives of the integrated assessment will not only focus on technical feasibility or economic efficiency, but must be formulated in the light of a systematic appraisal of economic, social, and environmental aspects.

An integrated approach is also a systems approach which treats the land resource base as a system consisting of biophysical, socio-economic, political, and institutional components. A system is an integrated whole and cannot be understood by only examining each isolated component. According to a systems point of view, the whole is more than the sum of its parts. The simultaneous and mutually interdependent interactions among these components determine the uniqueness and characteristics of the system.

Given the complex interrelationships among various components in natural resource development and management, analysis of the resource problem and assessment of resource development projects, programs, or policies from a systems perspective seems appropriate. To improve our understanding of the natural resource system for the purpose of understanding sustainable economic development, there is an urgent need

for resource analysts to develop a research framework which integrates different components and reflects the linkages of the natural resource system.

The purpose of this study is to develop a comprehensive and systematic framework to assess multigoal and multisector land resource development for a broad region. The study establishes a comprehensive land resource data base and develops an integrated analytical framework by which to assess alternative land use prospects with respect to environmental, social, and economic goals, and to identify trade-offs between conflicting land uses in three resource sectors. Although many assessment and evaluation methodologies have been designed for comprehensive analyses, these endeavours have been problem and sector specific. Most of these methods are single objective or single goal programming models and only consider land uses within a single sector. They do not offer an adequate framework for dealing with the potential conflicts and numerous trade-offs.

In this study, goal programming (GP) technique is adopted to form the integrated land assessment framework (ILAF) which can improve resource analysis to ensure sustainable resource development. GP is a multiobjective programming technique that has been applied to various resource management problems (Romero and Rehmon, 1987). Cocklin (1989a) has discussed in some detail the suitability and potential capability of GP technique with respect to making the concept of sustainable development operational. He suggests that GP is one of the methods which can be used to evaluate alternative strategies which may attain

5

resource system sustainability.

An empirical analysis is undertaken for the Peace River Region in B.C. to demonstrate the capabilities of GP models for integrated land assessment. This will provide information for decision making with respect to land resource development. The results of this study show the feasibility of developing a systematic and comprehensive framework for multigoal and multisector land use assessment.

The overall study seeks to provide answers to important and often unresolved questions in relation to integrated land resource management. In particular, the questions addressed are as follows:

1. What are the implications of land use conversion from one resource sector to another with respect to the capability to satisfy multiple land development goals?

2. How critical are the threats of land degradation in terms of diminishing sustainability of the land base?

3. Do land use conflicts exist among different resource sectors?

4. If conflicts exist between different land uses, how serious are they and how can compromises be reached?

5. What are the possible trade-offs between different land use objectives or alternatives?

1.2 Outline of The Thesis

The thesis is divided into eight chapters. Chapter 1, the introduction, identifies problems in land resource use and presents the purpose of this thesis. Chapter 2 provides an overview of the major determinants of land use systems and discusses three critical problems in resource and environmental management. The literature in natural resource and environmental analysis and management is surveyed to appreciate current conceptual and methodological problems and issues in these areas. This discussion provides the main rationales for the development and application of multiobjective and multisector approaches to resource assessment and planning. Chapters 3 and 4 are methodological reviews. Since the purpose of this study is to develop an integrated resource assessment framework, a review is undertaken of the strengths and weaknesses of several assessment approaches in natural and environmental resource management. In chapter 3, environmental, social, and economic impact assessments are profiled. The presentation of mathematical programming models follows in chapter 4, in which the basic features of both single objective and multiobjective programming models are evaluated. Chapter 5 develops a comprehensive and systematic analytical framework to undertake multigoal and multisector land resource use assessment. The main stages of an integrated land resource assessment framework are illustrated sequentially. In chapter 6, the general research framework developed in chapter 5 is operationalized with respect to specific land use problems presently occurring in the Peace River Region of B.C. This involves not

only the presentation of the study area but a detailed formulation of the data base, possible goals and strategies, or scenarios, for development, and the analytical framework. Discussion of the results from various applications is presented in chapter 7. The applications illustrate the versatility of the research framework for integrating different resource use goals and sectors, identifying trade-offs, and assessing environmental and economic impacts of alternative land use policies. Chapter 8 concludes the thesis with a summary of contributions of this study to natural resource and environmental management, and to the development of geographical research in land use and environmental issues. This chapter also indicates some limitations of the study and suggests some potentially important research directions with respect to integrated resource assessment.

CHAPTER II

ISSUES IN LAND USE

2.1 Introduction

Sustainable development is now a widely accepted concept in resource use and economic development. Although this concept lacks uniform definition, a general consensus holds that sustainability must be explicitly included as one of the objectives in resource use decision making (Barbier, 1987; Tisdell, 1988; Simon, 1989). The desire for sustainability in land use decision making reflects an increasing public concern over the question: can the existing resource base provide goods and services to meet various social and economic demands, and maintain the biophysical functions, services and quality of land resources over time (World Conservation Strategy, 1980; FAO, 1984; WCED, 1987; Pierce, 1990; Pearce and Turner, 1990)? The answer to this question with respect to the sustainability and the adequacy of the resource base relies, among other things, on knowledge of two basics: the supply of, and the demand for, land resources over time (Manning, 1988). In this study, the term sustainability is defined narrowly and refers to sustainable land use. Following the studies of Douglass (1984), and Smit and Brklacich (1989), a working definition of sustainable development for this study includes mainly three themes (i) environmental stewardship (ii) resource productivity and (iii) economic well-being.

The purpose of this chapter is to highlight some major determinants of the demand for and supply of land. Among the issues to be discussed are three distinct types of land use problems which arise in the face of changes in the land base supply or in demands on that base. This will then serve to focus and organize discussion on the necessity to develop appropriate assessment and evaluation methodologies for appraising sustainable land development. To provide a visible context for the subsequent discussions, Figure 2.1 conceptualizes some of the major components which influence land use problems discussed in this chapter.

2.2 Major Determinants in Land Resource Development

Societies' use of the land resource base reflects a complex set of interrelations involving biophysical, social, and economic factors on both the demand and supply sides of the land use equation. Manning (1986) indicates that it may be logical to treat the current biophysical and socio-economic factors as potentially limiting or facilitating. In that sense they become determinants as to whether the land base can provide various functions. These factors and their interactions form three systems, the biophysical, economic, and social. In this respect, Smith and Krutilla (1979), deGroot (1987), and Brouwer (1989) have identified a very wide range of ecological, production, life supporting, carrier, regulatory, and education functions/characteristics of land resource systems. The biophysical functions/characteristics include life-support for biomass growth,

10

Biophysical System

Functions/Characteristics: Biogeochemical and Hydrological Cycling, Habitat, Diversity, Resilience, Production, Amenity.

Variables: Climate, Soil, Land Quality, Land Quantity, Topography, Location/Distribution.

Economic System

Functions/Characteristics: Net Return, Stability of Income, Food, Fiber, Timber, Mineral, Energy.

Variables: Relative Location, Land Use Pattern, Population, Technology, Managerial Skill.

Social System

Functions/Characteristics: Housing, Employment, Defence, Public Park, Education.

Variables: Land Tenure, Land Policy, Regulation and Program, Equality, Living Standard.

Demand: Multiple Objectives

Conflicting Uses
Competing Users

Supply: Constraints and Opportunities

Land Availability
Land Suitability

Land Use Problems

Land Allocation, Management, and Externalities or Intersectoral Conflicts

Need For Integrated Resource Management

Sustainability and Adequacy of Land Base

Figure 2.1: Determinants of Land Use and Current Land Use Problems

genetic diversity, and wildlife habitat; an assimilating function or resilience to absorb chemical wastes and pollutants through its biological chains and chemical cycles; and hydrological and microclimatic regulations. The economic functions/characteristics of the land resource base are: supplying useful raw minerals and energy as inputs for economic production; and food for human consumption. In addition, the land base provides a stream of social functions that are essential for supporting human welfare such as housing, employment, defence, recreation, health, cultural, scientific, educational, and aesthetic services (d'Arge, 1972). These functions can serve various human values, preferences, and aspirations to meet multiple demands from a variety of users such as agriculture, forestry, wildlife, recreation, industry, settlement, transportation, and communication. This study focuses primarily on some of the major factors which influence land uses in agriculture, forestry, and wildlife habitat.

2.2.1 Biophysical Determinants of Land Use

In agricultural and forestry land uses, ecosystems are transformed into hybrid agroecosystems and forest ecosystems for the purpose of food, fiber, and timber production. These hybrid systems are directly dependent on biophysical factors and essential ecological functions for sustainability (Conway, 1985). The major biophysical determinants that are related to the use of land are listed in Figure 2.1 (Biophysical System). Climatic variables (temperature and precipitation), the slope of land, as well as soil type and fertility are some critical

biophysical determinants relating to the supply of land for agriculture and forestry. The quantity, quality, and distribution of land resources, and the way they are utilized, are other essential factors for land use decision making.

The supply of good land available for meeting increasing demand in each particular area is limited. The existence of possible absolute biophysical constraints on land use activities implies some limits to exploit the land resource base. Therefore, the alleviation of the threat of land scarcity requires that land be used within its biophysical limits or capability (Page, 1977; Daly, 1984). For example, because of the poor climatic and soil conditions throughout Canada, only 0.5% of the total land area located in the extreme southern parts of the nation has no biophysical limitations for intensive crop production (Manning, 1986).

There is increased concern about the effects of climatic change arising from economic activity on the availability and suitability of the land base for agriculture, forestry, and wildlife (Bolin, et al., 1986; Parry and Carter, 1987; Barbier, 1989b). Climatic change by changing the biophysical determinants of land use could most directly affect various functions of land resources. Changes in these biophysical determinants of land use would likely result in negative impacts on productive, hydrological, and other functions of the land resource base (Bolin, et al., 1986; Gleick, 1987; Crosson, 1989). The implication is that climatic change will affect the supply of land resources with respect to land availability, suitability, and

13

distribution.

2.2.2 Economic Determinants of Land Use

Economic determinants provide another set of opportunities or limitations to land resource use (Fig. 2.1, Economic System). Advanced technology and managerial skill have raised land productivity. In turn, this may have eased land shortages. If future technology and managerial skill can continue to improve the productivity of the land resource base at a rate faster than the growth rate in demand, no additional land will be needed for cultivation or forest production (Pierce, 1990).

Population and income growth will contribute to the growth in demand for land resources. The earliest popular description of the concept of carrying capacity as related to human population was by Thomas Malthus and may be referred to as the limit of a given land base to support the demand and consumption levels associated with a human population (Berry, Conkling, and Ray, 1987). This concept has also been applied to establish economic, social, and behaviorial thresholds beyond which the environmental quality will deteriorate and user enjoyment will decline (Mitchell, 1989). For example, Wall (1981) defined carrying capacity as the maximum number of people who can use a recreational site without an unacceptable alteration in the physical environment and decline in the quality of the recreational experience.

14

With high standards of living, people in industrialized countries demand low density housing which often translates into sprawling urban development and costly services. Industrialized countries, with only one quarter of the world's population, consume about 80% of the world's goods (MacNeill, 1989). In addition, modern societies desire more open space for recreation and public parks. Many of these developments occur in productive farmlands, forestry lands, and areas which are perceived to be of natural, historical, cultural, scenic, or scientific importance. For example, in the eighty largest Canadian urban centers, more than 87,000 hectares of farmland were converted to urban uses over the period 1966 - 1971, and 62,300 hectares of farmland were converted to urban uses between 1971 and 1976 (Smit et al., 1984).

Economic development and urbanization in both developed and developing countries are often accompanied by increasing stress on the land resource base and cause significant adverse effects on the ecosystem (Hufschmidt, 1983). Many economic development activities do not pay sufficient attention to land resource depletion and environmental deterioration. Land degradation, such as erosion, salinization, desertification, and land compaction has caused a decline in crop yields and an increase in production and environmental costs (Pierce and Furuseth, 1983). The coal burning plants and modern transportation vehicles which generate sulphuric and nitric oxides not only affect the sites next to them, but also spread acid rain over long distances, to the detriment of the ecosystem and the land resource base (Wetstone and Foster, 1983).

It has been argued that a reduction in the supply of agricultural land resources may be justifiable if productivity gains by technology more than offset the production lost from land retirement (Crosson, 1982). Unfortunately, the prospects for technological advancement are not clear. Whether or not future technology can continue to improve the productivity of land resource base as it did in the past is a matter for speculation. Furthermore, the new technologies may be also accompanied by a number of problems such as increasing incidence of pest, disease, and weed problems; deterioration in soil structure and fertility; and increased inequity among farmers in LDCs (McNeil, 1972; Pearse, 1980).

Relative location and the current land use pattern are the other two determinants affecting the supply of, and demand for, land resources. The concept of relative location was introduced by Von Thunen, and is still one of the central elements applied by modern economic geographers (de Souza and Foust, 1979). In general, there is a higher demand for land nearer market centers. Moreover, the present land use pattern is the result of historical land resource development and places some restraints or advantages on future land use options.

2.2.3 Social Determinants of Land Use

People with different cultural and historical backgrounds perceive and value land resources in different ways. Moreover, their perceptions and valuations with respect to land resources have changed over time (Rees, 1985; Tisdell, 1989). Different perceptions and valuations often

lead to alternative land uses. For example, the environmental movement has influenced land use patterns through an increase set aside of wilderness areas. Land tenure is a further constraint determinant of land resource use. In Canada, land resources are owned by private individuals, provinces, and the federal government. With these different land ownerships, the processes of acquisition or sale of land for various purposes are quite different. Other social factors affecting land use include land use policy, development programs, government regulation, inter and intragenerational equality issues (Fig. 2.1, Social System) which will be discussed in subsequent sections.

2.3 Key Problems in Land Resource Use

The factors that determine the outcome of the interaction between the supply of and demand for land are many and uncertain. Along with biophysical and socio-economic determinants of land use, societies also rely on different institutional means, such as government versus market forces, to allocate land for different uses. These create many difficulties and problems in land resource development. Among these land use problems are three key issues to sustainable land development: land allocation, land management, and externalities (Manning, 1988). All of the three distinct types of problems arise in the face of changes in the supply of and demand for the land base.

2.3.1 <u>Problems</u> <u>in</u> <u>Land</u> <u>Resource</u> <u>Allocation</u>

How to allocate land resources effectively among competing uses to meet various demands remains a critical issue for policy makers (Manning, 1986). Additionally, in land resource allocation, both market and extra-market means have their own problems. The distinction between market failures and the problems with extra-market allocation will help to clarify issues in land use allocation.

2.3.1.1 Market Allocation and Failures

Neoclassical economic theory claims that the competition through the operation of free market systems will guide land resource allocation to a social optimum (Barnett and Morse, 1963). According to this theory, technical and economic efficiency are the principal criteria in selecting the "best" option among alternative courses of action. The degradation of the land resource base, and the effects of land resource development on environmental quality, are of little concern. In most developed countries, market driven systems dominate land resource allocation.

In the free market system, land is treated simply as a good or commodity with an exchange value. A particular parcel of land is purchased for a specific land use. Relative land prices, reflecting the economic rent of the land resources over time, can provide an efficient mechanism for land resource allocation. For example, if land becomes scarce, the market price of land will rise. This provides an incentive

to use land more intensively and to substitute technology or capital or some other cheaper factors for land in production. In agriculture and forestry, more fertilizer, irrigation, silviculture, advanced machinery, and modern management can be used to increase grain and timber production with less land.

This system, however, is not without its weaknesses. The free market fails to allocate lands among competing uses in a socially efficient way under many circumstances. Even assuming for the moment that the market is efficient, there are important equity issues not addressed in a market-driven land alloction system (Lecomber, 1979; Pierce and Furuseth, 1982).

Free market allocation assumes that individuals and firms have perfect information. In fact information is neither perfect nor complete. Crosson (1989) indicates that the social scarcity of resources is not always appreciated by individual farmers. Lack of information/ignorance causes difficulties in reaching rational decisions. Many risks and uncertainties are always associated with land use decision making such as weather, technology advancement, future demands, and other market uncertainties.

When considering intertemporal land allocation, the discount rate becomes a key issue. Discounting often causes problems when applied to resource analysis. The higher the discount rate, the faster the resource depletion rate (Heal, 1981; Pearce and Turner, 1990). Many consider that the current discount rates used are too high, which

thereby may disadvantage future generations and limit sustainable land use practices. For example, a resource development option, such as clear cutting, which may yield near-term benefits but which may also create devastative ecological consequences for future generations will likely be favored by a cost-benefit analysis with a high discount rate.

Land owners attempt to maximize their profits in the market allocation system. In pursuit of larger profits from their lands, land owners may convert farmland to housing, industry or other urban uses, or drain wetland habitats or other special sites for alternative uses. If these lands will eventually be required to meet demands for food and timber production, or if science and education will need these special sites for scientific research, such irreversible land conversions could create substantial costs or consequences for future generations. Land use planners need to answer the question of how to optimally allocate the limited land resources to meet the demands of both the current as well as future generations (Krueger, 1978).

Market failure may also occur when the goods and services concerned have no markets. Such goods are known as public goods because the market system fails to provide any incentive for their supply. That is, the amount used by one individual will not diminish the amount available to any other individuals. The consumer who is not willing to pay cannot be excluded from using the resources. There is no incentive for any individual to manage public goods because he or she cannot capture rent or income. Therefore, public goods cannot be provided efficiently by market systems. There are many instances of public goods

which are important to land allocation such as defence reserves and national parks. One example is associated with the establishment of a public park in a region. Unless access can be restricted and user fees charged, the park must be provided as a collective good because private markets will not do so (Dawson, 1984).

Another form of market failure is when costs of production and consumption are not internalized. These third party effects or externalities are often expressed in the form of water and air pollution, decrease in amenity value and a general decline in environmental services (Norton, 1984). This externality issue is treated in detail in section 2.3.3.

2.3.1.2 Extramarket Allocation and Nonmarket Failures

The preceding discussion of market allocation of land resources shows that, in many circumstances, free market land allocation may fail to allocate lands among the competing uses in a manner which can generate the highest societal welfare. Further, the free market system cannot always be successfully used for analysing problems related to land resource development. In land use, it is important to fulfil social goals and consider public interests rather than purely private desires which are only one aspect of the social goal (Bromley, 1986). Government intervention or regulation in land resource allocation becomes, in many cases, necessary to rectify market failures and to serve social goals.

One objective of government policies is to maximize social welfare subject to certain conditions. Some land use policies aim at specific sources of market failure in land resource allocation. However, nonintegrative government policy may still result in ineffective land use. While a satisfactory land use policy relies on information about the trade-offs within and between biophysical, social, and economic systems, the knowledge of how to make trade-offs efficiently remains to be improved (Manning, 1986). For example, whether a particular parcel of land should be preserved for agricultural use depends on the social value of its use in agriculture compared with the social values of its uses for other purposes. That is, the opportunity cost of keeping land in agricultural production must be taken into consideration in public land use decision making. For example, a policy which holds land in agriculture would imply a opportunity cost in the form of nonagricultural output foregone (Crosson, 1989). It is suggested that land use change or conversion represents a problem only if it can be reasonably demonstrated that such a modification would constrain society's ability to satisfy its goals. Specifically, these goals include production levels, economic efficiency, and environmental quality (Pierce, 1983; Cocklin et al., 1987).

Various land use policies and programs have been created and implemented to limit or prohibit the utilization of certain lands by individuals and groups. Controversies have occurred, of course, as a result of such policies. One group may argue that more intensive use of land will lead to detrimental consequences while others may claim that

the land is able to sustain long-term production. There are a number of interest groups in our society who attempt to influence land use policies and may be affected by those policies.

Although some policies or regulations increase the efficiency of land resource allocation, they often also make some people or regions worse off and others better off because policies are primarily redistributive in nature (Lee, 1981). This means an added social cost or benefit with the implementation of the policy. Frankena and Scheffman (1980) indicate that land use policies rarely consider the social and economic effects of regulation and control, and often ignore information on trade-offs and opportunity costs when they formulate land use policies.

One example of government intervention in land resource allocation is the B.C. Land Commission Act of 1973, authorizing the establishment of a 4.7-million hectare agriculture land reserve (ALR) through exclusive agricultural zoning. The underlying reasons for establishment of exclusive agricultural zoning are to preserve agricultural land for farm use and to maintain family farms (Canada. Environment Canada, 1979). This restrictive land use policy serves to further its objectives and increase the flexibility in agricultural land use options. Pierce (1982) indicates that, on the one hand, this land use policy reduces the rate of agricultural land conversion and provides a measure of stability to the rural environment, as well as contributes to increases in the food self-sufficiency of British Columbia. Yet, on the other hand, it also creates a large income transfer from one group

23

to another, violates basic property rights, and weakens the efficiency of the land market by creating conditions of artificial scarcity.

Land use policies and programs are often uncoordinated and inconsistent because government agencies are highly fragmented and constrained by narrow outlooks and actions (Simon, 1989). Governments often organize their agencies based on definable resource sectors such as the Ministry of Agriculture, the Ministry of Forests, and the Ministry of Environment in British Columbia. Land use objectives in each ministry are geared to its own interests in accordance with the agency mandate. A potential for conflict exists because these ministries may all be interested in the same land. For example, an extensive land use program which might be considered as effective in the agricultural sector, might conflict with the goals of the forestry sector. It is conceivable that the pursuit of a large agricultural land base might require more forestry land being converted for agricultural uses (Canada. Environment Canada, 1985a).

In summary, both market and extramarket means have their shortcomings in land resource allocation. The foregoing discussion illustrates that free market forces often fail to allocate land in an efficient way. Thus, extramarket mechanisms are often adopted by society to choose land uses. However, government intervention is not in itself justifiable as a more effective or better approach than the market approach in land resource allocation. Too often, land use policy is formulated on the basis of a poor analytical base. Such unjustified government intervention in land allocation may impose a variety of

unnecessary costs on society in relation to society's goals and preferences for the use of land (Smit and Johnston, 1983).

2.3.2 Problems in Land Resource Management

Agricultural land, forests, and wetlands are all important resources. They are directly dependent on ecological processes and functions whose care and management are essential for the sustainability of the important life-support systems. Damage in any of these ecological processes or functions through change in the quantity and quality of the land resource base can have serious consequences. In many parts of the world the supply of land is threatened by various kinds of degradation and environmental change. Among the most important forms are soil erosion, deforestation, desertification, and climatic change. All such abusive factors can affect the overall sustainability of the land base. It is therefore crucial to adopt management means and practices to counteract the stresses and shocks imposed by land degradation and environmental change (Crosson and Rosenberg, 1989; Pierce, 1990).

One of the most challenging problems for land management is to devise the effective policies or programs aimed at sustainable resource use. In order for new policies to be effective, they must be based on sufficient knowledge of the ecological, economic, and social effects of environmental change. However, land use policy makers have been working without sufficient knowledge of global change and land degradation, and the quantitative effects of such environmental changes on the supply

and quality of land (Brouwer, 1989). Given the unpredictable nature of global change, understanding of the ecological resilience of land systems is also critical (Conway, 1985). However, knowledge of the diversity and complexity of ecological processes is inadequately developed, which makes it extremely difficult to understand the conditions necessary for ensuring ecological stability and resilience (Holling, 1978; Clark and Munn, 1986).

Perhaps one of the most important land management problems is the level of ignorance of the consequences of resource management policies, programs, or regulations. Understanding the potential socio-economic and environmental impacts of alternative management measures is essential for determining appropriate policy responses. Information of this kind is either ill-suited to the requirements of land use decision makers or rejected by them because it is too complex (Manning, 1986). For example, as the impending falldown in the annual allowable cut (AAC) places pressure on the B.C. forestry sector, alternative silvicultural, forest protection, and land alienation programs could be implemented to avert or reduce the problem. Yet, the various environmental, social, and economic impacts of these forest use programs are poorly understood (FEPA, 1989).

In addition, policy effects have to consider both the temporal and spatial dimensions which increase the complexity of land resource management. It is apparent that different spatial and temporal distributive impacts of management measures can create equity problems. One example is the preservation of upstream forestry areas to reduce

26

flooding of downstream farms. Such conservation policy can ensure that the ecological functions and the resilience of the land base are maintained for future generations. The cost of implementing this kind of upstream conservation practice creates benefits for downstream regions, and thus creates a redistributive effect.

A major factor deterring the adoption of management practices in land use is that, over the short-term, these practices may result in reduced profits and loss of competitiveness in the market with other land users who do not adopt these practices. A major trend in North American agriculture since World War II has been the a movement away from crop rotation toward the continuous raising of a single crop, such as corn. Monocropping has, to a large degree, facilitated the application of advanced farming technology and management, and thus increased food production. However, the practice of monocropping has also accelerated the rate of soil erosion. While crop rotation can alleviate soil erosion, rotating a soil depleting crop such as corn with a soil replenishing crop such as forage means rotating a high economic value crop with a lower value one. It is generally believed that farmers have little incentive to adopt resource conservation practices in land use because they often lose profits in the short-term by implementing such practices (Crosson, 1982).

Another important issue in resource management is the different perspectives and values with respective to resources among various individuals or interest groups (Cocklin, 1988). For a parcel of forest land, the farmers will perceive it as a potential source of cropland;

for the forest company, it is a timber supply area; and for the ecologists, it is a diverse and rich ecosystem which serves as an important wildlife habitat. Thus, a parcel of land could be good for several alternative uses which are not always complementary to each other and often are mutually exclusive. Conflicts and therefore trade-offs between uses and users will arise.

In land use planning, one common criterion for determining the relative value of land resources is the economic value. The maximization of profits often becomes the ultimate criterion in land use decision making. With this criterion, land users often neglect an important fact that land value is a multidimensional issue within which the economic aspect is only one part. Nonmonetary aspects of the land value, such as social, ecological, aesthetic, educational, and historical values, should be fully taken into account (Sampson, 1981). Bryant and Russwurm (1982) suggested that five perspectives of farm land value could be identified: as residual after other uses; as a special asset; as a production input; as amenity value; and as opportunity cost. This implies that land use management requires a multidisciplinary approach. It can no longer be considered as solely an economic issue but must be integrated with other perspectives.

Furthermore, it should be recognized that the public attitudes and values toward resources also vary over space and time. People of countries with different cultural and historical backgrounds, and at different stages of economic development, possess different attitudes and values on resources and environment. In general, developed

28

countries tend to emphasize issues of resource depletion and
environmental degradation, while people in LDCs are more concerned with
the basic human needs of adequate food, clothing, and housing.
Environmental quality concern in many LDCs is often treated as a low
priority goal in resource development decision making. With respect to
the temporal dimension, the current environmental movement is a
reflection of changing attitudes in the world toward resource
conservation and environmental protection (Tisdell, 1989).

Just as perspectives on resources in our society vary, and
differences of values toward resource use exist, land management has
also failed to recognize different and changing public values of
various interest groups, and to reconcile the diverse value sets in
land resource management. Many wetlands which, in the past, appeared to
have no future value, were treated as waste lands and converted to more
'productive' uses. This perception of wetlands led to millions of
hectares of wetlands across Canada being drained or filled for
agricultural, industrial, and urban uses (Canada. Environment Canada,
1986).

Drainage of wetlands has adverse effects on the hydrological,
ecological, and wildlife system functions. There is a growing
recognition that wetlands are valuable resources and the reduction of
genetic diversity and waterfowl habitat with loss of wetlands has
caused a significant decline of wetland natural values (Canada.
Environment Canada, 1983). This example shows that it is a risk to
eliminate biological species which may prove valuable in the future.

Wilson (1989) has argued that the current rate of human-induced habitat destruction is accelerating because of the ignorance of the potential future value of many species.

2.3.3 Externalities and Intersectoral Impacts

Another type of land use problem arises from the concern over the existence of negative externalities or external effects of land use activities. External effects or spillover effects occur when land use activities of one user or one resource sector generate costs which fall on third parties. The externalities or third party effects which cause conflict and mismanagement of resources can result from the lack of property rights and knowledge of sustainable resource use (Dowall, 1981).

Due to external effects, some land uses may make incompatible neighbors. One example is nonfarm residence in urban fringe areas which often create noise and disrupt the normal operation of farming life. Another example is soil erosion from rural land uses which pollutes the water courses and constitutes a serious environmental problem. The negative externalities of farm operations such as off-farm erosion or increasing amount of downstream silt often result in high environmental costs to society (Crosson, 1983). To internalize such social and environmental costs arising from land uses is a difficult task. It may be more appropriate for the government to establish regulations to insist that those who generate the externalities pay for the suffering or to minimize their effects. For instance, zoning land use can

separate farms from residential houses in order to reduce the conflicts between the two land uses.

Little comprehensive information on the magnitude of such external costs is available, although their symptoms are widely visible. This is perhaps because in many situations, externalities involve many affected entities, and often the external effects on each of the entities are not identified and thus are not compensated. Under such a situation, individuals who create the externalities have no incentive to apply the available control measures to reduce the spillover effects.

Externalities also cause intersectoral conflicts. Land use planning in each of the three major resource sectors--agriculture, forestry, and wetland--is undertaken independently following certain narrowly defined mandatory rules. Land use objectives within and between different resource sectors often conflict with each other, and thus one use may impose significant negative effects on others. For example, the drainage of wetlands for agricultural or other uses, and the clear-cutting of forests, can disturb or remove wildlife habitat. In counterpoint, a wetland enhancement project may increase crop damage by waterfowl in nearby fields. Agencies responsible for managing agricultural production are separate from, and inadequately coordinated with, those controlling wildlife and environmental protection. It is difficult to coordinate the policies and programs of two ministries such as agriculture and environment to determine the most effective land use regulatory arrangements.

Another important consideration with land use is the irreversibility of certain externalities. The concept of irreversibility indicates that once development of land, or its conversion from one use to other uses occurs, it may not be able to return to its natural state or be converted back to its original use except at an unreasonably high cost (McAllister, 1973; Dawson, 1984). Thus land resource management should avoid unnecessary irreversible changes of the resource base. Some externalities such as environmental damages, especially irreversible damages, have significant effects which may, for a long time period, reduce land use options for future generations. Thus, the long-term effects of irreversible damage such as species extinction may become an intergenerational equity problem (Page, 1983). On the other hand, the cost of avoiding irreversible damage is likely to fall mainly on the current generation whereas future generations are likely to be the main beneficiaries (Tisdell, 1988).

2.4 Need for Integrated Resource Management

These land use problems are examples of some of the main reasons for uncertainty concerning the sustainability of the land resource base to support future societal demands. The pursuit of sustainable land resource system needs to determine how land resources can be allocated over space and time to meet social needs, aspirations, and desires within constraints imposed by nature, capital availability, technology, and ecological resilience. What has been implied throughout the preceding discussion is that major research gaps exist which inhibit a

satisfactory resolution of many land use problems.

Current research methods or techniques which frequently have been
applied to natural resource analysis are mainly based on one dimension
of the resource use system, and thus are often desirable for the
assessment of either ecological, social, or economic impacts. Another
important rigidity of these methods is that they often deal with one
resource sector in isolation, failing to recognize the importance of
intersectoral relations. Sustainable land use is highly complex and
involves many interest groups, and has to consider multiple objectives
which are often in conflict. The integrated and interdependent nature
of sustainable land use requires a method to integrate a wide range of
objectives, preference, resource sectors, and intersectoral relations
into an assessment framework. An integrated approach can provide a
valuable way for evaluating land use sustainability (Cocklin, 1989a).
Manning (1986) presents a list of strategic research opportunities most
vital to the resolution of the most pressing land use problems. Among
these key research gaps, attention needs to be given to integrated
resource management (IRM), or as he calls it <u>structural</u> <u>management.</u>

2.4.1 <u>Integrated</u> <u>Approach</u> <u>to</u> <u>Land</u> <u>Resource</u> <u>Management</u>

Integrated resource management is an approach by which resource use
planners and analysts attempt to share different perceptions of
resource values, to make compromises over various resource uses, to
make explicitly the trade-offs, and to coordinate a broad range of
agencies and institutions (Lang, 1986a; Manning, 1986; Cocklin, 1989a).

33

The purpose of IRM is to adapt a comprehensive, systematic, and coordinated approach to achieve the best use of natural resources in a specific region. Lang (1986b) indicates that IRM is strategic, interactive, and that it adopts multiple perspectives. These are the three main characteristics which distinguish IRM from conventional resource management.

The underlying philosophy of IRM is utilitarianism. That is, the total objective of resource use in the public sector is to achieve the greatest good for the greatest number, in a sustainable way (Canada. DREE, 1970a). It is important to remember that the modern approach of IRM is just the latest phase in the long evolution of the concept. A good way to understand the contemporary development of IRM is to briefly examine the historical evolution of IRM from multiple purpose project to the modern stage. The concept of IRM can be traced back to the U.S. conservation movement in the late 19th century. It was recognized then that the resource base must accommodate a number of different, and often conflicting, uses and activities to meet societal needs. However, the formal introduction of IRM to resource management was delayed until 1928 when the Boulder Canyon Project Act was authorized to approve the Hoover Dam project on the lower Colorado River. The Hoover Dam is considered the first multiple purpose resource development project in the United States (Mitchell, 1986). Other examples of IRM in the United States include the establishment of the Tennessee Valley Authority in 1933; the Delaware River Basin Plan; the Ohio Conservancy Act; and so on (Browning, 1949; Owen, 1973). The U.S.

experience shows that IRM is being applied with varying levels of intensity in resource development and management, particularly in water resource management and river basin planning. Now, the major components of the concept of integrated river basin development include multiple purpose storage projects, basinwide programs, and comprehensive regional development (Kates and Burton, 1986).

The Canadian experience with IRM is similar to that of the United States (Mitchell, 1986). Although some basic components of IRM had been discussed at a number of Canadian forestry conventions and other resource conferences since 1906, the first important operational experience of IRM was initiated in 1946 with the creation of the Ontario Conservation Authorities Act (Canada. DREE, 1970a). In 1961, the Resources for Tomorrow Conference in Montreal set a benchmark in the history of IRM in Canada. The Canadian Council of Resource Ministers (CCRM) was established as a result of the Conference. The CCRM provided an intergovernmental forum for exchanging views and facilitated joint planning among the federal and provincial governments. A major initiative to promote integrated and comprehensive resource planning was taken in the late 1960s through the joint federal-provincial river basin planning in each region of Canada (Tate, 1981). One of the most prominent uses of IRM is the policy of integrated resource management for Alberta's Eastern Slopes (Lang, 1986).

It is apparent that, according to the examples previously presented, the concept of IRM has been in use for quite a long time.

Yet, successful implementation of IRM is uncommon (Mitchell, 1986). Several major obstacles may have to be removed in order to successfully implement integrated approaches in resource management. For one, IRM is often time consuming. It usually takes several years to complete all the procedures, so that the results of a IRM study may be out of date for implementation. To reduce the time needed for integrated resource planning, efficient and effective resource assessment and evaluation methods could be adapted and applied in resource analysis. Such methods will also take an integrative and holistic approach.

Inappropriate resource use legislation, and an inadequate institutional arrangement in resource management, have become barriers to applying IRM. Increasingly in Canada, resource planning is conducted at the provincial and federal levels by relatively few ministries such as agriculture, forestry, energy, mines, and wildlife. In the majority of cases the allocation and designation of land still reflects single sector biases and historical inertia with little understanding or appreciation of the trade-offs involved. For example, in British Columbia despite the importance attached to wilderness and wildlife values, forestry interests dominate all but a few of the crown land designations. The gap therefore between the theory and the practice of IRM remains large as is the number of conflicts over use of land. While there are numerous political and institutional reasons for this gap, such as the dominance of some resource ministries over others and the inability to define long-term goals, the gap can be narrowed by more thoughtful and systematic use of available techniques and information

for integrated land use assessment.

Furthermore, the lack of an appropriate analytical framework to facilitate IRM also creates difficulties for its implementation (Barbier, 1987; Cocklin, 1989a). IRM needs to consider multiple objectives, alternatives, and interest groups. These multiple aspects are often in conflict with each other. In IRM, sharing, coordination, and cooperation of values associated with different resource sectors are necessary. Interrelationships and trade-offs between different resource sectors may have to be identified. Therefore, a major challenge arises in designing new analytical methods that will contribute to this task.

2.4.2 The Need for Integrated Assessment Methods

The development and operation of IRM will be facilitated by rigorous and systematic analysis. An important aspect in undertaking IRM will be to identify the consequences of alternative courses of action. In turn, integrated resource management requires the development and application of appropriate evaluation systems with which to assess various land development prospects, and to indicate the potential implications of land resource policies and plans for attaining land use goals. Land use analysts should be able to identify the extent of particular land use problems, and to collect data required for analysis. Moreover, analysts need to develop comprehensive evaluation systems to assess social, economic, and environmental impacts of alternative land use options to decide which option can ensure

37

sustainable development (McAllister, 1973). Thus, IRM is dependent upon resource analysis.

Integration is also needed for resource assessment and evaluation. It is obvious, therefore, that more promising and powerful analytical tools are desirable for integrated resource analysis. Relatively more resource analysts and decision makers are now aware of the need for research in developing and applying integrated land assessment methods. This awareness has been combined with an understanding of the promise inherent in systems analysis and mathematical programming modelling (Nijkamp, 1980; Braat and Van Lierop, 1987; Cocklin, 1989b).

In the following, a set of guidelines or criteria is established to evaluate the appropriateness of various methods for integrated land assessment. The fundamental aim for this evaluation of methods is to highlight a group of attributes to be considered in an integrated resource assessment methodology. The wide variety of applications to which integrated resource methodologies can be put, assures that none of the methods will meet all of the criteria. And this might be attributed to what McAllister (1982) has termed the "evaluation dilemma". Trade-offs might be necessary to select the most appropriate method for this study. Some commonly used criteria in comparative evaluation of methods, such as simplicity, cost and time required for solving the problem, may be dopted in the appraisal (Hwang and Masud, 1979). In addition, since the purpose of this evaluation is to examine the suitability of methods for undertaking integrated land assessment, a method needs to have several critical characteristics. The method

38

should be appropriate to the study purpose, systematic and comprehensive, multiple objective and multiple sector, relatively easy to identify explicitly trade-offs, and be able to identify desirable land use alternatives.

* Appropriateness of the method in serving the study purpose

Evaluating how suitable different methods are depends on the purposes that various methods serve. Methods can be grouped into several types based on their purposes. These types may include (i) forecasting or predictive (ii) descriptive (iii) normative or prescriptive and (iv) explorative (Hoffman, 1981; Swartzman and Kaluzny, 1987). It is important to keep these different purposes of methods in mind when choosing appropriate analytical methods for different kinds of research. As in this study, the research framework is built to assess the implications of alternative land use changes, options, or policies with respect to environmental, economic, and social goals. Thus, the method adopted to form the integrated land assessment framework here should be explorative in nature, rather than descriptive, predictive, or prescriptive.

* A systematic and comprehensive approach

The method should reflect the resource use system as closely as possible. Interactions between various variables, and interrelations between different land uses, can be explicitly represented by the model. The method is capable of incorporating biophysical, socio-economic, and other factors into the assessment. Data bases for assessment should also be established which are

systematic and comprehensive.

*   A multiple objective and multiple sector approach

Decision making in land resource management often involves the allocation of scarce resources to satisfy several economic, social, and environmental goals. Evaluation of the sustainability of resource use systems has to confront the problem that there is no universally agreed upon goal. It is necessary to consider a range of land use objectives in an integrated land assessment. There is a need to allocate land resources to many uses in different sectors such as agriculture, forestry, and natural reserve areas. It is possible that one land use option which might be considered sustainable for one resource sector (for example, agriculture) but might affect the sustainability of another resource sector (for example, wetland). Some of these goals or different uses are compatible, whereas others are often in conflict with one another. Therefore, methods which accommodate multiple objective and multiple sector considerations more realistically portray land use systems. Evaluation of alternative land use options to identify which ones are sustainable requires an integrated approach.

*   A research framework which has the mechanism to identify trade-offs and conflicts

Land use management must deal with conflicts among various uses. Demands for lands are increasing rapidly which creates pressure on limited land resources. There are many difficult choices in land use decision making. How many hectares of land

should be allocated for food production? How much land should be
for forestry? How much land for wetland reserve versus how much
for urban uses? The integrated approach can provide analysts with
a framework to evaluate trade-offs between alternative land use
options and between land use objectives.

*   Flexible in designing desirable land use alternatives

The importance of this criterion lies in the need for an
assessment to be able to deal with a potentially infinite number
of continuous options. A land use option which a user may choose
is among an infinite number of alternatives. Thus, those methods
which are specifically designed for the selection of the best
option among a limited number of predetermined alternatives are not
desirable for integrated land assessment in the context of this
study.

Barbier (1987) suggests that in order to make the concept of
sustainable economic development operational, there is a need to
develop and apply new analytical tools to integrate different
conditions within and between biophysical, social, and economic systems,
and to identify the trade-offs among these systems. While Cocklin
(1989a) accepts Barbier's expression that resource planning and decision
making may be facilitated by the development and application of
methodologies to several resource problems, he further suggests that an
important evaluation issue is to move away from the traditional
emphasis on technical and economic efficiency concerns, to systematic
and holistic assessments. In this respect, the following two chapters

review different types of methods and approaches available in resource analysis, examining the suitability of these analytical methods as means for integrated resource assessment with respect to the guidelines presented above.

CHAPTER III

METHODS FOR LAND USE ASSESSMENT

3.1 Introduction

The approach to land resource assessment has, during the last three decades, evolved from simple appraisals of the suitability and capability of land for a given activity to comprehensive and integrative appraisals of the prospects of numerous uses of land. Integrated resource assessment is now the basic means to achieve integrated resource management (IRM) which is a comprehensive, systematic, and coordinated approach aimed at achieving the 'best' use of natural resources (Mitchell, 1986).

Decision makers and planners alike recognize, at least in theory, the multiple uses of land reflecting possible choices and options for society and the need to evaluate the economic, social, and environmental implications of these choices (McAllister, 1973; O'Riordan and Turner, 1983; Rees, 1985). As such, IRM is now a widely accepted concept in resource planning.

A large number of methods and techniques for resource use analysis and management are available (Cocklin, 1989b). These methods run the gamut from land classification to mathematical programming with different functions and applicability. Various empirical applications of assessment methodologies can be found in the literature of different disciplines (Despontin et al., 1984). However, the majority of the

applications focus either on economic or biophysical aspects of the land use systems. Applications which take a holistic viewpoint are relatively rare. Despite the rapid development of various methods, many problems and limitations still exist in the use of these resource analysis methods. It is common that comprehensive methods are highly specific to the purposes, regions, and conditions for which they are constructed (Walker, 1976). Thus it is normally difficult to apply any methods to problems other than their original one without modification.

In order to adapt methods for integrated resource analysis, it is important to know if any of these methods have the capability to provide appropriate and adequate information for IRM? A good way to understand the current development of analytical methods and to appreciate their suitability for integrated land assessment for this study is to examine these methods to identify their merits and shortcomings in the course of resource analysis. This chapter reviews some methods and approaches which have been widely applied in resource assessment and planning. Based on emphasis and main characteristics, these methods are classified into three groups: a biophysical and ecological approach, social impact assessment, and economic analysis.

This methodological review starts with a brief survey of the main characteristics of various methods and approaches which have been used for natural resource assessment and planning. The main principles of these methodologies are discussed, and then some examples are presented. A set of fundamental characteristics of integrated resource assessment has been presented in chapter 2. These characteristics can

be used as guidelines or criteria in method evaluation. A brief evaluation of the methodologies against these criteria is undertaken to highlight their suitability for integrated resource assessment. Their potential value as a means for integrated land resource assessment as well as their limitations are identified. Review and discussion of the mathematical programming technique is placed in chapter 4. This approach is separated from other approaches because mathematical programming modelling is one of the foci of this study.

3.2 Biophysical and Environmental Approach

The main philosophy underlying the biophysical and environmental approach is that the biophysical system is a unique entity which is controlled by some essential natural laws. Every region is different and possesses its own charateristics. This biophysical or ecological approach focuses on the protection, conservation, and improvment of the physical environment. In the case of land resource management, emphasis has been placed on sustainable land resource development to minimize land degradation, and to preserve genetic diversity and wilderness features of the land base. That is, to create, where possible, a harmonious environment between natural and human ecology. A key concern in a sustainable land use system is to make the best use of the land without weakening its productive capacity, ecological stability, and resilience. By preserving the productive potential of land, the interests of future generations are protected (World Conservation Strategy, 1980; Myers, 1987). Many rural land use analyses have been

45

based on biophysical conditions of various lands in an attempt to achieve an understanding of the potential productive capacity and the resilience of the land resource base (Found, 1971; Carpenter, 1983).

This section presents three different methods or approaches in land resource assessment and planning which emphasize biophysical conditions. Land classification, biophysical systems analysis, and environmental impact assessment (EIA) are discussed to show how well these methods can be used for land resource assessment.

3.2.1 Land Classification

A traditional approach used by geographers and others in land use studies is land classification (LC) (Stamp, 1940). The purpose of LC is to group lands into categories based on shared biophysical conditions. LC often differentiates units and subunits on the basis of selected climatic, soil, morphological, and vegetative criteria.

Land resource allocation and planning are based upon information provided by various land inventories and classifications. Land classification approach is widely used to formulate land capability classifications. Land capability can be defined as the ability of land to accommodate a particular use or activity without permanent damage (Lang, 1980). Land capability classifications (LCC) group lands which are homogeneous according to soil, climate, topography, and other biophysical properties that are pertinent to a particular use. Several LCC schemes have been developed for alternative land uses such as

46

agriculture, forestry, wildlife, and recreation. For example, agricultural land classification systems generally assess capability from known relationships between crop yields and physical factors of soil, site, and climate (Flaherty and Smit, 1982).

LCC schemes generally consist of between 5-8 classes. One class is usually defined as having no or few limitations for the particular land use. Other classes have increasing degrees of biophysical limitations. Classes may be divided into subclasses according to the kinds of limitations such as wetness, slope steepness, and soil erosion. LCC can provide useful information about the properties of land which are, in turn, the basis for assessment of the suitability of land for particular uses.

Attempts have been made to extend land classification schemes by incorporating additional socio-economic information. For example, an approach developed by researchers at Cornell University incorporates both biophysical and socio-economic factors which affect agricultural land use. This system provides information about where farms are more productive or profitable (Conklin, 1959).

The LCC system developed by the Soil Conservation Service (SCS) of U.S. Department of Agriculture (USDA) has been adapted for assessing agricultural productivity (Fabos, 1977). To do this, the LCC system, with additional information provided by SCS, and a land use classification system, provided the basis for grouping land into three classes (A,B,C). Then, crop yield was determined for each of fourteen

crops and for each of the three classes. The results showed that a direct relationship existed between land classes and crop yields. The capability-for-agriculture classes of the Canada Land Inventory have also been ascribed yield equivalents for selected types of crop (Hoffman, 1971).

The information provided by LCC is useful for evaluating the potential productive capacity of a region. However, LCC is mainly descriptive in nature and is not designed for other purposes. Thus, LCC is unsuitable to provide explorative functions needed by this study. Although a few LCC schemes have tried to take account of socio-economic conditions such as technological advances, market price, and farmland conversion to nonfarm uses, the vast majority are concerned solely with biophysical conditions and limitations. And although the LCC is for different land uses, it is not designed for use in making trade-offs among alternative conflicting land uses. The LCC system is not therefore a comprehensive approach for land resource assessment and as such does not provide a systematic framework to deal with the complex demands on land resources.

3.2.2 Biophysical Systems Analysis

The term system has been used widely in resource and environmental management. Systems analysis is a broad research strategy which is characterized by a set of specific objectives and analytical techniques. Systems analysis provides decision makers with a research framework which can be used to choose a desirable course of action, or

to predict the outcome of one or more courses of action. It does so by organizing data and information in an orderly and logicaly manner (Coffey, 1981). The following example of biophysical systems analysis is a specific case study, and does not represent a genuine systems analysis approach. More detailed discussion on biophysical systems analysis can be found in Wilson (1981) and Jeffers (1988).

Recently, FAO, in collaboration with the United Nations Fund for Population Activity (UNFPA) and the International Institute for Applied Systems Analysis (IIASA), adapted a systems analysis approach to study the potential population supporting capacities of lands in the developing world. Estimates of the potential population supporting capacities are compared with data on present and projected population to show crucial areas where land resources are inadequate to meet the food demand of present or future populations (FAO, 1983). This approach provides a systematic assessment of the potential population supporting capacity, using a sequential procedure which integrates various factors and brings together the potential demand and supply of land resources.

The first step of the FAO approach is to identify biophysical conditions or suitability of land resources. The FAO agro-ecological zones project provided essential data on soils, topography, climate, and other physical characteristics which determine the suitability of land for crop production (FAO,1971-81; FAO,1978-81). This was achieved by superimposing climate maps on soil maps to create unique land units. By comparing the biophysical conditions of each land unit with the growth requirements of a number of alternative crops, the agro-climatic

49

suitability and potential productivity are determined for each crop. A particular crop is then chosen for each land unit to maximize caloric production.

The second step is to adjust available inventoried land resources for food production by deducting other competing land uses for housing, transportation, recreation, and other urban requirements.

The third step is to modify the potential productivity in relation to the adjusted land base and to determine the potential population supporting capacity. The analyses of potential production are based on three technological input levels: (i) low; (ii) intermediate; and (iii) high. Potential productivity is further adjusted by assumed levels of land degradation. Then, the adjusted potential productivity is converted to calorie-protein for each crop. The potential population supporting capacity is calculated by dividing the total potential calorie production by the per capita calorie consumption recommended by FAO and WHO for each country (FAO, 1977). Finally, the potential population supporting capacities for specific regions are compared with existing and projected populations to determine those countries with insufficient resources to meet their food needs now and in the future. Results from this study provide useful information on population pressures and crucial areas where land resources at different input levels are inadequate to meet future food requirements.

The results of this example only represent a first approximation of the overall physical potential for food production. Such studies do

not provide mechanisms to make explicitly trade-offs among conflicting land demands such as agricultural, urban, and other uses. As well, other important economic factors such as market relationships are not considered.

Biophysical systems analysis provides a framework of thought rather than a specific technique for resource assessment. The introduction of systems analysis establishes a linkage between resource analysis and the resource systems. It appears that the systems analysis approach can be used as a guide in designing an integrated land assessment system because it meets most of the criteria. There are some limitations in this approach. Lacking is any systematic consideration of socio-economic, institutional, and political constraints.

3.2.3 Environmental Impact Assessment (EIA)

EIA provides an instrument for resource use planners to ensure that a conscious and systematic effort is made to assess the positive and negative consequences of potential resource development projects by public and private agencies. In 1969, the creation of the National Environmental Policy Act (NEPA) in the United States became the first national requirement for EIA. Many countries followed by implementing environmental impact assessment (EIA) procedures for large resource development projects and regional planning (Lee, 1983). In Canada, an environmental assessment and review process (EARP) was established by a decision of cabinet in 1973 (FEARO, 1984; Mitchell, 1989). In essence, EARP adopted an administrative regulatory approach in which EIA

51

procedures are implemented.

There have been various EIA methods and processes to guide the design of new resource development and environmental management projects (Day et al., 1977). EIA approaches can be grouped into five categories: (1) identification; (2) data assembly; (3) prediction; (4) evaluation; and (5) communication. Various methods or techniques have been developed to facilitate environmental impact analysis. Among them are the checklist, matrix, map overlay, network, and other methods (Warner and Preston, 1974). These approaches and methods are reviewed in some detail by Cook (1977), Jain and others (1977), and Lee (1983). This section does not attempt to undertake a systematic review of EIA methodologies. Rather one example is presented to show the capability of EIA in resource assessment and planning.

Environmental Evaluation System (EES) for Battelle Institute

A number of endeavours have been made to develop integrated methodologies capable of comparing the relative importance of various impacts and systematizing evaluation procedures (O'Riordan, 1983). An Environmental Evaluation System (EES), developed at the Battelle Institute of Columbus, Ohio, for the U.S. Bureau of Reclamation, uses value functions to weight, standardize, and aggregate different impacts to form a impact composite index for alternative development projects (Dee et al., 1973).

The purpose of EES is to evaluate the significance of environmental impacts associated with alternative water resource

52

planning. Based on a hierarchical arrangement of environmental quality indicators, a specific EES included four levels: category, component, environmental parameter, and environmental measurement, from the top down. The top level, category, consisted of four groups: ecology, environmental pollution, aesthetics, and human interest. Each category was further divided into eighteen components (level 2). Each component was composed of several similar parameters (level 3). There were a total of 78 parameters in the specific EES and each of them represented an aspect of environmental significance. The lowest level of the EES consists of environmental measures which constitute the data needed to obtain estimates for parameters. A commensurate measurement, environmental impact unit (EIU) was used for the evaluation.

EES was applied to the Bear River Basin development project for evaluating the significance of environmental impacts (Dee et al., 1973). The application shows that EES provides a useful means to evaluate environmental impacts associated with resource development projects. In addition to providing information on the significance of individual and aggregated environmental impacts, EES can also indicate sensitive elements or red flag parameters which will induce significant impacts on the environment with respect to a particular resource development. EES is considered one of the best known methods for environmental impact assessment (O'Riordan, 1983).

However, the environment is a very complicated system and existing knowledge on environmental processes and interactions is far from complete. This results in difficulty to evaluate various impacts and to

53

scale the significance of the impacts (Rees, 1985). The value functions determining the scales or scores of environmental impacts reflect the subjective judgement of the analysts. The scaling and weighting methods adopted in EES are subjective and a source of bias. It seems difficult, if not impossible, for everyone to approve a specific value function for environmental parameters in the EES.

EIA has become a useful approach for examining the significance of environmental impacts associated with resource development. It provides resource use planners with a systematic assessment framework to generate information for resource management. In an EIA process, several methods may be applied for the evaluation of impacts, care must be taken to achieve synthesis among environmental, social, and economic impacts. Since various impacts are studied independently, it is difficult to identify explicitly the trade-offs among different impacts. Maclaren (1985) argues that the use of an aggregated 'final score' for each project alternative in determining the 'best' alternative should be avoided. The aggregation masks the strengths and weaknesses within each alternative. Maclaren and Whitney (1985) suggest that any meaningful EIA studies need to integrate the relevant components of the biophysical and socio-economic systems.

3.3 Social Impact Assessment Methods

In response to problems inherent in economic assessment which neglect social values in the assessment procedure, and with the

54

establishment of the National Environmental Policy Act (NEPA) in the United States, social impact assessment (SIA) was developed around 1970 (Rohe, 1982). The purpose of SIA is to incorporate nonmarket social values into the assessment of potential policies, projects, or programs (Finsterbusch, 1985). Most of the resource development decision making has been made on the basis of economic assessment within which maximization of profit or economic return is the key criterion for judging alternative options. It is becoming increasingly recognized that social value is an equally vital criterion in resource use assessment. The public is now concerned with the implications of resource development for the quality of their lives in terms of population, public service, employment, equity, and other social relations. SIA is used to counterbalance strictly economic and environmental assessment in resource use decision making.

There has been considerable effort devoted to the development of SIA methodologies (Rossini and Porter, 1983; Finsterbusch, 1985). To a large degree, these methods use traditional social science research methods such as surveying, interviewing, observation, and statistics. Although many methodological approaches have been used in SIA, a general SIA methodology developed by Wolf (1983) provides a standardized procedure. It consists of ten steps: scoping; problem identification; formulation of alternatives; profiling; projection; assessment; evaluation; mitigation; monitoring; and management. The bottom line of this procedure is to identify both negative and positive impacts on social conditions resulting from new resource use projects,

policies, or programs. Mitigation measures may be taken to ease negative impacts if they are unacceptable.

Profiling, projection, and assessment are three major steps in most SIAs. Profiling describes the social units which are affected by various resource use policies, projects, or programs. Projection is used to predict the impacts of new projects upon social units. In the assessment stage, estimates are made to identify the magnitude and significance of social impacts that an action would induce. A wide range of techniques have been used in the above three SIA steps. Some of them have been drawn from traditional social science disciplines and have been applied in environmental and economic impact assessments, while others have been developed for specific social impact assessments (Leistritz, 1986).

Many traditional techniques in social science disciplines have been used in SIA processes. For example, checklists and matrix methods have been widely applied to assess the impacts of resource development upon social conditions (Christensen, 1976; Boothroyd, 1978). A comprehensive checklist of factors to be considered in SIA is provided in a matrix. These often include employment, population, housing, community land stage, health, and safety. Also, another checklist is presented to show crude ratings of the magnitude and importantance of social impacts identified. A matrix which has a provision for recording crude ratings for different groups of people who may be affected can be used for assessing impacts on equity. The cross impact matrix seeks to account for interdependent effects among various impacts. It identifies

important higher order or cross impacts.

Two other methods are alternative scenarios and delphi techniques. The construction of future scenarios provides means to simulate future social conditions with some specific development projects. Since the future is full of uncertainties, prediction of future change based on extrapolation of historical trends or other empirical data is risky. By creating alternative future scenarios which describe an array of plausible futures, this scenario approach can show possible future social consequences or impacts of development plans or projects. Scenarios indicate what might occur under certain conditions. They have been used as connecting thread in systems analysis (Chen, 1983). A delphi is a much broader based technique which is based on experts' judgements. Questionnaires are sent out to experts and feedback reports are then gathered in an iterative process. The final result of a delphi is the refinement of guesses and predictions about the future, and reflects the mean opinion of experts (Rohe, 1982).

It is obvious that the traditional social impact assessment techniques are generally simple and easy to apply by both professionals and ordinary people. They are also relatively inexpensive. These techniques can be comprehensive to include various social impacts. They highlight major issues in SIA and are good for communication between the public and planners. Modelling techniques have been adopted and applied in recent SIA studies (Rossini, 1983). It seems that modelling has great potential to show explicitly interrelationships between components of a social system. Implementing these models requires

extensive data. Data collection is extremely costly and time consuming, and it is particularly difficult to quantify some social values and impacts. Limitation in data base development has been a major barrier to the application of more comprehensive and systematic SIA models.

SIA is now becoming a promising research field and could deservedly be considered more systematically. SIA could be incorporated into an integrated resource management scheme which could provide a framework to assess economic, social, and environmental impacts simultaneously.

3.4 Economic Impact Assessment Methods

Economists have been active in undertaking research on resource allocation, assessment, evaluation, and planning (Barbier, 1989). Maximizing economic welfare becomes the dominant objective in resource use decision making. There are many techniques or methods which have been adopted for economic assessment (EA). Most of them were originally developed by economists. The intention of this review is not to discuss all methods in EA, but to focus on the two most widely used methods: cost-benefit analysis (CBA) and input-output analysis (IOA).

3.4.1 Cost-Benefit Analysis

Cost-benefit analysis is perhaps the most widely used method in economic impact assessment. CBA has been applied for three broad purposes (i) to assess the economic implications of natural resource

development (ii) to evaluate projects subject to a given purpose (iii) to evaluate projects given a set of purposes (Sewell et al., 1961). Analysts list a set of options and identify possible benefits and costs under each. Normally, the option which creates the greatest benefit-cost ratio is considered the most desirable (Pearce et al., 1990). CBA provides decision makers with information of effects on economic, social, and environmental components associated with a resource development project. But its appropriateness for assessment of natural resource management has been widely questioned (McAllister, 1980; Rees, 1985; Cocklin, 1989a).

In CBA, impacts on the economy, environment, or society are quantified in monetary value. All costs and benefits, including primary and higher order, are summed to derive an overall cost and benefit for a particular evaluation. The ratio of costs to benefits is calculated, which can then be used as a grand index to assess the economic efficiency of particular development projects (McAllister, 1980). One concern is the use of CBA in evaluating projects through aggregation of all impacts to a grand score, the cost-benefit ratio, for each alternative. Such application is prescriptive in nature, and is unsuitable for the purpose of this study. Thompson (1990) suggests that methods which provide a 'final score' for various impacts should not be used as assessment tools because they may remove the responsibility for the decision from decision makers to analysts. Even Hufschmidt and others (1983), who are admirers of CBA, also have reservations about appropriateness of the CBA for natural resource analysis.

The underlying philosophy of CBA comes from neoclassical welfare economics (Bromley, 1986). It is based on the concept of potential Pareto improvement. Under this concept, a change is considered economically efficient if the gainers can compensate the losers. That is, if a resource development project generates total benefits exceeding total costs then it is judged desirable because of economic efficiency (Randall, 1986). In CBA, future benefit and cost flows are converted into present values by applying discount rates. Since discount rates are determined by the current generation, and since all future values are discounted, the technique is biased toward the current generation in resource use decision making (Rees, 1985).

Based on welfare economics, traditional CBA focuses almost entirely on the criterion of economic efficiency, ignoring other concerns. It was indicated in chapter 2 that sustainable land development should evaluate resource development projects or plans based on multiple objectives or criteria. Due to pressure exerted by the recent environmental movement, and with the new concerns for sustainable economic development, some attempts have been made to broaden the formal CBA technique by incorporating environmental consideration in evaluating natural resource development (Sewell, 1975; Rees, 1985; Hufschmidt et al., 1983). However, how to identify trade-offs between different impacts are not made explicitly.

The economic valuation techniques for assessing environmental or social impacts, either market-based or survey oriented (willingness to pay), are applied in CBA to convert any environmental and social

effects into monetary terms. Application of economic valuation techniques to nonmarket goods and services in environmental and social systems creates many difficulties and problems. Major difficulties arise in putting a market price on wetland loss, landscape amenity, genetic diversity, irreversible resource depletion, human health damage or death, and other social impacts. Evaluation of such intangibles as amenity and genetic diversity is normally based upon willingness to pay estimates. But this ignores among other things the ability to pay problem and the bias toward the present generation. Given these shortcomings of CBA, the method is precluded from explicitly examining the trade-offs among impacts.

Furthermore, Cooper and Vlasin (1973) argue that not all land values can be expressed in monetary terms. There is no such pricing mechanism to assign a dollar value to environmental or ecological goods and services, simply because they are not marketed. The incorporation of environmental quality and social cohesion into land use evaluation is not just an economic process. There may also exist some political constraints and security goals in land allocation. One example is that land resource development may be related to import replacement, or provision of a secure domestic supply to enhance self-reliance in food stuffs (Canada. Agriculture Canada, 1985). The need arises, then, to substitute new value measures for monetary units. Some welfare economists attempt to make various values commensurate by a single unit known as utility. Utility value is the extent of an individual's satisfaction derived from the consumption of goods or services. It is

assumed that individual's utility functions can be identified (Zenely, 1982). Decision makers will select the land use option which will maximize total social utility in the case of land resource allocation. Inevitably, the utility function is criticized for its arbitrary and subjective nature (Simon, 1978). Cocklin (1989b) argues that utility is based on individual's state of psychological well-being, and thus is inherently nonquantifiable.

3.4.2 Input-Output Analysis (IOA)

The impact assessment of a natural resource project has to be based in a regional context and must consider interregional effects. For example, environmental pollutants may cross regional or national boundaries and have national or global significance. Assessment methods which can provide information not only on the magnitude and type of impacts of a resource development project, but also on which economic sectors or regions are likely to be affected, are more appropriate for resource analysis. To identify the regional distribution of various impacts associated with resource projects, the structure of the method should reflect the interactions between sectors and between regions. IOA provides such a framework for resource analysis.

IOA was developed by Leontief during the 1930s for the purpose of describing the patterns and interrelationships of sales and purchases of goods and services among the various sectors in the modern U.S. economic systems. All industrialized countries now possess a national-level input-output accounting framework. IOA has also achieved

popularity in recent times as a useful tool in resource related studies such as watershed project evaluation; resource use, conservation, and development assessment; and river basin plan evaluation (Czamanski, 1972; USDA, 1978; Yeates, 1978; Lonergan and Cocklin, 1985). The main contributions of IOA is that it provides explicit supply and demand characteristics of individual economic sectors of different regions, and illustrates the nature of interrelationships among these economic sectors and between regions (Isard, 1960).

The basic structure of IOA consists of three tables or matrices. The first table is a transaction table or input-output flow table. Each row of the table indicates how output of a sector is distributed to all other sectors and to final buyers, and each column represents the purchases made by one sector from all other sectors. Like most other economic analyses, the total outputs and total inputs in the table will reach an equilibrium. Though physical units can be used in transaction tables, monetary units are normally used in the traditional input-output matrix. The second table presents technical coefficients. This table displays the required input from each producing sector to produce $1 worth of output in a respective sector. Leontief's inverse matrix or direct plus indirect coefficients is the third basic table in IOA. Each coefficient in the table shows the direct plus indirect requirement, or total output requirement from a sector associated with $1 of additional increase for final demand. This table is one of the most important achievements for IOA. It quantifies a large number of direct and indirect interrelationships among various sectors in a

63

economic system. This table can be used to predict impacts of proposed changes in the final demand for goods or services resulting from alternative policies or plans. The above discussion indicates that IOA models can serve for descriptive or predictive purpose.

Since the late 1960s, IOA has been extended to incorporate environmental factors into the economic input-output analysis. This was achieved by (i) adding to the original input-output table extra rows and columns to represent pollution emission and abatement activities (Miller and Blair, 1985) (ii) designing economic-ecological models (Isard, 1972) and (iii) developing commodity-by-industry models (Victor, 1972). Additional interrelationships or flows within and between economic and ecological systems are established in extended input-output models. Environmental impacts of resource development plans can be estimated (Cumberland, 1974; Leontief et al., 1977). In some cases the environmental effects are translated into monetary units, while in other cases appropriate units of measurement of environmental quantities will replace the economic unit of traditional models (Whitney, 1985).

IOA is a very useful method for estimating the direct and indirect impacts on a regional economy associated with the implementation of a natural resource project. The IOA provides analysts and planners with a systematic research framework which simulates the structure of a regional economy. This framework permits the specification of complex interactions between sectors. Many applications of IOA models have been reviewed in detail by Lonergan and Cocklin (1985), Miller and Blair (1985), and Whitney (1985), and are not discussed here.

64

Despite the potential of economic-environmental input-output models in resource evaluation, they are relatively not used much in resource studies. Some applications of these models indicate that structural relationships between economic and environmental systems are not appropriately integrated (O'Riordan, 1983). In addition, the data requirements and the time for collecting the basic data for IOA are substantial. Lonergan and Cocklin (1985) indicate that the assumption of fixed coefficients is one constraint on the power of IOA models for prediction purpose. Another limitation of IOA is its inflexibility in operation.

3.5 Summary

This chapter has reviewed several approaches and methods which have been widely used in assessing environmental and socio-economic impacts of resource development. Section 2.4.2 has presented a number of guidelines which may be either essential or desirable in the integrated resource assessment defined in this study. These guidelines are used as criteria against which various analytical approaches and methods are evaluated, and as a guide in Table 3.1 wherein the extent to which the methodologies meet the criteria is shown. Table 3.1 provides a broad outline of the characteristics held by different approaches and methods.

Generally, land assessment and evaluation approaches have been based either on biophysical conditions of land resources or concerns

Table 3.1: Methods Reviewed on Resource Assessment.

Method	Approach	Evaluative Criteria						
		Multiple Objective	Multiple Sector	Systematic/ Comprehensive	Flexible to Change	Goal Trade-offs	Limited Alternatives	Purpose
Land Classification	Biophysical	NA	No	Possible	No	No	Yes	Mainly Descriptive
Ecological Systems Analysis	Biophysical	Possible Biophysical Objectives	Possible	Yes	Varies	Possible	No	Varies
Environmental Impact Assessment	Mainly Biophysical	Possible	Possible	Possible	Varies	Possible	Yes	Varies
Social Impact Assessment	Social	Possible	Possible	Possible	No	Implicit	Yes	Varies
Cost-Benefit Analysis	Mainly Economic	No	Yes	Yes	No	No	Yes	Prescriptive
Input-Output Analysis	Mainly Economic	NA	Yes	Yes	No	NA	Yes	Descriptive or Predictive

NA: Not Applicable

for economic and technical efficiency. Resource analysis tends to focus on a limited set of aspects of land use systems. Conventional economic analysis abstracts from nature and analyses, in detail, the economic dimension or the economically useful functions of the land resource systems (Found, 1971; Barlowe, 1972; de Souza and Foust, 1979; Barbier, 1989). In conventional economic analysis, consideration of environmental quality and ecological functions of land resource systems is usually absent. Land is considered as a commodity, a factor of production. Thus, the depletion of land resources may be justifiable based on an economic analysis and unsustainable land uses may be indicated as economically rational (Tisdell, 1988; Daly and Cobb, Jr. 1989).

Similarly, biophysical approaches abstract from the ecosystem and investigate the ecological factors and functions of land use systems to the detriment of economic concerns (de Neufville, 1981). The biophysical approach is incomplete as a means to the general understanding of the land use system because it exclusively concentrates on physical and biological factors, and fails to take economic and technological factors into consideration (Chorley, 1973). This approach has relied widely on resource survey data and land capability measures (Rees, 1977; Dumanski and Stewart, 1981). In ecological land management, the ultimate objective is to maintain the stability and resilience of the land resource system (Holling, 1978; Conway, 1983). The inadequacy of the biophysical approach for integrated land evaluation has been explored in depth by Flaherty and Smit (1982).

The evaluation of various methods has indicated that different methodologies serve different analytical purposes. The integrated land assessment for this study requires explorative or heuristic methods that do not claim to look at an 'optimal' solution. Among these methodologies, LCC systems are mainly descriptive in nature, CBA is a method for prescription, and IOA models are for prediction purpose. Thus, LCC, CBA, and IOA methods are inherently unsuitable for the research problem defined in this thesis. In addition, other methodologies listed in Table 3.1, except the biophysical systems analysis approach, are mainly designed for the evaluation of a discrete number of predefined resource use alternatives or options. Integrated land assessment needs to take account of a continuous number of options. In fact, the methodologies should assist analysts to identify the desirable land use alternative. Hence, despite the potential of the above evaluated approaches and methods in resource assessment, they are not employed directly to form an integrated land assessment framework for this study.

This does not mean that all these methodologies are rejected by this study. On the contrary, many aspects, considerations, or methods provided by these approaches are incorporated in the integrated land assessment framework (ILAF) here. For example, the systems analysis approach is adapted as a guide in designing the ILAF system. Results of previous land classification, EIA, and CBA studies are used in this study. Biophysical assessment methods, such as the Universal Soil Loss Equation (USLE), are incorporated in the integrated land assessment.

Jeffers (1973) claims that effective land use will never be achieved based on partial analyses of the total land use system. Land resource assessment is not simple and one dimensional, but considers several objectives of an economic, social, and environmental nature. It is necessary to study economic activities within the social and ecological context. Resource analysis requires a multidisciplinary and holistic approach which makes it possible to deal with the interrelations between the economic system and the ecological and social systems. The approaches and methods discussed above, based on selected segments of the resource use system, need to be incorporated into an integrated assessment framework.

CHAPTER IV

MATHEMATICAL PROGRAMMING AND ITS APPLICATION

To allow for simultaneous consideration of many factors and dimensions a mathematical programming (MP) model is desirable. MP is a modelling technique useful in decision making where there is choice among a set of feasible alternatives. In particular, the analyses can provide decision makers with information for justification of alternative resource allocation programs and their impacts on such goals as economic efficiency, regional development and environmental quality (Hassan, 1985). MP models can serve planners especially where there is wide latitude in how resources might best be allocated to achieve some specified objectives (Wagner, 1969; Chiang, 1984).

MP provides a means by which land use patterns and interactions can be explicitly analysed. MP models have been viewed as a valuable tool to assess and evaluate resource development prospects. Models provide the basis for generating quantitative forecasts and offer the means of evaluating the effects of alternative policies upon multiple development goals. In particular, models which represent land use systems can provide a research framework for examining those systems. Moreover, the use of appropriate MP models makes it possible for geographers to gain a deeper understanding of the interdependencies of land use systems. Such an understanding may improve theory in geography (Wilson, 1980).

Mathematical programming in resource use has been applied for three decades to both large and small scale problems. In micro applications, it has been applied to farm decision and land resource management problems where limited resources must be allocated appropriately to achieve some overall objective (Hazell and Norton, 1986). In the macro context, programming models have been applied to national, interregional, and regional scales to analyse the impacts of alternative policies, or technological and environmental changes (Walker and Monypenny, 1976; Heady, 1983; Klein and Graham, 1985). But these endeavours have focused only on a specific aspect of land use planning within a single economic sector such as agricultural, forestry, or other resource sectors. This chapter only reviews two types of programming models: the single objective linear programming (LP) model and the multiple objective programming model (MOPM). Following a survey of the basic features of these models, their applications in resource management are presented.

4.1 Single Objective Programming Model

Most existing programming models for resource use assessment and planning are economic general equilibrium models and deal with a single resource use sector. They can be called single objective and single sector linear programming models. From now on, if not specified, LP represents those single objective models. A linear programming model useful for land resource analysis can be expressed in the following general mathematical form:

$$\text{Min. } C = \sum_{ij} c_{ij} \cdot x_{ij} \quad (4.1)$$

Subject to: $\sum_i x_{ij} \leq A_j$ for each j (4.2)

$\sum_j x_{ij} \, y_{ij} \geq D_i$ for each i (4.3)

$x_{ij} \geq 0$ (4.4)

where:

C is a objective function to minimize total costs;

x_{ij} is the production level of activity i in land unit j;

A_j is the availability of land in unit j;

y_{ij} is productivity of i in land unit j;

D_i is specified demand for product of activity i;

c_{ij} is the production cost for activity i in unit j.

The constraints of the model represent certain biophysical and economic conditions in a particular region. These constraints include: the resource used cannot exceed the resource available (4.2); yields are known and the products produced must meet the specified demands (4.3); and the activities cannot be negative (4.4). LP models usually are constructed to assess economic efficiency. The objective function of the LP models relates to minimizing costs of production (4.1), or to maximizing profits or economic returns given the constraints.

The constraints specify the conditions and prescribe feasible resource allocations. Within the feasible region of solutions, a solution algorithm identifies the "optimal" allocation, that is the solution which minimizes the total production cost or maximizes the profit. In many applications a model is run several times under different sets of conditions by changing one or more coefficients in

the constraint set.

Apart from information regarding "optimal" resource allocation, LP models also indicate whether or not certain sets of conditions will affect the feasibility of solutions. For "optimal" solutions, the output also indicates those constraints which are particularly binding on the result, thereby permitting estimates of resource values or shadow prices. Sensitivity analysis in LP method can indicate how the "optimal" solution will change given changes in various coefficients of the problem. For example, in an agricultural land use problem it can address questions such as: what effect will a change in yields have on the total cost of production?

One well known application of mathematical programming is the development of a specific sector programming model, CHAC (from the name of the Mayan rain god), which is a LP model of the Mexican agricultural sector developed by the World Bank. The aims of CHAC are to portray the major sources of interdependence among product supply, domestic demand, international trade, factor inputs, and government policies for agriculture. CHAC was designed to assess the effects of specified policy packages, and changes in exogenous factors, on the agricultural sector's behaviour as defined by production and employment levels, prices and incomes, and other variables (Norton and Solis, 1983).

Another application of mathematical programming modelling with respect to land use issues was undertaken by an interdisciplinary project team known as the Land Evaluation Group (LEG) at the University

73

of Guelph (LEG, 1983). Various land evaluation models (LEM) have been developed to assess the sustainability of land resources; that is, to measure the gap between the productive capacity of land resources and the expected requirements for food production. This gap can be interpreted as a measure of the flexibility in the food production system under specified conditions and the criticality of resources (Brklacich et al., 1984; Chapman, Smit and Smith, 1984).

LEM models have been applied to assess the effects of potential changes in biophysical or socio-economic conditions on options for resource use and food production (Smit et al., 1984). Various formulations of these models have been employed to test the sensitivity of food production to agricultural land losses related to urban expansion, reduction in energy availability, changing supply of feed and livestock, and crop yield reductions associated with acid rain and soil erosion.

In order to resolve land use conflicts, and to satisfy future land resource needs in both the agricultural and forestry sectors, a pilot study was undertaken by LEG to extend LEM for the development of a multisector land evaluation system (MLES) (Canada. Environment Canada, 1985). A potential application of MLES for New Brunswick was discussed. The pilot study was intended to develop an analytical framework to integrate the agricultural and forestry sectors. But it is still at a preliminary stage of development. This MLES links the agricultural and forestry sectors via land available for production. Evaluation for each sector is undertaken individually. Actually, this MLES is two single

sector evaluation systems linked by land availability for each sector. It does not integrate different sectors into one analytical framework.

Where CHAC is concerned with optimal resource allocation in the economic sense of maximum societal welfare, LEM identifies the regional production potential of land resources given certain conditions. In assessing agricultural land resource development projects for a region or nation, CHAC is useful for analysing the potential effects of alternative land use plans on the regional or national economy. LEM can be used to assess the implications of alternative land uses for regional production potential. Both CHAC and LEM are single objective programming models. Each is capable of identifying only parts of the whole. CHAC shows the economic impacts, whereas LEM explores the impact on regional land use flexibility.

Of course, land use planning may be pursued through multiple dimensions which include environmental, social, as well as economic dimensions. The need to evaluate land use development projects with respect to multiple, and often conflicting, goals is widely recognized in resource use planning (Bell, 1977). A major limitation of the single-objective model, such as CHAC and LEM, is that it does not offer an adequate framework for integrated land assessment. LP consists of only one objective function to be maximized or minimized. In multiple land use planning, LP is not flexible in dealing with potential conflicts among various resource development goals.

Generally, the LP method defines land use goals in a common unit such as dollars or production levels in the objective function. LP is often guided by the consideration of economic efficiency using maximization of economic profit, or minimization of costs, as the decision criteria. Decision makers realize, however, that land development is subject to numerous goals and is often expressed by incommensurable units. For example, the goals and the measurement units in the agricultural sector are different from those in forestry. Moreover, the outputs of some activities such as recreation and wildlife, do not have a market price, or prices may not reflect real social values. As a result, application of LP to multiple goal and multiple sector land use problems has limitations in identifying explicitly trade-offs among different land use goals.

Some LP models based on such assumptions make it possible to construct a utility function which somehow includes various objectives. However, this utility function has limitations because some objectives are difficult to be represented in a utility term. For example, some empirical studies have indicated that the preference and behavior of decision makers are often inconsistent with the assumptions in utility theory (Wierzbicki, 1982).

Anderson (1974) indicated that every model, in a loose sense, 'simulates' its modelled system. But it is important to distinguish between a model which mimics the behaviour of a system and a model which only represents part of a system. In order to analyse multiple goal land development, a multiple objective programming (MOP) model is

more suitable which represents the integrated nature of the land use system more closely.

4.2 Multiobjective Programming Model

Even though the earliest consideration of multiobjective programming (MOP) method can be traced to the work by Kuhn-Tucker (1951) and Koopmans (1951), most progress in this area has come since 1970. This development is the result of the emergence of environmental concerns and recognition of the inadequacy of economic efficiency as the sole criterion in decision making. MOP made the new multidimensional approach to natural resource assessment possible (Nijkamp and Rietveld, 1986).

There are a number of diverse methods in multiobjective decision making (MODM). These methods can be generally classified into two categories: discrete multiobjective decision making versus continuous multiobjective decision making. In discrete MODM, also known as multiple attribute decision making (MADM), a set or limited number of predefined alternatives is known before assessment or evaluation. A well known MADM method is the goals-achievement matrix (Hill, 1968). In contrast to the discrete decision making approach, continuous MODM is not characterized by predetermined alternatives. The common methods of continuous MODM are MOP modelling.

MADM requires predetermined alternatives before resource assessment or evaluation. The absence of a mechanism to identify alternative

77

resource use options in MADM is a crucial limitation in resource assessment. Methods applicable to MADM have been reviewed in some detail (Keeney & Raiffa, 1976; Hwang and Yoon, 1981; Nijkamp and Rietveld, 1986), and are not discussed here. This review of methods concentrates on MOP modelling.

The structure of a MOP model includes multiple objective functions, decision variables, and a set of well defined constraints. These objectives, variables, and constraints are formulated in an analytical framework to generate alternatives and to identify trade-off information.

The structure of a MOP model is somewhat different from that of a LP model. In a MOP model, a single objective function is replaced by a vector objective function. A simple formation of the linear multiobjective programming model useful for land resource analysis can be expressed as follows:

Max $F(X) = f_1(X), f_2(X), \ldots, f_k(X)$

Subject to: $\sum_i x_{ij} \leq A_j$, $(j=1,2,\ldots,n; i=1,2,\ldots,m)$

$$\sum_j x_{ij} \cdot Y_{ij} \geq D_i$$

$$x_{ij} \geq 0$$

where:

$F(X)$ is a vector-valued objective function encompassing multiple objectives $f_1(X)$, $f_2(X), \ldots f_k(X)$. There are k objectives, n decision variables, and m constraints in the model. According to these objectives or goals, the model will

choose the preferred or satisficing alternative from various solutions; X is an n-dimensional vector;

x_{ij} is the production level of activity i in land unit j;

A_j is the availability of land in unit j;

y_{ij} is productivity of i in land unit j;

D_i is specified demand for product of activity i (Saygideger et al., 1977).

A great deal of effort has been devoted to the development of suitable techniques for solving MOP problems (Cohon and Marks, 1975). Two main solution methods in MOP are generating techniques and those based on the articulation of preferences. Goal programming (GP) is a specific technique of the latter. The essential aim of the two techniques is to identify a preferred or satisficing solution while taking account of trade-offs among objective functions. This study emphasizes the development and application of goal programming in land resource allocation and management.

Generating techniques are applied to identify a set of nondominated solutions for multiple objective problems (Zionts, 1980). A nondominated or noninferior solution is defined as a solution in which no objective can be better off without making at least one of the other objectives worse off. That is, there are no other solutions in the feasible space which will achieve the same or better performance with respect to all objectives. The idea of nondominated solution is based on the Pareto optimality principle (Zeleny, 1984). After generation of the nondominated set of solutions, a preferred solution is chosen by the

79

decision maker from those nondominated solutions. Selection of the preferred solution is based on some additional criteria and depends on the decision maker's preferences toward each objective (Hwang and Masud, 1979). Generating methods have been widely applied in water resource management and has been indicated as an effective technique for resource analysis. Detailed discussion on MOLP can be found in Cohon (1978), and Chankong and Haimes (1983).

In natural resource management, many conditions and factors are uncertain and hence cannot be represented precisely in MOLP models. Furthermore, a decision maker's preferences and values are always difficult to quantify objectively so that the formulated model cannot be considered complete or impartial. Thus, with generating technique, a preferred solution may not be a true nondominated solution (Mendoza, 1988).

The major weaknesses of generating methods are the massive number of nondominated solutions and the heavy computer burden. Generating techniques usually generate large numbers of nondominated solutions. It is difficult for a decision maker to choose the preferred solution among so many nondominated solutions. The process to generate a set of nondominated solutions uses enormous amounts of computer time because of the large numbers of constraints, objectives, and possible trade-offs involved (Zeleny, 1982).

In the case of integrated land use decision making, generally, more than three objectives and a large number of variables and

constraints are involved. When a generating method is applied to land use problems, hundreds or even more nondominated solutions will be generated. Under such a situation, it is very difficult for decision makers to interpret the results and to identify the implications of land use change, or other environmental and policy changes, for different objectives. Obviously, the generating technique is not suitable for integrated land resource assessment and evaluation.

Another approach is the goal programming (GP) method. Since most land development projects are characterised by multiple goals, a GP approach, which provides a comprehensive analytical solution to land use problems seems appropriate. The GP approach provides a systematic and a comprehensive research framework to integrate various factors--social, economic, and ecological--such that resource production levels and environmental quality are sustained.

GP has been developed by system analysts and decision theorists to deal with private and public problems, by control theorists for engineering problems, and by resource analysts for resource planning problems (Romero and Rehman, 1985; 1987). Unlike LP models, GP does not consider economic optimization, but considers various pertinent objectives such as environmental quality, regional development, and energy conservation. GP recognizes that not all objectives can, or should, be optimized. It attempts to find a solution that comes as close as possible to the satisfaction of various goals. Thus, while linear programming models emphasize the optimization of a single objective, GP emphasizes the satisfaction of multiple goals.

Unlike MOLP which identifies a set of nondominated solutions, GP seeks to find the satisficing solution which matches the real behavior processes of the decision makers (Nijkamp and Spronk, 1979). H.A. Simon, the Nobel laureate in economics, indicated that the choice of satisficing or "good enough" solutions is generally more realistic in the decision making process than the choice of an ideal solution (Simon, 1969). MOLP does not need any explicit preference information from the decision makers when building the model. In the process of analysis, there is no interaction between decision makers and analysts. In the case of GP, preference information is needed before or during the formulation and application of the model. Interactions between analysts and decision makers are required.

To identify a satisficing solution, GP operates by minimizing the deviation from the goals or aspirition levels. There are two major approaches to resolve GP models. In the one, weighted goal programming (WGP), a weight is assigned to each goal. The objective function of a WGP model minimizes the sum of all weighted deviations from goals which represent aspiration levels of different objectives. In the other, GP can be structured by preemptive weighting or lexicographic ordering of goals in lexicographic goal programming (LGP) models. A lexicographic method requires that the goals be ranked in order of importance by the decision makers but not, weighted (Hwang and Masud, 1979).

One of the major problems associated with WGP is the assignment of the weights to the goal deviations in the objective function. The weights reflect the relative importance among objectives. Information on

weights is contingent upon the capability of decision makers to specify the values of weights for all the goals in a WGP model (Neely, Sellers, and North, 1980). The LGP can avoid this problem because goals in LGP are ranked in order of importance by the decision makers. Since it is more difficult for decision makers to precisely estimate future values of weights for goals than just to rank relative importance among goals in an ordinal scale, this study is based on LGP.

A general goal programming model can be expressed as following (Ignizio, 1982):

Minimize $Z = [g_1(d^-,d^+), g_2(d^-,d^+),..., g_k(d^-,d^+)]$

Subject to: $X = (x_1,x_2,...,x_j)$ for each j;

$f_i(X) + d^-_i - d^+_i = b_i$ (i = 1,2,...,n)

$X, d^-_i, d^+_i \geq 0$

Where:

Z is a vector-valued function encompassing the successive decision criteria which represent a number of preemptive priority levels among the objectives. The concept of preemptive priority assumes that any goals at priority level k will always be preferred to any at lower priority levels k+1,...;

$g_k(d^-,d^+)$ is a linear function of the deviation variables at priority level k;

X is the feasible region from which to select the vector x;

$f_i(X)$ is a function of decision variables associated with the ith objective;

b_i is target value for goal i;

d^-_i and d^+_i are the negative and positive deviations from b_i respectively;

d^- and d^+ are vectors of $(d_1^-, d_2^-, ..., d_i^-)$ and $(d_1^+, d_2^+, ..., d_i^+)$ respectively.

The Z vector is the objective function which selects the resource use activities and resource use alternatives so as to approach some desired goals as closely as possible by minimizing the deviations from the target levels. Target levels are established for each goal given certain priority or weight and subject to the resource constraints. When there exists a desirable value of Z* which is preferred to, or the same as, any other vector Z, the corresponding desirable solution X* of the goal programming model is considered most satisfactory (Ignizio, 1982).

If the minimum value of Z is zero, there is a no-conflict solution for the model. All goals can be met in this situation. When the minimum Z value is not zero, this shows there is some level of nonachievement for the associated goal levels. For any particular goal, there are three possible outcomes: (1) a complete goal attainment; (2) a positive deviation from the goal (d^+) when more than the desired goal level is obtained; (3) an underachievement (d^-) when the desired goal level was not attained. All these three outcomes are illustrated in Figure 4.1. The target level of a goal cannot be both under and over achieved. Thus, at least one of the deviational variables for each goal, either positive or negative deviation, equals zero. The most desirable

84

solution is obtained when the sum of the absolute values of the nonattainment of goals is minimized according to the preemptive priorities of the model.

The following hypothetical example using a graphical aproach to the solution of a linear goal programming model indicates the basic principles of GP approach and clarifies some of the terminology of goal programming. For this hypothetical example, the problem is described as follows: a farm specializes in two types of activities, growing wheat and corn. There are only 85 ha of land available. The profits generated by each ha of wheat and corn production are $60 and $70 respectively. The farmer wants his total profit to exceed $6,500 annually. Each crop causes soil erosion. It is assumed that wheat production generates 4 units of soil loss per ha annually and corn production creates 6 units of soil loss per ha per year. It is also assumed that the total soil loss should not exceed 360 units in order to protect the land and to maintain environmental quality. Finally, the yields of wheat and corn production on this farm are assumed to be 50 and 70 units per ha respectively. The farmer has agreed to supply 2,500 units of wheat and 3,500 units of corn to the market.

The objectives and priorities of this problem are listed below:
Rigid constraint: total land use cannot exceed the available land resources;
Priority 1: achieve annual profit of at least $6,500 ($g_1$);
Priority 2: avoid soil loss exceeding 360 units (g_2);
Priority 3: supply the market at least 2,500 units of wheat annually

↑ d+: Positive deviational variable
                              ¦
─────────────────────────────┼───────────────────────── Goal level
                              ¦
                              ¦ d-: Negative deviation variable
                              ↓
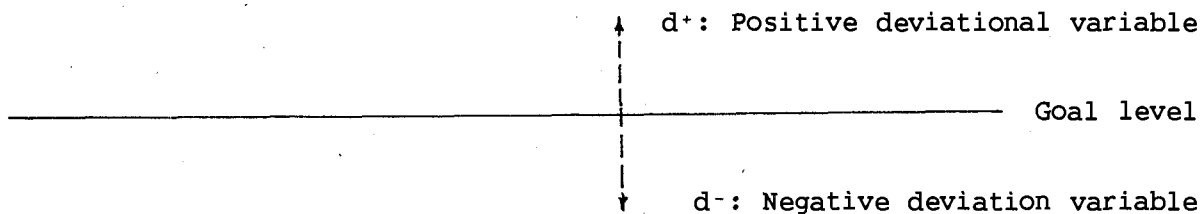
Figure 4.1: A Two-Dimensional Goal Space

(g_3);

Priority 4: supply the market at least 3,500 units of corn annually (g_4).

This priority ranking reflects the farmer's preference for the attainment of each goal level. According to the above statements, the next step is to determine specifically the rigid constraint and to find which type of goal achievement is most desirable. The rigid constraint of the model reflects the limitation of land resources. The total land allocated to various uses cannot exceed 85 ha. Goal 1 is to minimize the underachievement (d_1^-) of the goal level ($6,500 profit per annum). The second concern is to minimize the overachievement (d_2^+) of goal 2 (360 units of soil loss). Finally, priority 3 and 4 are assigned to minimize the underachievement of goal 3 and goal 4 (grain supply requirements).

The problem is then formulated mathematically as:

lexicographically min. $Z = [(d_1^-), (d_2^+), (d_3^-), (d_4^-)]$

Subject to:

constraint: $x_1 + x_2 \leq 85$

$$g_1: \ 60x_1 + 70x_2 + d_1^- - d_1^+ = 6500$$

$$g_2: \ 4x_1 + 6x_2 + d_2^- - d_2^+ = 360$$

$$g_3: \ 50x_1 + d_3^- - d_3^+ = 2500$$

$$g_4: \ 70x_2 + d_4^- - d_4^+ = 3500$$

$$x_1, \ x_2, \ d^-, \ d^+ \geq 0$$

Where:

x_1 and x_2 are lands (ha) allocated for wheat and corn production respectively.

This sample problem is illustrated graphically in Figure 4.2. The fundamental principle of linear goal programming is to seek a solution region that provides a compromise to a set of conflicting goals. The major steps of the graphical approach are listed below:

1. Plot all the goals as straight lines. Only the decision variables, x_1 and x_2, are used in the plot. The deviation variables (d^- and d^+) are represented by arrows at objective lines. And the particular deviation variables to be minimized are circled;

2. Determine the solution region for goal 1;

3. Move to the next goal and determine the "best" possible solution region which will not degrade the achievement values already obtained for higher-priority goals;

4. When the solution region is reduced to a single point, the procedure can be terminated because no further improvement is possible.

Figure 4.2 demonstrates that the graphical approach first attempts to meet the condition set by the rigid constraint. The solution region

87

Figure 4.2: Graphical Solution of the Example
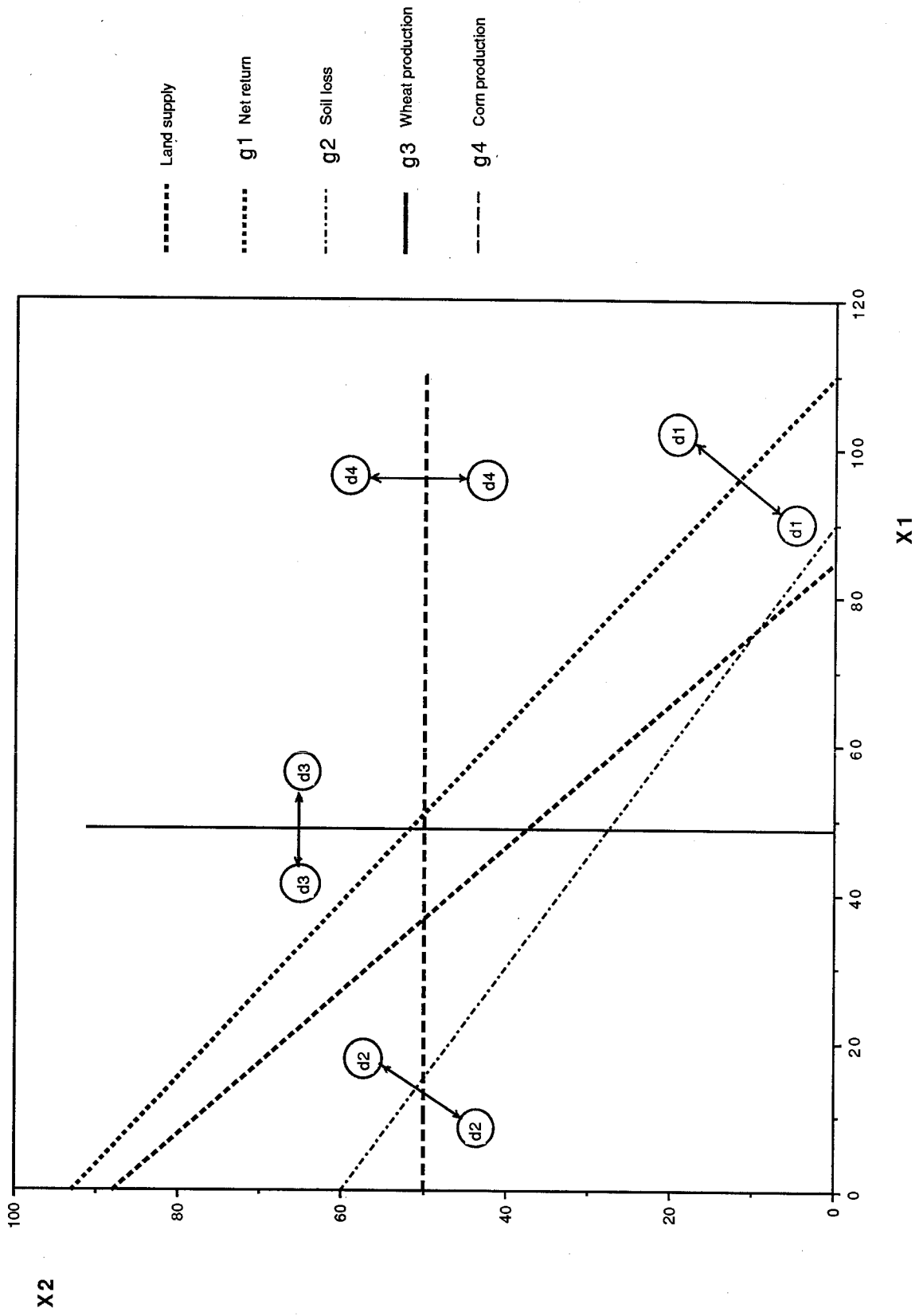
which satisfies the rigid constraint is indicated by the cross-hatched feasible solution area. The next step is to satisfy goal level 1 within the feasible solution area. The underachievement d_1^- cannot be set to zero since this would go beyond the feasible solution area. The minimum value of d_1^- is at $x_1 = 0$, $x_2 = 85$ which is indicated in Figure 4.2. The procedure is now finished and the final solution is:

$x_1^* = 0$

$x_2^* = 85$

$Z^* = (8, 25, 50, 0)$

This simplified example indicates that only goal 4 is reached, and the rest of the goals cannot be achieved.

It is clear that a graphical approach is only applicable to problems with three or fewer variables. However, a typical goal programming model encompasses many more variables and thus requires a more general approach. Another technique to solve the linear goal programming problem is the multiphase simplex method which has been described in detail by both Lee (1972) and Ignizio (1976).

To deal with economic and environmental changes, and to take consideration of uncertainties in resource assessment, the sensitivity analysis of goal programming can provide a systematic procedure for analysing the implications of changes and uncertainties for achieving resource use goals. In the multiple goal land use assessment, different land development prospects are represented in the model's structure by varying coefficients in the matrix and the right-hand side vector, and the objective functions. By altering the priority schemes or weights in

the sensitivity analysis, multiple goal analysis may be helpful in considering conflicting objectives and preferences among different sectors or interest groups. Such analyses show the trade-offs among various alternatives and, in turn, the consequences of different resource management options. Sensitivity analysis involves a series of procedures which are repeated several times until a desired solution is reached. Interactions between decision makers and analysts can be incorporated in the analysis. The procedures consists of two main steps: (1) calculating the solution of a model; (2) adjusting coefficients and priority scheme or weights of the model after decision makers respond to the solution. Through test runs reflecting different scenarios, it is possible to show which scenarios would or would not be compatible with the resource development goals.

GP models have been applied primarily to assess multiple goal resource management and planning for a single sector, particularly in forestry or agricultural land uses. There are a number of applications in forest management (Dane et al., 1977; Schuler et al., 1977; Chang et al., 1981; Buongiorno and Gilless, 1987), agricultural land uses (Salygideger et al., 1977; Bartlett and Clawson, 1978; Dobbins and Mapp, 1983), fishery management (Weithman and Ebert, 1981), water resource use (Lohani, 1979), recreation planning (McGrew, 1975), and urban and industrial location analyses (Charnes, Haynes, Hazleton, and Ryan, 1975).

An application of a multigoal programming model to a food production problem was undertaken by the Center for Agricultural and

Rural Development (CARD) at Iowa State University to analyse trade-offs between agricultural production efficiency and soil loss control in agriculture. The study was intended to assess the trade-offs between the cost of producing the nation's food supplies and maintenance of the productive capacity of land resources with a high level of environmental quality (Saygideger et al., 1977). The study employed a two-goal objective function in which each goal is weighted to represent alternative social preferences. The relative weights for the goals were altered, and a trade-off curve was obtained. The trade-off curve represented alternatives open to decision makers. In the case of the hypothetical trade-off curve of Figure 4.3, gains in agricultural production imply sacrifices in soil conservation and vice versa. This study provided information for the selection of "optimal" programs for agriculture in which environment quality was concerned.

Other examples can be found in studies of multiple use forest development and management (Field, 1973; Schuler et al., 1977; Dyer et al., 1979; Chang and Buongiorno, 1981; Cocklin, 1984). Multiple goal programming models were applied to provide solutions to the problem of multiple use planning in forest management. These models allow decision makers to specify the exact goal level for each management activity, to examine varying degrees of management intensity, and to identify the trade-offs between activities. Alternative goals were set and weighed with respect to economic efficiency, regional development, energy efficiency, and environmental quality. In particular, those goals include timber harvesting, income, recreation day, energy use, and
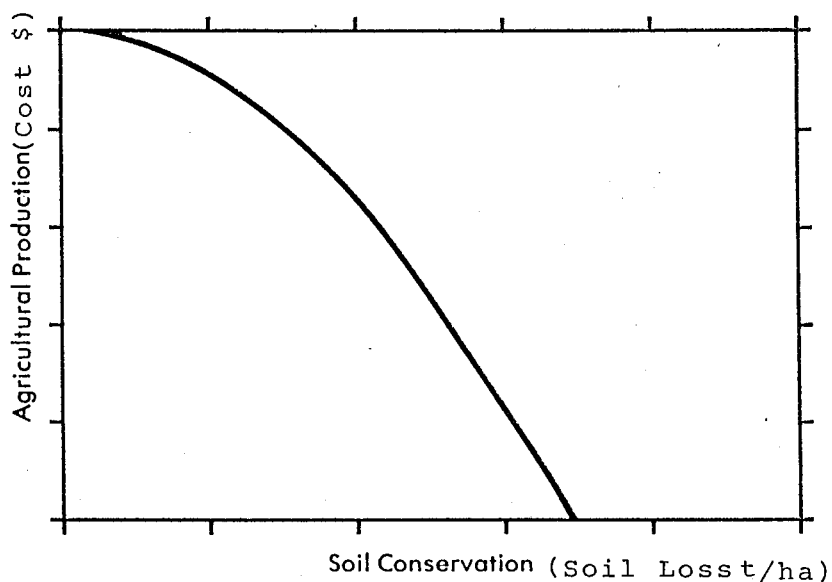
Figure 4.3: A Two Goal Hypothetical Trade-Off Curve

environmental quality targets.

4.3 Summary

The main function of GP for resource analysis is to relate
components and processes to simulate the resource use systems
(Ignizio,1982). It was shown in the previous discussion that GP can be
effective at addressing decision-making processes in relation to
comprehensive land use planning. The availability of GP and its
capability of handling multiple noncommensurable goals, provides a
useful basis to evaluate the many uncertainties that may be associated
with specific resource development proposals. In addition, GP provides

answers to certain fundamental questions relating to trade-offs between conflicting goals, which is vital information to decision makers.

However, GP should not be a substitute for the decision making process. The models are not intended to replace decision makers, but to provide a framework for analysing and evaluating the complex interdependencies typically associated with resource development problems and ultimately sustainable development (Cocklin, 1989a). GP analysis provides essential information which permits decision makers to anticipate the consequences of their actions. Decision makers are still the core in natural resource management. Their preferences, aspirations, and values are essential for resource assessment. Furthermore, decision makers always play a major role in evaluating, comparing, ranking, and selecting the final solution from the analyses.

An interactive GP, which involves a process of systematic interactions between resource analysts and decision makers, can improve resource use decision making. In the interactive approach, the decision maker works with the resource analysts in an interactive way. That is, the decision maker specifies acceptable values for each of the goals, and ranks priorities for those goals; while the analysts solve problems and present possible solutions. Then, the decision maker respond to the possible solutions by expressing his or her preferences. This process is repeated until a satisfactory solution is reached (Batten, 1984). The interactive approach provides communication opportunities between the analysts and the decision makers.

Some criticisms of goal programming have focused primarily on its inability to account for many of the nonquantitative and intangible development goals, and of the use of the sequential, preemptive goal priorities (Dyer et al., 1979). For example, some objectives which relate to community relations and environmental aesthetics are difficult, if not impossible, to be expressed quantitatively in the models. In some cases, they have to be excluded from a goal programming model. The preemptive priority procedures, which assume that any goals at a higher priority level will always be preferred to any at a lower priority level, involve subjectivity and value judgements. This method relies on subjective trade-off analysis which is based on predetermined preference criteria. In fact, the preemptive priority is based on the most extreme weighting, a zero-infinity weighting system. Because of this, inaccuracy and inconsistency in the preference assessment process may be encountered (Chankong and Haimes, 1983).

These limitations, however, may only be of theoretical interest. Romero and Rehman (1984) argued that in reality, a hierarchical goal structure appears to be consistent with the behavior of decision makers in multiple land use planning. Even if the preemptive priority does not supply the most desirable measure of achievement for a particular problem, GP is generally efficient at finding a good starting solution which may be improved by relaxing the strict interpretation of the preemptive priority and encompassing other measures of achievement (Ignizio, 1982). By increasing computational runs, numerous sensitivity analyses of parameters representing weights and preference ordering of

various goals will help to resolve this problem.

The number of applications of the GP technique in resource planning is impressive. Generally these studies have focused on providing some sort of prediction of satisfactory patterns of natural resource allocation. However, the primary purpose of this thesis does not aim at providing "best" or "optimal" solutions in resource development. Rather it focuses on identifying and developing an analytical framework to assess the implications of changes in resource use, or environmental and institutional changes for various resource development objectives. This study is based on the recognition that the properties of resource use systems are composed of biophysical and socio-economic components and are governed by interactive processes. Thus, understanding the structure of resource use systems, rather than solutions for a specific resource use problem, is more fundamental in resource studies. Clearly, GP is not simply a mathematical modelling technique but a learning process which helps to understand the structure and interactions of a natural resource system. GP is a potential tool for both decision makers and analysts to deal with resource problems more systematically than the traditional approaches. It also serves as a communication device to link decision makers and analysts.

The above review indicates that there has been a lack of study on multisector land use assessment. Land resource use decision making involves trade-offs among various uses which include forest, agricultural, and wildlife sectors. Sustainable land use assessment must

deal with these often conflicting land requirements and make trade-offs between sectors to meet multiple regional development goals.

It is proposed here that GP will be applied in a somewhat different manner than its conventional use in resource allocation to undertake multigoal and multisector land use evaluation. The following section provides a detailed conceptual framework of land resource evaluation and its application to a broad region.

CHAPTER V

RESEARCH PROCEDURES

An integrated land assessment framework (ILAF), based on a specific type of goal programming (GP) model, is developed in this chapter to undertake multigoal and multisector land use assessment. This framework can be used to address the following questions:

* What are the implications of alternative land uses with respect to achieving multiple land use goals given certain conditions?

* How does one evaluate trade-offs among alternative land use options and what are the possible trade-offs for different objectives and land uses?

* How critical are the threats of land conversion and land degradation in maintaining sustainable resource production and economic return?

* If conflicts exist among land uses or sectors, how serious are they and how can compromises be reached?

The main elements of the integrated land resource assessment framework are illustrated in Figure 5.1. The research procedures are purposely kept general and are composed of the following steps:

1. The procedure begins with an identification of goals. Land resource development goals in the public sector are diverse. They represent the preferences of decision makers at federal, provincial, and regional levels of government. These goals might include: (1) sustainabiliy of resource production to meet future domestic and

97
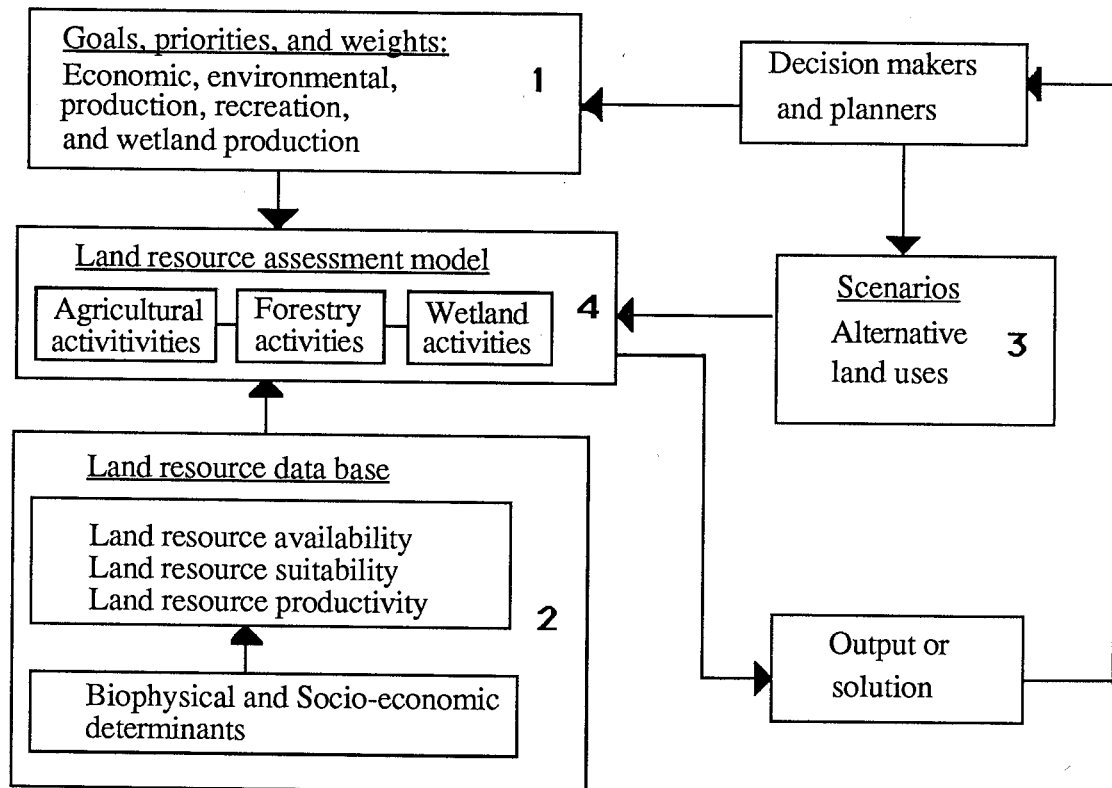
Figure 5.1: Research Framework.

export needs; (2) economic efficiency which may maximize returns or minimize costs; (3) soil erosion control from land development; (4) habitat and wetland conservation.

2. Next, information is required on the quantity, quality, and distribution of the land resource base. To this end assessments need to be made of the capability and suitability of various land uses and the extent to which technological and other socio-economic factors might influence the prospects for various land uses.

3. Then various land use scenarios are created to assess the implications of land use change or environmental change for achieving different development goals. Scenarios, reflecting possible future land use conditions, may represent a base-line condition, a continuation of the status quo or different assumptions about the growth and distribution of certain land uses.

4. Finally, goal programming models are developed to evaluate and compare these land resource use alternatives, and to determine the economic and environmental implications.

Each of these precedures is now discussed in turn.

5.1 Land Resource Development Goals (Box 1)

The procedure starts with an identification of land use objectives or goals. The terms objective and goal are often used interchangeably in management science literature (Hwang and Masud, 1979) and this study also treats the two terms as interchangeable. Generally, goals are

reflections of the preferences and desires of decision makers and indicate some specific target levels to be achieved (Zeleny, 1982). In land resource assessment, goals also act as decision criteria or standards by which the efficiency or the impact of resource use options can be measured. Goals also serve as tasks which are to be satisfied as closely as possible in land use assessment and evaluation. All efforts to assess impacts of resource use must first confront the problem of identifying and specifying multiple goals. Thus, the effects of a land use change or land use policy in terms of progression toward or regression from these goals can be examined. In other instances, the environmental and economic impacts of future environmental changes such as soil erosion and climate change can be identified.

Cohn (1978) suggests that the operational usefulness of an objective as an evaluative criterion in resource assessment is a key point in developing MOP models. The selection and incorporation of operationally useful objectives in MOP models require analysts to acknowledge two important issues: the sources for identifying goals and the specification of goals. This section first presents three sources and then discusses some common goals in land resource management.

5.1.1 Sources for Identifying Goals

When applying MOP models in resource assessment, ideally, a set of well defined objectives can be provided by the decision maker(s). However, in most cases, this kind of situation does not exist. In general, neither the analyst nor the decision maker has a clear set of

objectives with respect to problems. Three sources for the identification of resource use objectives suggested by Cohon (1978) are: (1) the decision maker's and analyst's knowledge and background on the resource issue; (2) representatives of interest groups and experts of resource use; (3) literature and previous research work on the resource issue.

Understanding of the components and the processes of the resource use system by the resource analysts is obviously the first source. The second source is the representatives of interest groups related to the resource issue. There are often a number of different interest groups, each with its own objectives. It is important to identify these interest groups involved in a specific resource use problem and to examine their objectives, preferences, and aspiration levels with respect to resource use. Cohn (1978), Zeleny (1982), and Despontin and others (1984) suggest that the representatives of different interest groups are often unable to express explicitly and precisely various objectives and aspiration levels relative to resource development and planning, and are reluctant to rank or weight priorities of different objectives.

The third possible source of information is government reports, documents, and other published materials in relation to the resource issue. These reports and documents provide some information on resource use objectives. Yet, it is not always the case that all the objectives and goals which are required for an integrated resource analysis will be presented. In order to obtain adequate data to define objectives or

goals, it is worthwhile to pursue all three information sources.

5.1.2 Specification of Goals

Traditionally, the maximization of production and economic efficiency are considered as the principal objectives in resource use decision making. However, in reality, resource use planning is often characterized by multiple objectives which are frequently in conflict. This consideration is quite obvious when sustainable economic development is considered. Barbier (1987) suggests that sustainable economic development requires the consideration of various goals in three major systems of interest: the biophysical, the economic, and the social systems. The goals in the three systems include genetic diversity, ecological resilience, provision for basic needs, income equity, social justice, public participation, and several others. Four goals, sustainability of regional resource production, economic efficiency, control of soil erosion from various land use activities, and conservation of wetland resources, are used here and discussed in some detail next.

The sustainable resource production goal may be defined as the ability of a resource base to maintain in perpetuity a given flow of goods and services. This goal is important in the renewable resource sectors because of the need to meet future demands. Sustainable production can be considered as a security goal to achieve independence of imports or self-sufficiency (Canada. Agriculture Canada, 1985). It may also be seen as an intergenerational equity goal to safeguard the

resource base for not only our generation but future generations as well.

Another common goal for public sector resource management is economic efficiency which attempts to maximize net income benefits or to minimize costs. According to neoclassical economic theory, individuals are assumed to be driven by a profit or utility maximizing goal. The attainment of economic efficiency is assumed to assure a state of maximum social welfare. Today, economic return is still an important goal in resource use decision making.

It is now generally realized that an environmental quality goal should be incorporated in resource use decision making in an effort to achieve sustainable development (Cocklin, 1988). There are a large number of parameters that may can be used as indicators of environmental quality. In different resource problems, the meaning of environmental quality will be quite different. For example, environmental quality may mean maximizing dissolved oxygen at several different points in a lake, or it may mean minimizing the concentration of atmospheric carbon dioxide at a global scale. Land degradation, particularly soil erosion, is considered one of the major environmental problems in rural land resource management (Sparrow, 1984).

Other goals in land management may include wetland conservation and wildlife habitat protection (Goldman, 1981). Wilderness areas possess various societal values and preserving natural areas represents some public interests. For example, wetlands provide ecological functions

which are required for the maintenance of natural capital. Also, wetland is valuable for wildlife habitat, water purification, erosion control, flood retardation, recreation, and aesthetic scenes. It is obvious that the conservation of wetland should be one goal in multiple goal land use assessment (Canada. Environment Canada, 1983).

5.1.3 Relationships Among Goals

Interrelationships between goals are quite complex. Some goals are complementary. For example by increasing the attainment of one goal it is possible to increase the attainment of other goals. Goals are compatible when the attainment of one does not sacrifice the attainment of others. However, goals are often conflicting in that the achievement of one goal precludes the achievement of another (Gadow, 1978). In multiple land use decision making, it is common that not all the goals can be achieved simultaneously. Possible trade-offs between goals therefore need to be identified.

Given the existence of trade-offs among goals, a choice must be made to place different priorities for different goals in a multiobjective assessment. Much of the effort in MODM has been devoted to constructing the preference relations between goals. In GP modelling, decision maker's preferences toward goals are expressed by ranking relative importance among goals in an ordinal scale. This process is also called the preemptive priority method or lexicographic ranking (Ignizio, 1976).

5.2 Information of the Land Resource Base (Box 2)

The establishment of a common data base which incorporates data sets from different sectors such as agriculture, forestry, and wetland is a necessary step for integrated resource assessment. This requires a common format or set of rules covering some aspects such as definition, land unit, and scale. Information on the land resource base involves data on land availability, suitability, distribution, current use, and the rate and extent of land use change between different sectors. The particular study area has a range of subareas, varying in terms of land resource availability, suitability, and productivity. An important procedure before evaluation is to define the land unit as a basis for assessment. Land units are the basic units for analysis. They identify areas which are relatively homogeneous with respect to the biophysical, social, and economic conditions which influence them. Selection of a land unit is determined by data availability, assessment scale, and study objectives. The land unit can be defined based on biophysical conditions, such as soil and climate zones. Also it can be delineated on the basis of economic, social or cultural conditions, or jurisdictional boundaries. Alternatively, land units can be divided in terms of a geographical grid or a soil zone if the study is at a sufficiently large scale. The land unit can also be disaggregated into Crop Insurance Agencies' Risk Districts based on land productivity classes if one wishes to provide more detailed information on producers.

In many earlier studies of land resources, analysts often used land units which were defined predominately by biophysical factors (Moss, 1983; FAO, 1983; Forman and Godron, 1986). Land units may consist of certain biophysical attributes which represent regional similarity or uniqueness. Climate, soil, hydrologic, morphological, or vegetational boundaries are all possible determinants for delineating land units. However, biophysical boundaries generally do not make economic sense. Economic characteristics and interrelationships usually do not correspond to biophysical land unit boundaries (Smit et al., 1984b).

Jurisdictional or administrative boundaries, such as counties or townships, have been used widely as basic land units in land resource analysis and planning. Land resource analysis based on such jurisdictional regions has some practical advantages. For example, social and economic data are commonly collected on a county or a township basis. Administration regions are the basic units on which government statistics and census are based. Land resource analysis based on political units can also work to the advantage of implementing the result of the analysis. Regional authorities are clearly identifiable and every region's area of responsibility can be easily delineated. One drawback in the use of administrative units for land resource analysis is their failure to correspond to ecologically homogeneous units. It is a difficult task to arrange consistent biophysical data for each of these political land units with reasonable accuracy.

Land resource analysis can also study a region by dividing it into subregions based on geometric grids. Biophysical and socio-economic data from government statistics, census, survey, interviews, or questionnaires are transferred to each grid (land unit). Overlapping or superimposing methods, and other mathematical procedures are often employed to transfer data from various sources to these geometric grids. The choice of values selected always requires some subjective adjustment or compromise.

After establishing the land units for data collection, the next step is to identify the principal types of data needed for integrated land use assessment. The required data are basically determined by the nature of the resource problem at hand.

Useful information for land resources is available from government agencies and nongovernmental entities. The Land Potential Data Base at Agriculture Canada is a geographic information system (GIS) containing data on soil, climate, physiography, land use, land degradation, crop growth rates, and potential yields for selected crops. These data are based on soil map units of the Soils of Canada Map (Clayton et al., 1977). The data base is basically perceived as a tool to aid in land evaluation (Canada. Agriculture Canada, 1983). The Canada Land Inventory created a comprehensive data base which provides land capability for agriculture, forestry, recreation, and wildlife (Munn, 1986). Land Capability Maps at a scale of 1:50,000 and a computerized data base are features of this system. Land Capability Maps for each sector are based on data from soil surveys, interpretation of air photos, and field

surveys of forest and wildlife resources. These data have been used widely in land use development and planning.

While there are various data available for land resource analysis, they may not be appropriate for a particular land analysis problem. Data must have specific characteristics to be used in a particular land management process. In integrated land assessment, much potentially useful data may be lost because the information is often not comparable. It is important therefore to ensure that data gathered by different agencies are compatible.

It is common in Canada and elsewhere that data are collected by a wide range of agencies and individuals often in support of their own research purposes. For example, while Agriculture Canada is mainly interested in data on crop yields, farm income, and the price of agricultural products, the Department of Forestry is more concerned about timber growth rate, timber price, and annual allowable cut. In Canada, agricultural data are usually collected on farm bases or other administrative units such as county or province. This differs from data compilation in the forestry sector where most forestry data are based on a forestry district, a timber supply area, or a tree farm license. Land Capability Classification for agriculture also differs from that for forestry in terms of criteria and class unit. Incompatibility in data collection also exists in academia. Data gathered by scientists from different disciplines are used for different purposes. Ecologists collect data based on ecosystems, soil scientists assign data to soil map units, and economists often use data on firms or administrative

units.

In order to undertake integrated resource assessment, data comparability is needed. Certain techniques have been developed to enable the transfer of incomparable data into compatible ones. Map overlapping is probably the simplest method in land assessment and planning to integrate data with different map scales, land units, and classification systems (McHarg, 1969). The rapid advance of geographical information system (GIS) techniques have made the management of data from various sources much easier. It may be possible in the future to integrate data based on different land units into a common unit. This will permit the results of computations to be formatted for different geographical units with the assistance of a GIS system (Crain and MacDonald, 1984; Woodcock et al., 1990).

5.3 Alternative Land Resource Use Prospects (Box 3)

Assessing the implications of different land use options, environmental change, or land use policies for achieving sustainable resource development is a complicated task. This situation exists because uncertainties prevail over future conditions such as production mix, land conversion, environmental change, and technological development. In this study, several scenarios are created to represent alternative land use prospects. A scenario is a sketch of a possible future situation which describes the implications of future sequences of events based upon explicit assumptions of lifestyle, levels of

109

technology, population increase, land use strategies, and environmental or policy change.

Manning (1988) suggests that the key to analysis of future supply of and demand for land resources is to establish a range of scenarios. Such scenarios can be established based on ongoing predictive work, or on "worst case" assumptions. Two broad approaches, simulation and synthetic scenarios, for scenario specification can be adopted for land resource assessment (Brklacich, 1989). While simulation utilizes a variety of mathematical models to project a set of future conditions, synthetic scenarios are based on incremental or parametric adjustments to selected parameters representing various potential future changes.

To provide information on the future consequences of land conflicts in a region, a time period, suppose 10 years, must first be specified. The analyst then attempts to sketch out the land availabilities and qualities of land for different uses in the region in 10 years based on certain assumptions. Thus, a scenario for assessing future land use conflicts could be created. The development of scenarios requires a large amount of data, knowledge, and ideas pertinent to specific resource problems. Scenarios usually represent a systematic process to explore the possible future conditions rather than providing predictions of the future (Lave and Epple, 1985).

The number of scenarios an analyst needs to create for land resource analysis depends on how many land use issues or policies need to be investigated. In order to assess the impacts of different use

110

options or policies on land use systems, a base scenario reflecting current conditions of the land resource base is usually created for comparison. Alternative scenarios can then be created to reflect conditions coupled with a reduced or enhanced resource base, or future demands which may be placed on the land. Impact assessment requires the comparison of alternative scenarios. The impacts of change on a land use system are the differences with and without the change, or differences between the base scenario and an alternative scenario.

For each scenario under analysis, the results of a model are obtained by adjusting input parameters in the model such as land resource availability, crop yields, rotation activities, land degradation, and development goals to simulate the corresponding conditions of alternative land use prospects. Results from repeated runs of the models provide 'if-then' information based on different scenarios.

5.4 Assessment of Alternative Land Development Prospects (Box 4)

Because integrated land assessment involves multiobjective and multisector considerations, there is a need for a new analytical framework to incorporate economic, social, and economic aspects of the resource systems under examination (Barbier, 1987; Cocklin, 1989a). A major challenge for a new research framework is to identify and measure the trade-offs and conflicts between different objectives and sectors. It was indicated in chapter 4 that goal programming (GP) is one

technique capable of integrating several objectives and sectors. GP can deal with different measurement units and identify trade-offs among alternatives. Thus the GP technique is adopted to formulate the new analytical framework for integrated land assessment.

The basic structure of the GP models used in this study includes goals and constraints. The specific equations of these models are grouped into following types: resource and other restrictions, supply-demand balances, and objective functions which represent the resource development goals. A general goal programming model is presented in some detail in chapter 4.

GP is commonly used to allocate land resources to various uses such that a set of predetermined goals is best satisfied (Romero and Rehman, 1987). One of the distinctive features of the models developed here is the emphasis placed on scenario analysis. Several meaningful scenarios reflecting various land use conditions can be represented in models to examine implications of various land use alternatives for sustainable development.

The main challenge in land use assessment is to translate land use problems or policies into specific analytic questions that can be addressed by a model. Land use change or resource policy can influence productivity of lands, land availability for each sector, demands for resource products, and other land use factors. In the assessment process, different scenarios are represented in the structure of a model by parameters in the matrix, the right-hand side vector, and the

objective function. To assess the effects of specific land use options or policies, the following kinds of changes may need to be made in the model:

1. change the land resource availability in the right-hand side vector because of land conversion or restrictions set by land use policies;

2. change parameters for production, particularly the yields or unit values of resource uses.

One example would be the endowment of cropland which is represented by the right-hand side coefficient in the constraint equation of cropland. Continuous land conversion from forest to cropland would increase the cropland availability. An increase in the value of that coefficient can reflect this situation.

Alternative scenarios can be made to explore the possible implications of changes, such as land use conversion, soil erosion, or land conservation policies. This kind of land assessment requires at least two scenarios: a base scenario and a scenario reflecting changed conditions in the future. After a solution for the base scenario is obtained, the procedure followed is to alter the model in a way that reflects a new scenario, and then to solve the model again. By proceeding in this manner through a series of scenarios, it is possible to evaluate whether the changes that have or will occur are in keeping with the stated goals or objectives. Sometimes it is preferable to make only one change at a time, and then obtain a solution before making further changes. This permits identification of the impacts of each

individual land use change. However, sometimes several changes are needed to reflect a new scenario.

For integrated land management, one relevant example concerns environmental change. Climate change will affect the intensity of soil erosion and the amount of precipitation which may vary the yield for crop and forest. Such a change would be handled by altering the yield coefficients of the model from current yields, called the base scenario, to adjusted yields which reflect conditions following environmental change. By comparing the results of the two solutions under the two scenarios, information is obtained on the implications of environmental change for land use objectives in a particular region.

It is a simple matter to explore alternative conservation policy assumptions. Conservation policy is designed to avoid or to reduce the tendency of high-rate conversion of wilderness areas to cropland, from forest to farm uses, or from agricultural uses to urban uses. The concern of the conservation policy can thus be translated into the model by adjusting the right-hand side values of land availabilities for different resource sectors, or by changing the coefficients of land conversion rates.

This analytical framework can provide a basis for assessing some impacts of resource development projects. In impact assessment, situations such as altered resource use patterns or yields in response to a development project such as building an irrigation system can be represented by the framework. The model will simulate the conditions

associated with a development project by changing certain parameters. When tested, the model results will show the effect on resource production, economic return, soil erosion, and other development goals associated with the project.

To incorporate a time dimension in the analytical framework, the appropriate model parameters must be adjusted to estimate values reflecting conditions some years in the future. The models are then solved with these adjusted parameter values. Generally, several alternative scenarios are made to simulate potential future conditions under short, medium, or long-term assumptions.

One of the most important aspects of evaluating land system sustainability is to identify conflicts among various priorities, goals, and development prospects which represent different preferences and aspirations of several government agencies or interest groups. The multidimensional nature of multiple goal and multiple sector resource assessment implies that conflicts exist among different interest groups. For example, conflicts between the Ministry of Agriculture, which is more concerned about economic return from agricultural crop production, and the Ministry of Environment which is more interested in minimizing soil erosion from farm land and protecting wildlife. A wetland enhancement project might result in increased numbers of waterfowl and the value of wildlife habitat, which is one of the goals of the Ministry of Environment. At the same time, crop damage by waterfowl might increase, which is an important concern for the Ministry of Agriculture.

When applying the GP models in this study, it is assumed that a set of goals are ranked in order of importance on an ordinal scale, such as 'most important' or first priority, 'next most important' or second priority, and so on. In addition, a target or achievement level is assigned to each goal. Priority ranks and target levels represent a decision maker's preferences and aspirations respectively for a set of goals. Thus, decision makers associated with different ministries or agencies will usually provide rank order and target levels for a set of goals quite differently. Such differing value systems create conflicts in multiple goal and multiple sector land assessment.

To identify the extent of conflict among various interest groups, scenarios can be created to reflect alternative priority ranks or target levels of a set of goals. In general, the models can be solved several times under different goal priority orderings, or under different target values for the goals. Thereafter, sequences of solutions are obtained, in which each solution relates to a specific priority ordering. Comparisons of the results will show whether achievements of goals have significant changes from changes in priority ordering, or from change of one specific value of the goal target level. These results provide information on the nature of relationships between various goals, whether conflicting with each other or mutually compatible. Goal conflict analysis like this has been studied by Cocklin, Lonergan, and Smit (1988) to identify goal relationships for the analysis of forest energy development projects in Eastern Ontario, Canada.

CHAPTER VI

APPLICATION OF THE ILAF FOR THE PEACE RIVER REGION: DEVELOPMENT OF

GOALS, DATA BASE, AND ASSESSMENT MODELS

Chapter 5 described a conceptual framework for integrated land resource assessment in a region. This chapter applies this conceptual framework to a specific region to test its applicability. Through the preparation of an integrated resource assessment framework in subregions of the Peace River Region of British Columbia (B.C.), the feasibility of developing an integrated land assessment framework (ILAF) for a broad region discussed in the previous chapter can be investigated.

The reasons for selecting the Peace River Region as the case study area are as follows:

1. There are serious challenges and conflicts facing the land resource base. Primary activities contribute significantly to the regional economy in the region (Canada. Environment Canada, 1985a).

2. The productive potential of the resource base is threatened by a variety of resource and environmental constraints such as land degradation, land use conflict, and land use conversion, which could limit the growth of the region (Canada. Agriculture Canada, 1984). Unless these constraints are recognized and measured, our understanding of the land use trade-offs being made in development will be far from complete.

3. There are relatively large land resource data available for the region.

117

4. Government agencies in the region are interested in information for land use planning. Thus, the case study may provide information useful for integrated land use management.

6.1 Study Area and Background

The Ft. St. John area of Peace River Region is located in the northeast corner of British Columbia. The Rocky Mountain Trench and the eastern section of the Great Plains are the two predominant physiographic areas. Elevations range from 400 to 800 meters. The area has a moderate continental climate with average temperatures varying from -12 to -18 degrees Celsius in January and from 13 to 16 degrees Celsius in July. Annual precipitation varies from 400-500 mm. Gray luvisolos, gleysols, chernozemic, and solonetzic soils dominate. Organic soils occupy about 20 percent of the area. The study area is in the boreal forest zone (BCMOLP&H, 1985a). The main vegetation includes white spruce-aspen forest on better drained soils, and aspen on warmer and drier sites at low elevation.

Various land demands within the area include agriculture, forestry, wildlife, grazing, recreation, construction, and settlement. The study considers only the three major resource sectors--agriculture, forestry, and wetland--because of limitations in data, cost, and time. They are now described in turn.

6.1.1 Agricultural Land Use

Agriculture plays an important role in the regional economy. The Peace River Region is well known as one of the major agricultural areas in the province of British Columbia. The major agricultural activities in the region are grains and forage production.

Soil capabilities for agriculture in the Peace River Region range from class 1 to 5. A small proportion of class 1 and 2 lands are found in the Peace River valley as a result of favourable soil and climate conditions. The remaining area near the Peace River consists of class 2 and 3 lands. The area north of Ft. St. John includes large amounts of class 4 and 5 lands. There are no high capability lands left in the region for agricultural development.

Trends in demands for agricultural land in the Peace River Region over the last decade show a continuous increase (BCMOLP&H, 1985a). Clearing for crop and pasture land has primarily occurred on the north side of the Peace River. Between 1971 and 1976, 2400 hectares (ha) of land were cleared annually under the Agricultural Land Development Act (ALDA) program. And the number from 1976 to 1980 increased to 3500 ha annually. Including the amount of land converted through other channels, the total land cleared in Peace River Region was estimated at 7400 ha annually since 1976 (BCMOA&F, 1981). The B.C. Ministry of Lands, Parks and Housing estimated that the hectarage of cropland and improved pasture increased by about 69,000 ha (6,900 ha per year) between 1971 and 1981.

Many uncertainties exist concerning the anticipated agricultural production. For example, an economic downturn in agricultural production in B.C., associated with the decline in world prices for grains since 1981, has induced a decline in the demand for agricultural land. These economic uncertainties in agricultural production cloud future agricultural land requirements. Regional officials suggest that demand for cropland within the Peace River Region could still be significant for high capability lands close to service centers (Kok, 1988).

6.1.2 Forest Land Use

The forest sector is part of a diverse regional economy. The study area is located in the Ft. St. John Timber Supply Area (TSA) which is one of six TSAs in the Prince George Forest Region. The TSA is administered by the Ft. St. John Forest District of the B.C. Ministry of Forests. Although the species harvested are mainly coniferous, there has recently been interest expressed in utilizing deciduous trees.

There are approximately 4.57 million ha of land in the Ft. St. John District. Slightly over half of these are productive crown forest land; the rest is devoted to private land, reserves, provincial parks, or nonforest lands. In crown forest land in the Ft. St. John District, the relative harvesting shares of the leading species are about 47.8 percent spruce, 46.3 percent pine, and 2 percent deciduous (BCMOLP&H, 1985a).

The proposed annual allowable cut (AAC) for Ft. St. John District based on the regional forest plan is 900,000 m³ per year for coniferous species, and 950,000 m³ per year for deciduous trees. The AAC is based on current land uses and management practices in the area (BCMOF, 1987). The TSA Plan #1 indicates that although there is no deciduous manufacturing capability at present in the Ft. St. John area, the AAC target set for deciduous species is intended to encourage the location of deciduous manufacturing potential in the area. Other factors which also influence the setting of timber harvesting targets include utilization standards, priority cutting ages, and forestry management strategies.

Of the total 4,567,000 ha land base for the Ft. St. John Forest District, only 451,000 ha, or approximately 10 percent, are devoted to timber production. The reduction from the gross area to the net land base is calculated by subtracting areas of provincial park, private land, open range, environmentally sensitive areas (ESA), not satisfactorily restocked forest (NSR), noncommercial brush (NC), and other anticipated withdrawals (BCMOF, 1986). The forest land base provides a variety of activities other than timber harvest. It is subject to demands for alienation related to croplands, parks, hydroelectric expansion, wildlife, and recreation reserves. It was estimated in 1981 that the anticipated withdrawals from the forest land base were about 8,500 ha per year in the Peace TSA (BCMOF, 1987). In the short term, withdrawals of forest land would have no immediate impact upon the AAC since timber could be harvested in other areas.

However, they would affect the long-term sustainable yield by reducing the land base available for succeeding harvests.

6.1.3 Wetland Use

Wetlands in the Ft. St. John area are scattered throughout the region. A variety of wetland components are observed including shallow open water (SOW), marsh, meadow, and sedge fen. These wetlands are classified by the Canadian Land Inventory (CLI) for waterfowl use capability classes 1 to 7. Wetlands provide many functions and possess different values such as erosion control, flood retardation, recreation, and most importantly groundwater recharge. In this study wetland value is defined with respect to waterfowl habitat and hunting activity.

Wetlands in the Ft. St. John area are considered important for waterfowl migration and habitat (Canada. Environment Canada, 1985c). This region provides high capability waterfowl habitat and some of the finest waterfowl viewing and hunting opportunities. Three class 1 marshes for waterfowl were located here, of which one has been partially drained for agricultural purposes. Since the Peace River Region is the most important field crop production area in B.C., the nearby barley and wheat crops often provide an abundance of food for migrating ducks and Canada geese during the fall months. This region is situated on the western edge of the Central Fly Way of migrating birds. The number of ducks and geese which stage the area for fall migration depends largely on the abundance of water bodies available. In wet falls, water bodies are abundant and they induce migrating birds to

stage and stop over in this region. In dry years, however, inadequate water bodies become a limiting factor. The availability of water bodies in the area has also been reduced as a result of wetland alienation under agricultural development.

6.1.4 Land Use Conflicts

Given the finite land resource base in the Ft. St. John area, there are uncertainties regarding the ability of the land to meet expected demands for agriculture, forestry, wildlife, grazing, recreation, and conservation uses. Increasingly resource uses compete for the same land base.

One pressing problem in land use planning is to resolve whether a specific forest area should be alienated for agricultural or preservation purpose, or retained for timber production. Alienation of the productive forest land base for agriculture and other uses has become a serious problem in the Ft. St. John area. With the increased demand for timber and other forest products, this situation becomes more urgent.

Wetland conservation is another land use allocation problem in the region. Wetlands in this region are under continuous threat from agricultural expansion. A large wetland area has been drained for farm uses. Increased awareness of the importance of wetland as habitat for waterfowl and other wildlife, moderators of watershed hydrology, and recreation areas, has raised public concern about the extent of wetland

123

loss. The proximity of wetlands to croplands, and a decrease in the availability of high quality land for agricultural expansion, have caused wetlands to become economically valuable for agricultural production. About 99% of the wetland loss in Ft. St. John area was attributed to improved drainage via ditching (Canada. Environment Canada, 1985c). Some wetland drainage projects are financed by federal and provincial agricultural development programs (BCMOA&F, 1981a). Drainage of wetlands and cultivation to the edge of hundreds of small marshes situated on private farm land, have damaged duck nesting habitat and caused a decline in the waterfowl population. Public concern over the continued loss of wetlands has resulted in the development of wetland protection plans and wetland enhancement measures to protect their habitat, hydrological, recreational, and educational values.

The conflict between wetland conservation and enhancement on the one hand, and agricultural uses on the other is further reinforced by the loss of grains such as barley and wheat to waterfowl. Crop damage by waterfowl costs farmers in the Peace River Region of B.C. about $80,000 to $100,000 annually. Crop losses to an individual farmer by waterfowl can exceed $4,500 per annum. Much of the crop damage has occurred near Cecil Lake, northeast of Ft. St. John (BCMOA&F, 1985). Crop damage by waterfowl has become a sensitive subject to many grain farmers in this region. This often handicaps efforts to enhance waterfowl habitat (BCMOE, 1988).

124

6.1.5 Soil Erosion Problems

Novak and Van Vliet (1983) indicated that the Peace River Region was the highest erosion risk area among all agricultural reporting regions in B.C. The issue of land degradation has been identified as a serious problem in western agriculture by the Standing Committee on Agriculture, Fisheries and Forestry, the Senate of Canada and by Agriculture Canada (Sparrow, 1984; Canada. Agriculture Canada, 1984). Land degradation can cause increases in long-term economic, social, and environmental costs and threaten sustainable resource production systems. Among various forms of land degradation, soil erosion is the most serious threat facing rural land use in the Peace River Region.

Soil erosion changes the soil structure, and its physical and chemical characteristics. An eroded area generally absorbs and holds less water, has lower organic content, and is less fertile. Farming machinery use becomes more difficult on eroded land, and fertilizer and herbicide application rates cannot be adjusted to suit all parts of a field with eroded areas (Crosson and Stout, 1983). All these soil erosion effects reduce natural agricultural productivity and increase the production costs in the absence of mitigating measures.

Crosson and Stout (1983) suggest that soil erosion is likely to intensify other types of land degradation such as land compaction, increasing aridity, salinity, and alkalinity. Moreover, the movement of sediments into water courses may constitute a serious environmental problem quite apart from the on-farm effects.

A current study of soil erosion problems in the Peace River Region of B.C. (Van Vliet, 1989) suggests that the Dawson Creek and Ft. St. John areas, with 79 percent of the total cropland in Peace River Region, comprise 53 percent of the total predicted soil loss for the region (Canada. Agriculture Canada, 1986).

6.1.6 Need for Integrated Land Use Analysis

The preceding discussion illustrates the many land use problems challenging land use planners in the Peace River Region. In order to maintain long-term resource production in this region, erosion control strategies might be required. The land use problem has developed because agricultural and forestry uses are normally mutually exclusive, as are agricultural use and wetland protection. Substantial land use change on the agricultural-forest interface was identified in Fort St. John and Dawson Creek area (Canada. Environment Canada, 1985a). Conflicting areas between agriculture and waterfowl for the use of wetlands are also centered on this subregion (Canada. Environment Canadian, 1985c; BCMOA&F, 1985; Bornford, 1988).

Various land use policies and programs have been created to control land degradation, to regulate land conversion, and to deal with land use conflicts with adjacent users. Since government is so heavily involved in affecting land use allocation and management through subsidies, crown land delineation programs, wetland enhancement projects, and other programs, land planners need to know more about the importance and significance of land use conflicts, and the

126

socio-economic, and environmental implications of alternative land use policies. As indicated in chapter 2, integrated land assessment, which takes account of multiple goals and multiple resource sectors, is a desirable approach to deal with land use conflicts and to identify trade-offs.

To date, studies of integrated land use assessment and evaluation are limited. In particular, research on land use conflicts and change among areas of primarily agricultural, forestry, and wetland uses have been given only cursory attention. Several studies on land use conflicts and change have highlighted the growing concern over competing land uses (BCMOF, 1984). Subdistrict crown land planning programs have been developed to determine the optimal land uses in some deferred planning areas (BCMOLP&H, 1981; 1983). The objectives of these studies are to identify whether land resources in a specific area should be alienated for agricultural use, or retained as forest land. A number of limitations have been recognized for these subdistrict plans. Based mainly on the physical production capability of the land, such plans provide inadequate information for sound land use decision making.

Despite the recognition of the seriousness of land use conflicts and soil erosion, little information on the geographic extent, severity, and rate of increase of land use problems, and their economic, social, and environmental impacts has been available. Information on land use conflicts and soil erosion is useful for land use management and planning. To resolve the questions of competing use

127

options and soil erosion, it is necessary to identify the extent and severity of problems in this region, to assess impacts of various land use prospects and policies, and to provide a process to identify the trade-offs among land use goals or alternatives.

6.1.7 Study Area

In accordance with the problem of conflicting land resource uses indicated by existing private and public reports and documents and expert opinion, this study examines four problem specific areas. Figure 6.1 presents the study areas. The first study area (Area I) is part of Township (TP) 85 and Range (R) 18 which is located west of Beatton River. This area has six map sections of which each is 259 ha in size. Conflict between agriculture and wetland is significant (Clark, 1988). Wetlands in this area are mostly classified as high value for waterfowl (CLI class 2). A large number of these wetlands have been converted for crop production. The second study area (Area II) at Cecil Lake east of Beatton River consists of 16 map sections. The major land use conflicts are not land conversion but crop damage by waterfowl. In area III, north of area II, the main land uses are forestry and crop production. Area III has 9 map sections and represents an agriculture-forestry interface region where forestry and agricultural land uses dominate and are intermixed. The main land use trend in this area is the shift from forest to agricultural uses (BCMOLP&H, 1985). The fourth area is east of area II and III and has 20 map sections. The major land use characteristic of this area is the mixture of activities including

Figure 6.1: The Sub-Region of The Peace River Region
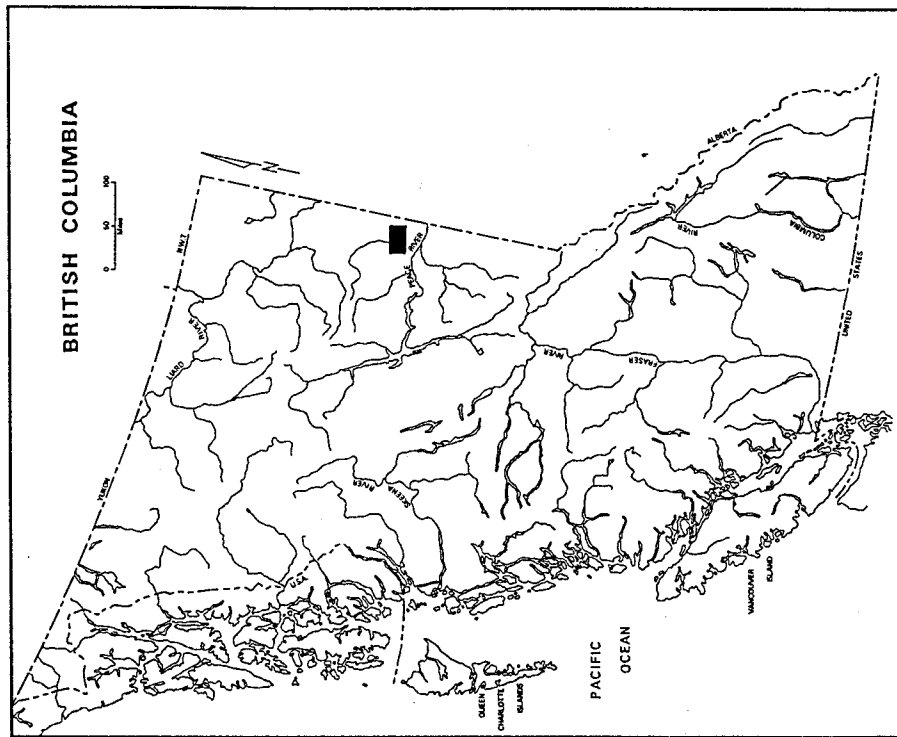
Note:

TP: Township; R: Range; Number in the Matrix: Number of Map Section

agriculture, forestry, and wetlands.

6.2 Integrated Data Base for Land Assessment

The establishment of a common data base which incorporates information from agricultural, forestry, and wildlife sectors is a necessary step for integrated resource assessment. An initial review of the available land resource data revealed inadequate and inappropriate biophysical and socio-economic information for integrated land assessment. The British Columbia government has collected various data on soil classification, climatic characteristics, land resource uses, and capability and productivity of land resources for different land uses. However, these land resource data have been collected by a wide range of government agencies often in support of their own interests. As a result, these data sources are based on different land units or different scales. It is difficult to use these data directly in integrated land resource assessment.

In this study, sources of data pertinent for land resource assessment are first reviewed and evaluated. An effort is then made to establish a data base appropriate for integrated land resource assessment. In particular, this data base is designed to meet the following objectives:

1. To identify subregions where land use conflicts exist between agriculture, forestry, and wetland.

2. To review and evaluate data sources available for integrated land

130

resource assessment and planning in the Peace River Region.

3. To compile biophysical and socio-economic data from various sources and to establish appropriate land resource data for integrated land use assessment.

4. To indicate opportunities for data improvement for land resource assessment and planning.

6.2.1 Data Sources

Information for the data base was obtained mainly from two sources: a review of published data and interviews with agency personnel. The review identifies the existing research work and data which have potential value for integrated resource assessment. Existing studies, undertaken by government agencies, consultants, and other research groups, provide extensive data for land resource analysis. The main statistical information is derived from documents and reports from the above agencies. In order to check the reliability of existing data and the availability of updated data, as well as other research and planning work related to land resource allocation and management, interviews were conducted with a wide variety of specialists whose names and affiliates are listed in appendix I. The specific purpose and tasks of the interviews are presented below:

* to collect detailed data and identify local decision makers' goals, priorities, and preference on land uses;

* to identify various land units on which data were collected and to examine the consistency of land units among agricultural, forestry,

and environmental sectors;

* to obtain data on the land conversion rate for each area, on the quality and current uses of the land being converted, and on land conversion trends;

* to check the data availability of soil erosion rates;

* to locate available maps including land use for agriculture, forestry, and wetland;

* to identify the "agriculture-forest interface region" and the "agriculture-wetland conflicting area";

* to indicate the availability of surrogate measures for land resource values; and

* to establish contacts with experts and decision makers in the appropriate resource sectors.

Data availability derived from the review and interviews is presented by sector.

6.2.1.1 Agricultural Sector

Chapter 2 indicated some key biophysical and socio-economic factors which are important variables in the integrated land assessment framework. These key variables can assist in defining the opportunities and constraints of the land resource base for sustainable land development. Data on land capabilities and suitabilities were derived from the B.C. Land Inventory Report (B.C. Standing Committee on Agriculture, 1978a; 1978b), the B.C. Farm Income and Crop Insurance's current report "Risk Identification & Measurement in The Grain Crop

Insurance Program" (BCMOA&F, 1988), and a draft "An Inventory of Crown Land Suitable for Agricultural Development in the Peace Region" prepared by Kok for the Ministry of Lands, Parks and Housing (BCMOLP&H, 1985).

Data on crop yields, areas of different land types, and prices of agricultural products were provided by the Agriculture Region Report, Peace River (BCMOA&F, 1981a), and the B.C. Farm Income and Crop Insurance report (BCMOA&F, 1988). Information on other key variables such as agricultural production cost, economic return, cropping pattern, and land conversion rate were obtained from the following sources:

*   a research project conducted by a consultant company in Fort St. John analysing the financial consequences of various land uses including cash cropping, perennial hay, and forest (Collins and Hadland, 1988);

*   a research report by Baehr and Dobb (1985) indicating the annual rates of land clearing and breaking in developed areas;

*   a research project report by Graham and Lopez (1976) concerning farm planning for the Peace River Region.

6.2.1.2 Forestry Sector

Data for the forestry sector are generally more detailed. The Forest Inventory Branch has detailed forest cover information for the Peace River Region. This information is available in hard copy and digital format. Forest survey information is maintained on a computer based mapping system. These data include age, site class, area, tenure,

133

species major, and major land base divisions such as water, nonforested land, nonproductive forested land, productive forested land, and so on. B.C. Ministry of Forests' (BCMOF) reports "Forest and Range Resource Analysis" (BCMOF, 1980a, 1984, 1985a) provide inventory data and statistics on timber harvest, range utilization, and recreational use. Land use conflicts between agriculture and forest are described in these reports. A background report of the 1984 analysis presents detailed data in tabular form for each subregion. Maps, diagrams, figures, and other forms of information are also included in these reports. Reports completed by the regional office of Ministry of Forests in the Peace River Region (BCMOF, 1981a, 1985b, 1985c, 1986, 1987) outline production targets and plans. Many data have been analysed and listed in these reports. Factors such as the available land base, the quality and location of the resources, demands of various users, technology improvements, and potential losses of the forest resources to other purposes have been considered in the analysis. The glossary sections of these reports define terminologies used in the forest sector.

6.2.1.3 Wetland Sector

Data on wetland alienation were provided by a report published by the Environment Canada (1985c). It deals with wetland conversion to agricultural uses in the Peace River Region for each CLI Land Capability Class for Waterfowl. Interviews with regional officers and specialists from Ducks Unlimited yielded some detailed data and

134

judgements. Data on the number of duck hunters and ducks killed were retrieved from a data base in the Fish and Wildlife Branch of B.C. Ministry of Environment (BCMOE) at Fort St. John based on wildlife management unit (MU). More detailed, site-specific information was estimated by a regional habitat biologist (Harper, 1988). Survey data on current waterfowl status and habitat value for ducks were collected from Ducks Unlimited (Clark, 1988). Ducks Unlimited at Prince George has conducted most waterfowl inventories in the Peace River Region.

6.2.1.4 Land Resource Maps

A wide variety of land resource map series which are of potential value for integrated resource assessments have been compiled by the federal and provincial governments. These maps provide information on biophysical conditions of the land base. Table 6.1 characterizes map series that assist land resource assessment. Maps summarized in Table 6.1 are presented in terms of their contents and scales.

6.2.2 Spatial Units of Analysis

Information about land resources, current land uses, and land use alternatives in the Peace River Region of British Columbia is available from a wide range of sources. Such data sources are limited for integrated resource assessment by inconsistencies in scale and coverage. That is, when several data sources are used, the variety of scales and mapping units used pose problems of comparability.

Table 6.1: Maps For Land Resource Assessment.

Map Name	Publisher	Information Provided	Scale
The Canada Land Inventory (CLI) Capability	DREE, 1970b Environment Canada, 1973, 1974, 1975.	Land capability for agriculture, forestry, and wildlife-waterfowl	1:125,000 1:250,000
Land Capability Analysis	Environment Canada, 1972.	The highest physical capability of different areas in support various land uses.	1:50,000
Land Use	Standing Committee on Agriculture, 1978b.	Land use patterns in B.C.	1:50,000
Forest Cover	B.C. Ministry of Forests 1971, 1980b.	Various data for forested land, non-forested land, unproductive land, water, and other land uses	1:15,840 1:50,000
Soil Erosion	Agriculture Canada (Van Vliet, 1989).	Soil erosion rates for different polygons	1:100,000 1:50,000
Air Photo	Maps B.C., (B.C. Ministry of Environment, 1985-86)	Land use patterns	1:50,000

If the data are identified spatially, it is possible to estimate the land resource availability within a defined capability class for any specific location (Manning, 1988). Data on land resources can then be related to particular sites or land units. Organizing and incorporating different data sets spatially from different resource sectors such as agriculture, forestry, and wildlife has been of considerable importance in integrated land assessment. The key point is to choose a suitable spatial framework which is appropriate to integrate information from diverse sources and to be used for modelling.

There are three possible approaches with respect to spatial land units for analysis. The first is to use administration units for data portrayal and integration. One problem in the use of this type of unit in this study is that only one administration unit exists in the Peace River Region.

The use of ecological units such as soils and climates is another approach. There is significant biophysical information based on soil and climate zones for the study region. However, social-economic information is not always available on the same basis.

A third type of spatial unit is geometric grids where data are synthesized and reported by grids, either sections or quarter sections. When compared with the two approaches discussed previously, this approach is the most appropriate for this study with regard to the size of the unit, flexibility of data reconciliation, and the spatial unit

137

used by the regional map.

In this study, the geometric units or map sections are used as the basic units for assessment. There are in total 55 sections in the study area (Figure 6.1). Each map section represents a unique area. The use of the map section as the basic land unit or data recording unit simplified data collection and handling. Information from various sources such as survey, census, administrative or ecological units were abstracted to the grid units or sections through the superimposition of various land resource maps. The result was a data base with a broad array of land use categories suitable for integrated land use assessment.

6.3 Main Structure of the Analytical System

An integrated land assessment system exhibits a hierarchical structure which contains a multiplicity of assessments by several resource use sectors. In such a system, the major role of integrated resource assessment is coordination. To this end, GP models provide a framework for the coordination of resource assessments made by the various resource use sectors which represent different components of the regional land use system.

The land assessment framework developed for this study consists of three submodels and an integrated model. The three submodels represent the agricultural, forestry, and wetland sectors. Relationships between submodels and the integrated model are depicted in Figure 6.2.

138

```
                    ┌─────────────────────────┐
                    │     Integrated model    │
                    │         Goals:          │
                    │   Resource production   │
                    │   Net economic return   │
                    │   Soil erosion control  │
                    │   Forest cover          │
                    │   Wetland protection    │
                    └─────────────────────────┘
```

┌──────────────┐   ┌──────────────┐   ┌──────────────┐
│ Agricultural │   │   Forestry   │   │   Wetland   │
│ sub-model   │   │ sub-model   │   │ sub-model   │
│ Goals: │   │ Goals: │   │ Goals: │
│ Production │   │ Production │   │ Habitat   │
│ Net return │   │ Net return │   │ and   │
│ Soil erosion│   │ Soil erosion│   │ hunting   │
│ control   │   │ control   │   │ value   │
└──────────────┘   └──────────────┘   └──────────────┘
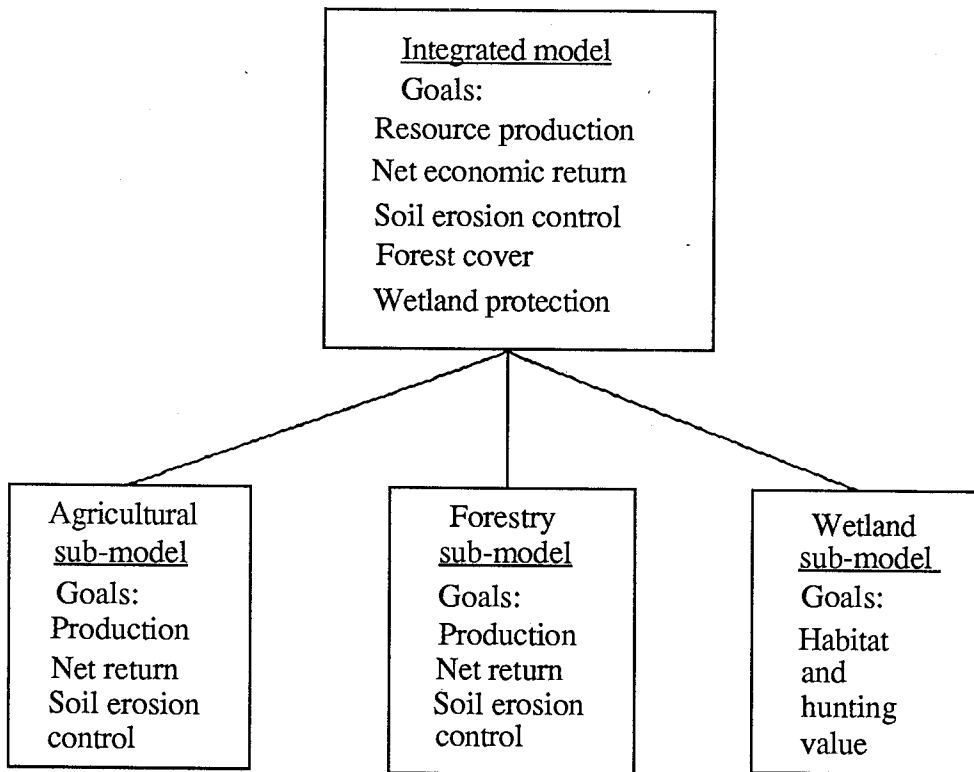
Figure 6.2: Hierarchical Structure of the ILAF System.

At the regional level, land resource assessment concerning various resource sectors as a whole may be based upon goals such as sustainable resource production, economic efficiency, soil erosion control and wetland protection. These regional resource development goals impose certain impacts on land use options at the sectoral level, whereas submodels for agriculture, forestry, and wetland are designed to explore multiple goals for each sector. Land use assessments at both the regional and sectoral levels must consider a range of goals which reflect the diverse preferences and aspirations existing among decision makers of sectors and the region.

6.3.1 Setting Goals and Priorities

A survey of preferences and aspirations for land resource management was conducted among the staff of offices in various ministries at both the provincial and regional levels in B.C. Interviews with resource supervisors, specialists, and administrative assistants provided information to determine land resource-use objectives. Questions were directed to those above mentioned individuals to rank a set of goals in order of importance on an ordinal scale and to relate each goal to an acceptable target level so that each could be expressed in the form of an achievement level.

The information collected was sorted into land bases, activities, and goal priority rankings (Table 6.2). Tabulations were made for three resource use sectors--agriculture, forestry, and wetland--and the regional land use system. The preference orderings established the

140

Table 6.2: Land Bases, Activities, and Goal Priorities.

Model	Land Bases	Activities	Goal Priorities
Agriculture	Improved Land	Wheat Oat Barley Canola Hay	Net Return Production Erosion Control
Forest	Woodland	Spruce Lodgepole Pine Deciduous	Net Return Production Erosion Control
Wetland	Wetland	Status Quo Enhancement	Habitat Value Duck Hunting
Integrated	Improved Land Woodland and Wetland	Sum of Activities In Three SubModels	Net return Production Erosion Control Forest Cover Habitat Value

goals, priority rankings, and land bases for each of the three submodels and the integrated model. The goals in the goal priorities column in Table 6.2 are listed in rank order. That is, from the top down, the priorities of goals decline. The submodels and the integrated model have their own goal rank orders.

6.3.2 Basic Structures of Submodels and Integrated Model

6.3.2.1 Agricultural Submodel

Table 6.3 shows the basic structure of a simplified version of the agricultural submodel developed in this study. This submodel is composed of decision variables which represent activities or land uses applied to individual land units. There are also deviational variables which measure deviations from target levels of the goal achievements in the simplified model.

Each row in the simplified agricultural submodel represents either a technical or resource constraint, or a goal constraint which is also called a goal achievement function. The coefficients in each row represent the relationship between the constraint or goal and the decision variables. For each decision variable (land use activity), certain "effects" are expected which are either outputs from the land use or inputs required for this activity. An example of an output for a land use activity might be yield, while an input would be the number of areas required to achieve the yield. Each coefficient in the model shows the amount and type of each effect expected for each hectare of

142

Table 6.3: Simplified Version of the Agricultural Submodel.

Item	Decision Variables						Deviational Variables						Target Levels or RHS Values
	WH	BA	OA	CA	HA	SF	Prod Less	Prod Over	NR Less	NR Over	Soil Less	Soil Over	
	x_1	x_2	x_3	x_4	x_5	x_6	d^-_1	d^+_1	d^-_2	d^+_2	d^-_3	d^+_3	
Objective							P2	P1			P3		
Land Constraint	1	1	1	1	1	1							< A1 (ha)
Production	y_1	y_2	y_3	y_4	y_5		1	-1					= b1 (t)
Net Return	R_1	R_2	R_3	R_4	R_5				1	-1			= b2 ($)
Soil Loss	E_1	E_2	E_3	E_4	E_5	E_6					1	-1	= b3 (t)

Note:

WH: wheat Production   Prod: crop Production

BA: barley production   NR: net return

OA: oats production   Soil: soil erosion

CA: canola production   Less: underachievement

HA: hay production   Over: overachievement

SF: summer-fallow

RHS: right hand side

P1, P2, and P3: priorities 1, 2 and 3

b1, b2, and b3: target levels 1, 2, and 3

A1:   land availibility for cropping

land used by a specific land use activity. The kind and extent of effects depend on the land capability and suitability of each land unit, and the nature of each specific land use. Each coefficient might be an estimate of the average amount of the effect for a specified time period. These coefficients are provided by the integrated data base.

The right hand side (RHS) values of the model represent either land resource constraints for agricultural uses or target levels of goals. The objective function rows are formulated to minimize the deviations between the achievement of the goals and their target levels. The GP technique can find a set of land use activities that meet the land resource constraints and minimize the nonachievement of goal target levels.

Agricultural Land Uses

The main land uses in the agricultural sector in the study area are field crops and forage. Land use activities considered in this study include wheat, barley, oats, canola, hay, and summer-fallow. These crops and forage may be grown in any of the land units in the study region, and they are represented in the submodel by decision variables. Data required for coefficients of the cropping and forage activities include prices of products, costs of production, average yields, and soil erosion rate which are obtained from the data base.

Constraints and Goals

In this study, the agricultural submodel includes one type of constraint: a land resource constraint, and three types of goals:

144

production requirements, economic return, and soil erosion control. The constraints reflect the finite nature of the land resource base. The goals reflecting the main concerns of the B.C. Ministry of Agriculture are frequently expressed in government documents (BCMOA&F, 1980). Constraints and goals have the same mathematical structure in the model. The difference between them lies in the meaning attached to the right hand side (RHS) of the mathematical formulas. With constraints the RHS must be satisfied in order to achieve a feasible solution for the model. With goals, however, the RHS is a target level to which the solution attempts to reach. It may, or may not, be achieved. More detail concerning each constraint and goal is presented next.

Land Resource Constraints

The land resource constraint states that the total area of land allocated to cropping, forage, and fallow activities cannot exceed the available lands for each land unit. This statement can be expressed by the following formula:

$$\sum_j x_{ij} \leq Al_i \quad (j=1,2,\ldots,6) \qquad (6.1)$$

Where:

x_{ij} is the area of land allocated to cropping, forage, or fallow uses j in land unit i (i=1,2,...,55) (ha);

Al_i is the total amount of land available for cropping or forage or summer-fallow uses in land unit i.

The 6 land use activities in this submodel have been discussed previously. The amount of land resources available for agricultural

145

uses in each land unit constitutes the right hand side of land resource constraint formula 6.1. In the agricultural submodel, there are 55 land resource constraints representing 55 land units in the study region. Land resources available for agricultural uses are derived from the data base and are presented in Table 6.4.

The identification of land currently available for agricultural, forestry, wetland, and other uses is a difficult task. There are no existing land use data which are based on map sections in this region. Considering the current land use dimensions in the Peace River Region, and the purpose of this study, land resources in the study area are classified into four groups: improved farmland which is land availability for the agricultural submodel; woodland denoting the area available for the forestry submodel; wetland is land availability for the wetland submodel; and nonproductive lands (NP) include river and rocky areas which are not suitable for any of the above uses. Current land use data for each of the 55 land units in the study region are derived from the computer data base of the forest cover inventory which records forested land, farm land, unproductive land, water, and other land uses (BCMOF, 1980b). This is accomplished by superimposing the forest cover map onto the 1:50,000 scale regional map with map section grids on it. From this the current forestry land use data and data for NP lands for each land unit are obtained from a simple weighting procedure in the formula:

$$A_{ij} = \sum_k P_{ik} * F_{kj} \qquad (6.2)$$

Where:

Table 6.4: Land Resource Availabiliby (ha) For Each Land Unit.

Township	Range	Section	Improved Land	Woodland	Wetland	NP (River)
TP85	R18	2	161	40	19	39
		3	209	22	28	0
		10	213	26	20	0
		11	205	33	21	0
		14	204	46	9	0
		15	181	29	10	39
TP84	R17	26	95	93	71	0
		27	158	101	0	0
		28	144	115	0	0
		29	135	124	0	0
		32	101	158	0	0
		33	57	185	17	0
		34	0	66	193	0
		35	90	86	83	0
TP85	R17	2	118	128	26	13
		3	0	95	164	0
		4	39	76	144	0
		5	142	117	0	0
		8	70	189	0	0
		9	138	121	0	0
		10	114	131	14	0
		11	158	101	0	0
TP85	R17	26	46	148	65	0
		27	55	201	0	3
		28	0	104	0	155
		33	0	241	0	18
		34	0	228	0	31
		35	64	169	26	0
TP86	R17	2	128	131	0	0
		3	37	222	0	0
		4	25	234	0	0
TP85	R16	4	151	95	13	0
		5	116	117	26	0
		6	111	148	0	0
TP85	R17	1	131	128	0	0
		12	102	133	0	24
TP85	R16	7	81	165	0	13
		8	133	118	0	8
		9	161	98	0	0
		16	158	101	0	0
		17	43	119	97	0
		18	34	173	52	0
TP85	R17	13	137	98	24	0
		24	103	132	24	0
TP85	R16	19	51	161	34	13
		20	67	124	68	0
		21	183	76	0	0
		28	159	100	0	0
		29	97	136	26	0
		30	30	82	17	130
TP85	R17	25	58	143	48	10
		36	84	127	48	0
TP85	R16	31	81	178	0	0
		32	121	136	2	0
		33	73	116	0	70

147

A_{ij} is the weighted area of land use j in land unit i;

k is the subscript denoting a forest cover map grid;

P_{ik} is the proportion of forest cover map grid k containing in land unit i;

F_{kj} is the area of land use j in forest cover map grid k.

Using formula 6.2 the land use inventory data which include forestry land, nonforestry land, and NP land are converted to current land use data representing individual land units. Area of wetland for each of the land units in this study region is derived from data files of the Ducks Unlimited in Prince George, B.C. by using a similar superimposing method. The current land use data for each of the 55 land units in the study region are tabulated in Table 6.4.

Net Return Goal

Economic efficiency is an important goal or criterion in the assessment of any proposed land resource use or development. In this study, net economic return to land resources is employed as a measurement of economic efficiency. In the land use process, one basic objective is to ensure that land resources are allocated in a manner which maximizes net economic return to the land. Land use planners usually expect positive net economic return to the development of the land resources. The net economic return goal for the agricultural submodel is expressed by the following equation:

$$\sum_i \sum_j R_{ij} * x_{ij} - d^+_6 + d^-_6 = b_6; \quad (j=1,2,\ldots,6) \quad (6.3)$$

Where:

R_{ij} is the net economic return per year to land use j in land unit i (\$/ha);

x_{ij} is defined as in equation 6.1;

d^+_6, d^-_6 are the overachievement and underachievement from target level of the net economic return goal respectively;

b_6 is the target level of net economic return goal.

This goal is to minimize the underachievement of the net economic return target. When the negative deviational variable d^-_6 is minimized to zero, the net economic return goal level is met. Overachievement from the target level, or positive deviation, is acceptable. Thus, only the negative deviational variable is considered in the objective functions of the submodel.

For each of the cropping activities, total cost per ha is assumed to be the same for each of the 55 land units in the study region because there is no production cost data for each of the 55 land units. Total costs for different crops in the study region are derived from Collins and Hadland's report (1988) which also provides price data for crops of the Peace River Region. Price and cost data for different crops are presented in Table 6.5. Net economic return to each activity in each land unit is presented in Table 6.6.

Gross return per ha for each crop and to each land unit is simply a result of the crop yield in that land unit times the price of the

Table 6.5: Average Price And Production Cost Data.

Commodity Or Activity	Unit	Price	Unit	Total Cost
Wheat	$/tonne	200.81	$/ha	240.06
Barley	$/tonne	134.38	$/ha	234.87
Oats	$/tonne	114.19	$/ha	234.87
Canola	$/tonne	430.48	$/ha	245.52
Forage(Hay)	$/tonne	40.00	$/ha	117.42

	Unit	Stumpage Price
Spruce	$/m^3	7.55
PL	$/m^3	3.38
Aspen	$/m^3	1.03

Sources: Collins, J. 1988; BCMOLP&H, 1982;
Agriculture Canada, 1985

Table 6.6 Net Economic Return Coefficients.
($/ha.)

Land Unit		Wheat	Barley	Oats	Canola	Hay	Spruce	PL	Aspen
TP85 R18	2	146.82	14.08	-9.24	137.26	63.38	16.23	7.19	1.90
	3	122.02	7.43	-23.34	105.37	34.73	9.88	3.75	0.74
	10	206.34	70.49	33.07	232.97	150.32	9.88	3.75	0.74
	11	122.02	7.43	-23.34	105.37	34.73	9.88	3.75	0.74
	14	122.02	7.43	-23.34	105.37	34.73	9.88	3.75	0.74
	15	171.62	37.30	-0.77	169.17	89.07	9.88	3.75	0.74
TP84 R17	26	176.58	40.63	4.87	179.79	97.96	9.88	3.75	0.74
	27	156.75	20.70	-12.05	137.26	62.39	10.82	4.25	0.89
	28	156.75	20.70	-12.05	137.26	62.39	10.82	4.25	0.89
	29	156.75	20.70	-12.05	137.26	62.39	9.88	3.75	0.74
	32	176.58	40.68	4.87	179.79	97.96	9.88	3.75	0.74
	33	176.58	40.63	4.87	179.79	97.96	10.82	4.25	0.89
	34	176.58	40.63	4.87	179.79	97.96	11.76	4.77	1.06
	35	176.58	40.63	4.87	179.79	97.96	9.88	3.75	0.74
TP85 R17	2	176.58	40.63	4.87	179.79	97.96	15.29	6.67	1.73
	3	176.58	40.63	4.87	179.79	97.96	10.82	4.25	0.89
	4	176.58	40.63	4.87	179.97	97.96	14.92	6.18	1.56
	5	156.75	30.65	-3.58	147.90	75.24	9.88	3.75	0.74
	8	107.15	4.10	-23.45	94.72	24.85	11.19	4.52	0.96
	9	126.98	14.08	-17.69	115.99	43.62	13.44	5.68	1.41
	10	141.85	24.03	-9.24	137.26	61.40	12.50	5.19	1.21
	11	141.85	24.03	-9.24	137.26	61.40	13.44	5.68	1.41
	26	-1.98	-55.62	-79.76	9.68	-12.70	13.07	5.43	1.33
	27	87.29	-15.81	-43.08	73.46	21.88	16.97	7.61	2.05
	28	-56.54	-112.06	-127.70	-64.76	-32.46	16.60	7.34	1.98
	33	122.02	7.43	-23.34	105.37	34.73	16.97	7.61	2.05
	34	122.02	7.43	-23.34	105.37	34.73	17.91	8.10	2.25
	35	72.41	-22.45	-45.89	62.84	9.04	14.35	6.18	1.56
TP86 R17	2	122.02	7.43	-23.34	105.37	34.73	16.60	7.34	1.98
	3	122.02	7.43	-23.34	105.37	34.73	16.97	7.61	2.05
	4	122.02	7.43	-23.34	105.37	34.73	16.60	7.34	1.98
TP85 R16	4	102.18	0.79	-28.97	84.10	16.94	9.88	3.75	0.74
	5	62.49	-29.07	-60.00	41.57	13.98	9.88	3.75	0.74
	6	131.95	10.74	-17.60	115.99	43.62	9.88	3.75	0.74
TP85 R17	1	176.58	40.63	4.87	179.79	97.96	9.88	3.75	0.74
	12	102.18	0.79	-26.16	84.10	17.93	9.88	3.75	0.74
	7	82.35	-9.16	-34.63	62.84	-1.83	9.88	3.75	0.74
	8	52.59	-5.85	-34.63	73.46	4.10	9.88	3.75	0.74
	9	72.42	-12.50	-37.45	52.19	-7.76	9.88	3.75	0.74
	16	72.42	-12.50	-37.45	52.19	-7.76	9.88	3.75	0.74
	17	17.86	-55.62	-74.10	-0.96	-24.55	9.88	3.75	0.74
	18	17.86	-55.62	-74.10	-0.96	-24.55	9.88	3.75	0.74
TP85 R17	13	42.66	-32.41	-54.36	30.92	-13.68	9.88	3.75	0.74
	24	42.66	-32.41	-54.36	30.92	-13.68	9.88	3.75	0.74
TP85 R16	19	-16.87	-75.56	-96.68	-32.85	-36.41	9.88	3.75	0.74
	20	42.66	-32.41	-54.36	30.92	-13.68	9.88	3.75	0.74
	21	72.42	-12.50	-37.45	52.19	-9.73	9.88	3.75	0.74
	28	62.49	-15.81	-40.26	52.19	-15.66	9.88	3.75	0.74
	29	47.62	-32.41	-54.36	30.92	-13.68	9.88	3.75	0.74
	30	-46.61	-98.76	-116.41	-64.76	-48.26	9.88	3.75	0.74
TP85 R17	25	17.86	-55.62	-74.10	-0.96	-24.55	11.19	4.52	0.96
	36	17.86	-55.62	-74.10	-0.96	-24.55	11.76	4.77	1.06
TP85 R16	31	82.35	-9.16	-34.63	62.84	-1.83	9.88	3.75	0.74
	32	82.35	-9.16	-34.63	62.84	-1.83	9.88	3.75	0.74
	33	67.46	-15.81	-40.26	52.19	-12.70	9.88	3.75	0.74

product. Calculation of the net economic return is accomplished by subtracting total cost from gross return. The net economic return target level is first estimated based on the prices of agricultural products and the crop production target set by Agriculture Canada. Then the economic return target level is varied in later analyses to examine the impacts of changing the return target on obtaining other goals.

Crop Production Goal

The ability of a region to provide for its food requirements, feed grain and other agricultural products has long been a measure of agricultural success. In some countries today, particularly in lesser developed countries, agricultural policies are often geared explicitly towards attaining complete self-sufficiency in food products. The examination of trends in crop production is useful for evaluating the economic efficiency and the sustainability of agricultural production system (Brklacich, 1989). The crop production levels are placed in the agricultural submodel as the second priority goals. The crop production goals are accommodated in the submodel via the following goal constraints:

$$\sum_i y_{ij} * x_{ij} - d^+_j + d^-_j = b_j \quad (j=1,2,3,4,5) \quad (6.4)$$

Where:

x_{ij} is defined as in equation 6.1;

y_{ij} is yield of crop j in land unit i (t/ha);

b_j is target level for production of crop j;

d^+_j, d^-_j are the overachievement and underachievement of target level for crop j respectively.

152

In this submodel, it is desirable to achieve the target levels of crop production. But in reality, land use might be forced to accept less than the target level when certain constraints exist. Overachievement of the production goals would be usually acceptable. This production goal therefore becomes the minimization of the underachievement (d^-_j) of the target levels of production goal. If the underachievement or negative deviational variable is minimized to zero, the target level of production goal is met.

The target levels of crop production goals for the study region are derived from the Agriculture Canada forecasts of grains, oilseeds, and forage seed for British Columbia and the Peace River Region (Canada. Agriculture Canada, 1986b). These target levels are classified into three categories based on three scenarios for potential development in the British Columbia crop production sector: moderate, optimistic and pessimistic scenarios. Target levels of crop production goals for the study region, which are based on the three development scenarios, are presented in Table 6.7. These targets are set for the year 1995. More information regarding the production targets can be obtained by referring to a report published by the Agriculture Canada (1986b).

The Farm Income and Crop Insurance Branch of the B.C. Ministry of Agriculture (BCMOA&F, 1988) has completed a study on crop risk identification and measurement which provides average crop yield data based on soil risk classes. The average yields are simple averages of the annual yields from the year of 1973 to 1986. Soil risk classes can

Table 6.7: Target Levels of Goals for the Agricultural Submodel.

Scenario	Goals						
	WH	BA	OA	CA	HA	NR	Soil
	(000's	tonne)				($)	(t/ha)
Moderate	2.00	3.55	1.07	1.62	7.02	195,560	11.2
Optimistic	2.36	3.80	1.15	2.20	7.02	250,000	11.2
Pessimistic	1.73	3.35	1.01	1.19	7.02	160,000	11.2

Note:

WH: wheat production

BA: barley production

OA: oats production

CA: canola production

HA: hay production

NR: net economic return

Soil: soil erosion control

be easily converted to their corresponding soil capability classes for agriculture. By using the following equation, which is similar to equation 6.2, crop yields for each of the land units of this study can be identified:

$$Y_{ij} = \sum_s P_{is} * Y_{sj} \qquad (6.5)$$

Where:

Y_{ij} is defined as in equation 6.4;

s is the subscript denoting a soil capability class;

P_{is} is the proportion of soil capability class s contained in land unit i;

Y_{sj} is the yield of crop j for soil capability class s.

The average yields derived from the B.C. Farm Income and Crop Insurance report (BCMOA&F, 1988) for 5 crops and for 55 land units in the study region are listed in Table 6.8.

Soil Erosion Control Goal

Novak and Van Vliet (1983) identified the Peace River Region as having the highest soil erosion risk among all agricultural reporting regions in B.C. Soil erosion is the major cause of land degradation and has become an environmental problem which reduces the productive capacity of the land resources (Sparrow, 1984). Controlling soil erosion is a major land use concern. A soil erosion control goal is incorporated in the model, which is represented by equation 6.6.

$$\sum_i \sum_j E_{ij} * x_{ij} - d^+_7 + d^-_7 = b_7, \quad (j=1,2,\ldots,6) \quad (6.6)$$

Where:

Table 6.8: Average Yield Data For Agricultural Sector.

Township	Range	Section	Wheat (t/ha)	Barley (t/ha)	Oats (t/ha)	Canola (t/ha)	Forage (t/ha)
TP85	R18	2	1.93	1.85	1.98	.89	4.52
		3	1.80	1.80	1.85	.82	3.80
		10	2.22	2.27	2.35	1.11	6.69
		11	1.80	1.80	1.85	.82	3.80
		14	1.80	1.80	1.85	.82	3.80
		15	2.05	2.03	2.05	.96	5.16
TP84	R17	26	2.07	2.05	2.10	.99	5.38
		27	1.98	1.90	1.95	.89	4.49
		28	1.98	1.90	1.95	.89	4.49
		29	1.98	1.90	1.95	.89	4.49
		32	2.07	2.05	2.10	.99	5.38
		33	2.07	2.05	2.10	.99	5.38
		34	2.07	2.05	2.10	.99	5.38
		35	2.07	2.05	2.10	.99	5.38
TP85	R17	2	2.07	2.05	2.10	.99	5.38
		3	2.07	2.05	2.10	.99	5.38
		4	2.07	2.05	2.10	.99	5.38
		5	1.98	1.98	2.03	.91	4.82
		8	1.73	1.78	1.85	.79	3.56
		9	1.83	1.85	1.90	.84	4.03
		10	1.90	1.93	1.98	.89	4.47
		11	1.90	1.93	1.98	.89	4.47
		26	1.19	1.33	1.36	.59	2.62
		27	1.63	1.63	1.68	.74	3.48
		28	.91	.91	.94	.42	2.12
		33	1.80	1.80	1.85	.82	3.80
		34	1.80	1.80	1.85	.82	3.80
		35	1.56	1.58	1.65	.72	3.16
TP86	R17	2	1.80	1.80	1.85	.82	3.80
		3	1.80	1.80	1.85	.82	3.80
		4	1.80	1.80	1.85	.82	3.80
TP85	R16	4	1.70	1.75	1.80	.77	3.36
		5	1.51	1.53	1.53	.67	3.29
		6	1.85	1.83	1.90	.84	4.03
TP85	R17	1	2.07	2.05	2.10	.99	5.38
		12	1.70	1.75	1.83	.77	3.38
TP85	R16	7	1.61	1.68	1.75	.72	2.89
		8	1.46	1.70	1.75	.74	3.04
		9	1.56	1.65	1.73	.69	2.74
		16	1.56	1.65	1.73	.69	2.74
		17	1.28	1.33	1.41	.57	2.32
		18	1.28	1.33	1.41	.57	2.32
TP85	R17	13	1.41	1.51	1.58	.64	2.59
		24	1.41	1.51	1.58	.64	2.59
TP85	R16	19	1.11	1.19	1.21	.49	2.03
		20	1.41	1.51	1.58	.64	2.59
		21	1.56	1.65	1.73	.69	2.69
		28	1.51	1.63	1.70	.69	2.54
		29	1.43	1.51	1.58	.64	2.59
		30	.96	1.01	1.04	.42	1.73
TP85	R17	25	1.28	1.33	1.41	.57	2.32
		36	1.28	1.33	1.41	.57	2.32
TP85	R16	31	1.61	1.68	1.75	.72	2.89
		32	1.61	1.68	1.75	.72	2.89
		33	1.53	1.63	1.70	.69	2.62

E_{ij} is soil erosion rate for crop j in land unit i (t/ha);

x_{ij} is defined as in equation 6.1;

d^+,, d^-,, are the overachievement and underachievement from target level of soil erosion control goal respectively;

b_7 is the target level of soil erosion control.

The main concern of this goal is to minimize the overachievement of the soil loss target. The negative deviation from the goal target, or underachievement of the target level, is quite acceptable. Therefore, only the positive deviational variable is to be minimized in the objective function, while the negative deviational variable is excluded.

To obtain information on soil erosion rate for each crop in each land unit, or to identify the soil loss coefficient, E_{ij}, the Universal Soil Loss Equation (USLE) is adopted. The USLE erosion model estimates long-term average soil loss from water erosion (Wischmeier and Smith, 1978). USLE can be expressed as:

$$E = R*K*LS*C*P \qquad (6.7)$$

Where:

E is the average annual soil loss in tonnes per ha (t/ha) by sheet and rill erosion for a given crop and given land unit;

R is the rainfall erosion factor;

K is the inherent soil erodibility factor;

LS is the slope factor consisting the length (L) and the steepness (S);

C is the crop cover and management factor;

P is the erosion control practice factor.

The study region has 55 land units and consists of a range of land types, varying in terms of soil properties, cropping patterns, topography, and so on, each with different consequences for soil erosion. To estimate the potential average annual soil loss due to sheet and rill erosion, using USLE, it is necessary first to determine indices of rainfall, soil erodibility, slope length, slope steepness, crop pattern, and conservation practice factors for each land unit in the study region. Van Vliet (1989) completed a study recently to predict water erosion for soils in the Peace River Region of B.C. He used USLE as a means to estimate the erosion rate for each land polygon in the Peace River Region of B.C. Methods for determining the values of R, K, LS, C, and P in USLE for each land polygon were described in his report. These water erosion data were compiled on water erosion maps at 1:100,000 scale, which combined soil and land use information. The USLE factor values developed by Van Vliet are the only data available for estimating soil loss in the study region.

To convert data from Van Vliet's data files to land units of this study, the water erosion maps were overlapped onto a base map of this study. The soil erosion rate for each crop and for each land unit, E_{ij}, was calculated by the following equation:

$$E_{ij} = \sum_{e} P_{ie} * E_{ej} \qquad (6.8)$$

Where:

E_{ij} is the soil erosion rate for crop j in land unit i;

158

P_{ie} is the proportion of map polygon e containing in land unit i;

E_{ej} is the soil erosion rate for crop j in polygon e.

Soil erosion rates for cropland, pasture, unproductive land, woodland, and summer fallow for each land unit in the study region are listed in Table 6.9. Data in Table 6.9 are used in the soil erosion control goal of equation 6.6. In order to estimate the long term soil loss, the annual loss is multiplied by the number of years involved, and the equation 6.7 is modified as:

$$E^* = R^*K^*LS^*C^*P^*N \qquad (6.9)$$

Where:

E* is the long term soil loss for a given land unit;

N is the number of years of continuous soil erosion;

R, K, LS, C, and P are defined as in equation 6.7.

Van Vliet (1989) suggests that efforts to reduce total soil loss in the B.C. Peace River Region are urgent. He further indicates that erosion control strategies should focus on the Dawson Creek and Ft. St. John regions. With respect to the target level of the soil erosion control goal, he suggests that the soil loss tolerance value, or T-value, is the best possible indicator which can be used as a target level of the soil loss control. Soil loss tolerance is a useful concept in the relationship between erosion and productivity. The degree to which a unit quantity of soil loss reduces yield is dependent on a range of soil characteristics, which may be summarised as "soil loss tolerance". Soils with a concentrated distribution of nutrients in the topsoil, and shallow rooting depths, are usually sensitive in yield

Table 6.9: Soil Erosion Rate (t/ha/yr) for Fort St. John.

Section	Crop	Pasture	Unproductive	Woodland	Fallow
I 2	6.17	1.03	0.62	0.41	20.56
3	5.00	0.80	0.50	0.30	16.80
10	2.65	0.52	0.27	0.17	8.75
11	5.60	0.90	0.60	0.40	17.61
14	5.20	0.90	0.50	0.30	17.17
15	7.50	1.30	0.80	0.50	24.90
II 26	8.80	1.50	0.90	0.60	29.20
27	10.30	1.70	1.00	0.70	34.20
28	16.10	2.60	1.60	1.10	53.60
29	5.20	0.90	0.50	0.30	17.17
32	4.40	0.70	0.40	0.30	14.60
33	4.70	0.80	0.50	0.30	15.60
34	5.80	1.00	0.60	0.40	19.30
35	8.70	1.50	0.90	0.60	29.20
2	8.60	1.40	0.90	0.60	28.64
3	6.60	1.10	0.70	0.40	21.90
4	4.60	0.80	0.50	0.30	15.30
5	7.60	1.30	0.80	0.50	25.30
8	7.50	1.26	0.80	0.50	24.90
9	10.90	1.80	1.10	0.70	36.29
10	11.70	2.00	1.20	0.80	38.90
11	14.10	2.40	1.40	0.90	46.90
III 26	15.30	2.50	1.50	1.00	50.90
27	20.00	3.30	2.00	1.30	66.60
28	22.39	3.73	2.24	1.49	74.50
33	22.39	3.73	2.24	1.49	74.50
34	22.39	3.73	2.24	1.49	74.50
35	18.30	3.00	1.80	1.20	60.90
2	17.40	2.90	1.70	1.20	57.90
3	15.90	2.70	1.60	1.10	52.90
4	16.20	2.70	1.60	1.10	53.90
IV 4	17.40	2.90	1.70	1.20	58.09
5	11.10	1.80	1.10	0.70	36.92
6	13.80	2.30	1.40	0.90	46.00
1	8.90	1.50	0.90	0.60	29.75
12	18.10	3.00	1.80	1.20	60.29
7	19.20	3.20	1.90	1.30	63.97
8	19.20	3.20	1.90	1.30	63.97
9	23.00	3.80	2.30	1.50	76.77
16	28.10	4.70	2.80	1.90	93.13
17	19.20	3.20	1.90	1.30	63.97
18	19.20	3.20	1.90	1.30	63.97
13	17.90	3.00	1.80	1.20	59.70
24	17.30	2.90	1.70	1.20	57.67
19	11.60	1.90	1.20	0.80	38.76
20	17.30	2.90	1.70	1.20	57.57
21	26.90	4.30	2.70	1.80	89.56
28	30.60	5.10	3.10	2.00	102.14
29	11.10	1.90	1.10	0.70	37.10
30	6.90	1.20	0.70	0.50	23.00
25	15.40	2.60	1.50	1.00	51.37
36	15.40	2.60	1.50	1.00	51.37
31	19.20	3.20	1.90	1.30	63.97
32	10.50	1.70	1.00	0.70	34.86
33	29.20	4.90	2.90	1.90	94.25

loss to soil erosion, and thus will have a low T-value. This denotes a soil with low tolerance to erosion. Soil with good structure, and deeply weathered with good nutrient reserves, will be less sensitive to erosion, and thus have a higher T-value (FAO, 1984). The T-value expresses a "tolerable" soil loss limit in order to retain productivity of the soil affected by erosion. No single tolerance value is applicable to all soil types. What an acceptable T-value would be for each type of soil is a difficult question. Most conservationists agree that in order to maintain the long term land productive capacity, the thickness or a sufficiently favorable rooting depth of the topsoil must be protected along with appropriate biophysical conditions for plant growth. They judge that 5 t/acre/year (11.2 t/ha/yr) is the maximum rate of soil loss for which soil productivity can be maintained (Sampson, 1981; ASA, 1982). This T-value is also considered reasonable for the Peace River Region of B.C. by Van Vliet (1988).

Objective Function

The objective function or the achievement function of the agricultural submodel is a vector. Each component of this vector represents the deviational variables (positive or negative) that must be minimized in order to achieve the goals as close to the established target levels as possible. The objective function reflecting a lexicographic minimization problem has the following form:

Minimize: $Z = [P1(d^-_6), P2(d^-_1+d^-_2+d^-_3 +d^-_4+d^-_5), P3(d^+_7)]$ (6.10)

Where:

P1, P2, and P3 mean priority 1, priority 2, and priority 3

respectively;

d^-_j and d^+_j are negative and positive deviational variables defined in preceding equations.

The GP algorithm seeks to find the lexicographic minimum of Z. This process implies the ordered minimization of the components in equation 6.10. In other words, it is necessary to find first, the smallest value of the first component in the objective function, d^-_6. Then the smallest value, compatible with the first value, of the second component, $(d^-_1 + d^-_2 + d^-_3 + d^-_4 + d^-_5)$, will be found, and so on. The first priority, P1, is made up of net return goal. The next priority in the lexicographic process, P2, is made up of production goal. Priority 3, P3, is referring to the minimization of soil erosion. There are several algorithmic approaches available to solve LGP models (Bartlett, Bottoms and Pope, 1976; Romero and Rehman, 1984; Love, 1986). The algorithmic technique adopted by this study is described later.

6.3.2.2 Forestry Submodel

The basic structure of the forestry submodel developed for this study is very similar to that of the agricultural submodel, and is illustrated in Table 6.10. The activities represented by decision variables x_{i7}, x_{i8}, and x_{i9} in this submodel are timber harvesting production of spruce, pine, and aspen trees respectively. The activity levels of x_{ij} (j=7,8,9) represent the land resources allocated to timber production in each of the land unit i. Concerns of wildlife

162

Table 6.10: Simplified Version of the Forestry Submodel.

Item	Decision Variables			Deviational Variables						Target Levels or RHS Values
	S	PL	D	Timber Less	Timber Over	NR Less	NR Over	Soil Less	Soil Over	
	x_7	x_8	x_9	d^-_7	d^+_7	d^-_8	d^+_8	d^-_9	d^+_9	
Objective				P2	P2	P1			P3	
Land Constraint	1	1	1							$< A2$ (ha)
Forest Cover	1	1	1							$> .21*A$ (ha)
Production	y_7	y_8	y_9	1	-1					$= b7$ (t)
Net Return	R_7	R_8	R_9			1	-1			$= b8$ ($)
Soil Loss	E_7	E_8	E_9					1	-1	$= b3$ (t)

Note:

S: spruce tree

PL: lodgepole pine

D: deciduous tree

A2: forestry land availability

b: target level

NR: net return

Soil: soil erosion

Less: underachievement

Over: overachievement

163

habitat and recreation value protection are represented indirectly in this submodel by forest cover constraints.

Land Resource Constraints

The land resource constraints in this submodel are similar to those in agricultural submodel, and can be expressed as:

$$\sum_j x_{ij} \leq A2_i \quad (j=7,8,9) \qquad (6.11)$$

Where:

x_{ij} is the area of land allocated to timber production j in land unit i (ha);

$A2_i$ is the total amount of land available for timber production in land unit i.

Forest Cover Constraints

Unlike the agricultural submodel which has only one type of constraint, the forestry submodel consists of a second type of constraint, the forest cover constraint. This constraint is set to ensure that a minimum forest cover will be maintained to provide thermal cover for wildlife, to regulate watershed runoff, and to preserve recreation sites. Based on the Ft. St. John forestry plan of the B.C. Ministry of Forests (1987), at least 21% of the total area of each land unit in the study region will retain forest cover. There is one forest cover constraint for each unit, of the form:

$$\sum_j x_{ij} \geq .21A_i \qquad (6.12)$$

Where:

x_{ij} is defined as in equation 6.11;

A_i is the area of land for land unit i.

Economic Return Goal

This goal refers to the wish to achieve target level of net economic return in forestry land uses. It is desirable to overachieve net economic return target, so as to meet the desired economic return target. The underachievement variable needs to be as close to zero as possible. When the underachievement variable is zero, the net economic return goal is met. A formula of the following type is formulated for the economic return goal.

$$\sum_i \sum_j R_{ij} * x_{ij} - d^+_{11} + d^-_{11} = b_{11} \quad (j=7,8,9) \quad (6.13)$$

Where:

R_{ij} is the net economic return to forestry land use j in land unit i;

x_{ij} is defined as in equation 6.11;

d^+_{11}, d^-_{11} are the overachievement and underachievement respectively from target level of the net economic goal;

b_{11} is the target level of net economic return goal in forestry land use.

The underachievement or negative deviational variable, d^-_{11}, is to be minimized in the objective function. The net economic return coefficient in equation 6.13, R_{ij}, is obtained by multiplying the average stumpage price for Prince George timber supply area (TSA) with yield of a tree species.

165

McConnell and others (1983) identify that stumpage prices exhibited substantial short-term fluctuations and systematic long-term trends. Theoretically, the stumpage system of B.C. is designed to estimate the net social benefits of forest activity. Stumpage price represents the resource rent to society accruing from forest land use (BCMOLP&H, 1982). Annual stumpage prices for different tree species and for different forest regions are published by the Ministry of Forests of B.C. (BCMOF, 1979-89). The average stampage prices of 1979-89 were used to calculate the net economic return coefficients.

The yield data for different tree species were obtained from B.C. forestry inventory (BCMOF, 1985a). Yield data used in this analysis were lower than the maximum sustainable yields (MSY) estimated by BCMOF (1986). Thus in long-run the rate of forest harvest would not exceed the rate of replacement in a given area. The exact rates of MSY are very difficult to project because of the variation of natural and economic conditions.

Since this study is not intended to measure economic impact of price variation, keeping the timber prices constant can simplify this analysis. The net economic return coefficients for forestry land uses are listed in Table 6.5. The target level of this economic return goal is established under the consideration of annual allowable cut (AAC) for the study region and estimated stumpage prices for that region.

Timber Production Goal

Timber production has important competitive and complementary relationship with other forestry products and is fully quantified in this region. This goal can be used as a criterion to evaluate timber production potential of the region to meet future demand. During a given time period, in this case, one year, the volume of logs harvested from the forest in the study region is desired to meet the target level of the production goal. This goal is also useful as a measure to sustain forestry production. Each year, the volume of logs harvested in the region cannot exceed the AAC. Thus, both positive and negative deviational variables exist in the objective function. If both the overachievement and underachievement are minimized to zero, the solution would exactly meet the target level of the production goal. The timber production goal is expressed by:

$$\sum_i Y_{ij} * x_{ij} - d^+_{(j+1)} + d^-_{(j+1)} = b_{(j+1)} \quad (j=7,8,9) \quad (6.14)$$

Where:

Y_{ij} is the yield of timber production for species j in land unit i (m^3/ha);

x_{ij} is defined as in equation 6.11;

$d^-_{(j+1)}$, and $d^+_{(j+1)}$ are the underachievement and overachievement of timber production for species j respectively;

$b_{(j+1)}$ is the target level of timber production goal for species j (m^3).

Yields for tree species are only available for different site classes in each forest region. Site classes are grouped in accordance

167

with site indices which are based on tree height as a function of stand age and usually expressed graphically as site index curves (BCMOF, 1981b). Data on yield projections are compiled in yield tables based on growth type group, age group, and site class for a given forest region (BCMOF, 1985a). The B.C. Forest Inventory has detailed forest cover polygon information for the Peace River Region. This information is available in digital format in a computer data base (BCMOF, 1980b).

In order to identify yield for each tree species in each land unit of the study region, several steps were involved. First, the average yield of each tree species was calculated for each site class in the Peace River Region based on yield tables in the Ministry of Forests' report (1985a). According to the priority cutting ages (years) by species established by B.C. Ministry of Forests, all timber harvested will be older than the following cutting ages unless insects or disease are present, growth has stagnated, or the timber has been damaged by fires: spruce, 121 year; pine, 101 year; and deciduous, 61 year (BCMOF, 1987). Thus, average yield is based on yields of those mature age groups. Second, land use data which consist of area of forest land and age of forests for each site class in each map polygon are retrieved from forest cover computer data base. Third, by superimposing the forest cover map onto base map of this study, the proportion of the area of forest cover map polygon which is located in each of the land units in the study region is determined. Then the area of forest land for each site class in each land unit can be identified. The yield of a tree species for a given land unit is calculated by the following

equation:

$$Y_{ij} = \sum_f P_{if} * Y_{fj} \qquad (6.15)$$

Where:

Y_{ij} is defined as in equation 6.14;

f is the subscript denoting a site class of forest land;

P_{if} is the proportion of forestry land for site class f in land unit i;

Y_{fj} is the yield of tree species j with site class f.

Yields for spruce, pine, and deciduous for each land unit in the study region are calculated and are compiled in Table 6.11.

Soil Erosion Control for Forest

Generally speaking, soil loss from forestry land is less than that from cropland. The canopy protection of forest cover reduces the severity of water erosion. The values of the C factor in USLE were changed to reflect forest cover conditions (Table 6.9). Methods to estimate soil loss rate have been presented in the previous section. The soil erosion control goal for the submodel is similar to that for the agricultural submodel:

$$\sum_i \sum_j E_{ij} * x_{ij} - d^+_{12} + d^-_{12} = b_{12} \quad (j=7,8,9) \quad (6.16)$$

Where:

E_{ij} is soil erosion rate for tree species j in land unit i (t/ha/yr);

x_{ij} is defined as in equation 6.11;

d^-_{12}, d^+_{12} are the underachievement and overachievement respectively of the soil loss control target;

169

Table 6.11: Average Yield For Timber Production.

Township	Range	Section	Spruce (m³/ha)	PL (m³/ha)	Aspen (m³/ha)
TP85	R18	2	2.15	2.12	1.85
		3	1.31	1.11	.72
		10	1.31	1.11	.72
		11	1.31	1.11	.72
		14	1.31	1.11	.72
		15	1.31	1.11	.72
TP84	R17	26	1.31	1.11	.72
		27	1.43	1.26	.86
		28	1.43	1.26	.86
		29	1.31	1.11	.72
		32	1.31	1.11	.72
		33	1.43	1.26	.86
		34	1.56	1.41	1.04
		35	1.31	1.11	.72
TP85	R17	2	2.03	1.98	1.68
		3	1.43	1.26	.86
		4	1.98	1.83	1.51
		5	1.31	1.11	.72
		8	1.48	1.33	.94
		9	1.78	1.68	1.36
		10	1.65	1.53	1.19
		11	1.78	1.68	1.36
		26	1.73	1.61	1.28
		27	2.25	2.25	2.00
		28	2.20	2.17	1.93
		33	2.25	2.25	2.00
		34	2.37	2.40	2.17
		35	1.90	1.83	1.51
TP86	R17	2	2.20	2.17	1.93
		3	2.25	2.25	2.00
		4	2.20	2.17	1.93
TP85	R16	4	1.31	1.11	.72
		5	1.31	1.11	.72
		6	1.31	1.11	.72
TP85	R17	1	1.31	1.11	.72
		12	1.31	1.11	.72
TP85	R16	7	1.31	1.11	.72
		8	1.31	1.11	.72
		9	1.31	1.11	.72
		16	1.31	1.11	.72
		17	1.31	1.11	.72
		18	1.31	1.11	.72
TP85	R17	13	1.31	1.11	.72
		24	1.31	1.11	.72
TP85	R16	19	1.31	1.11	.72
		20	1.31	1.11	.72
		21	1.31	1.11	.72
		28	1.31	1.11	.72
		29	1.31	1.11	.72
		30	1.31	1.11	.72
TP85	R17	25	1.48	1.33	.94
		36	1.56	1.41	1.04
TP85	R16	31	1.31	1.11	.72
		32	1.31	1.11	.72
		33	1.31	1.11	.72

b_{12} is the T-value of soil loss (t/yr).

Objective Function

The objective function of this submodel is the minimization of the nonachievement or deviational variables of all goals in order of the assigned importance ranking. The total objective function of the forestry submodel can be shown by the following formula:

Minimize: $Z = [\ P1(d^-_{11}), \ P2(d^-_8 \ + \ d^+_8 \ + \ d^-_9 \ + \ d^+_9 \ + \ d^-_{10} \ + \ d^+_{10}), \ P3(d^+_{12})]$ (6.17)

Each P in the objective functions is evaluated in order of assigned priority. Thus, P1, P2, and P3 simply mean priority 1, priority 2, and priority 3 respectively.

With this objective function, the GP algorithm will find a final solution which meets the land resource constraints and other constraints, and minimizes the nonachievement of the above three goals. The resulting minimized quantity is shown in Z.

6.3.2.3 Wetland Submodel

Within the study region, there are 27 land units which do not consist of identified wetlands. These 27 land units are excluded from the wetland submodel. For each land unit, specific management alternatives are determined. Habitat values and other values of wetland for the region must then be defined and incorporated into the GP formulation.

171

Generally, the major emphasis in wetland assessment has been on waterfowl because of the great interest in hunting and because waterfowl populations and migratory birds are critically affected by wetland losses (Schamberger, Short and Farmer, 1979). Complete inventory data on waterfowl population are not available, but data from limited surveys of nesting duck populations and migration birds by Ducks Unlimited provide valuable information for wetland evaluation. One of the most important uses of wetland resources is to provide habitats for nesting duck and migrating duck populations.

Waterfowl hunting is also an important wetland use in the Peace River Region. Hunting activities take place in the Peace Lowland area. The number of ducks killed and the number of duck hunters remained relatively constant from 1976 to 1980, but showed a decline from 1981 to 1986 (BCMOE, 1988).

Bird watching is favored increasingly as another activity of wetland use. Yet, no recorded data have been available for bird watching in this region. Thus, it is difficult to incorporate this activity into the wetland submodel. Due to the lack of data, other activities associated with wetland uses are also excluded from this submodel. However, the wetland submodel developed in this study can be improved when more refined and accurate information becomes available.

Since land use activities are not mutually exclusive, migrating bird populations and hunting activity could occur on the same wetland at the same time. The number of decision variables in this submodel is

much less than those in the two previous submodels. In the wetland submodel, different management alternatives are defined on the basis of wetland management intensity. For the purposes of this demonstrative case study, and lack of wetland information, only two management alternatives or decision variables are specified for each land unit. The first decision variable represents the status quo condition of the wetland resources. It assumes that the quality of the wetland will not change. The second decision variable takes consideration of habitat enhancement projects for wetland resources. The quality of the wetland resources will be upgraded with the enhancement project. More management options, such as disturbed wetland and wetland reserve, can be easily incorporated into the submodel when data become avaiable.

Wetland Resource Constraints

The wetland resource constraint represents total wetland availability for each land unit. There are altogether 28 wetland resource constraints in this submodel, each for one land unit in the study region. The wetland resource restrictions are represented by inequalities 6.18 in the submodel.

$$\sum_j x_{ij} \leq A3_i \quad (j=10,11) \qquad (6.18)$$

Where:

x_{ij} is the area of wetland with status quo condition (j=10) or with habitat enhancement project (j=11) in land unit i;

$A3_i$ is the total amount of wetland available for land unit i.

It is assumed that all classes 1 to 3 waterfowl capability wetlands do not need habitat enhancement because the biophysical

173

conditions of these wetlands are matched closely by the requirements for waterfowl habitat. Only class 4 waterfowl capability wetland might be upgraded by habitat enhancement projects. Data on wetland resource availability were drawn from files of Ducks Unlimited in Prince George, and were then compiled in Table 6.12.

Habitat Value Goal

Wetlands are valuable habitat for a wide range of waterfowl. The Canada Land Inventory (CLI) Land capability for waterfowl is based on the inherent capability of a wetland type to produce a sustained yield of waterfowl and divides wetlands into descending classes based on physical and ecological criteria (Peret, 1975). Ducks Unlimited in Prince George, B.C. has applied a simple method to estimate nesting duck and migrating duck populations for wetlands with different capability classes (Clark, 1988).

The abundance or number of waterfowl species has been commonly used as an index to reflect the "value" of wildlife habitat (Schamberger et al., 1979; Cable et al., 1989). It is assumed in this study that habitat value, habitat quantity and quality of wetland are directly related to numbers of ducks observed. The number of nesting and migrating ducks is used as a surrogate of the habitat value of wetland. The purpose of this goal is to protect waterfowl habitat. In this case study, this goal is achieved through maintaining or increasing the number of duck populations in the region, which is consistent with the objective of the regional wildlife plan. The habitat value goal in this submodel takes the form:

174

Table 6.12: Wetland Data For Sub-Areas In Fort St. John Region.

Township	Range	Section	CLI Class (Waterfowl)	1970s Wetland Area(ha)	1970s Migration Bird/yr	1970s Duck Hunters	1970s Hunting Value	1980s Wetland Area(ha)	1980s Migration Bird/yr	1980s Duck Hunters	1980s Hunting Value
TR85	R18	2	2	19.4	222	19	393.3	0	0	0	0
		3	2	28.4	258	28	579.6	26.3	240	35	724.5
		10	2	20.3	150	20	414.0	0	38	0	0
		11	2	21.5	168	21	434.7	20.3	138	27	558.9
		14	2	8.9	90	9	186.3	7.3	72	10	207.0
		15	2	10.1	96	10	207.0	0	0	0	0
TR84	R17	26	2	72.1	680	9	186.3	72.1	680	9	186.3
		27	7	0	0	0	0	0	0	0	0
		28	7	0	0	0	0	0	0	0	0
		29	7	0	0	0	0	0	0	0	0
		32	7	0	0	0	0	0	0	0	0
		33	2	17.0	164	2	41.4	17.0	164	2	41.4
		34	2	193.2	1820	23	476.1	193.2	1820	23	476.1
		35	2	83.4	789	10	207.0	83.4	789	10	207.0
TR85	R17	2	2	25.9	240	0	0	25.9	240	0	0
		3	2	164.4	1550	20	414.0	164.4	1550	20	414.0
		4	2	144.2	1360	17	351.9	144.2	1360	17	351.9
		5	2,7	0	0	0	0	0	0	0	0
		8	7	0	0	0	0	0	0	0	0
		9	2,7	0	0	0	0	0	0	0	0
		10	2	14.2	137	2	41.4	14.2	137	2	41.4
		11	2,7	0	0	0	0	0	0	0	0
		26	4	64.8	160	0	0	64.8	160	0	0
		27	7	0	0	0	0	0	0	0	0
		28	7	0	0	0	0	0	0	0	0
		33	7	0	0	0	0	0	0	0	0
		34	7	0	0	0	0	0	0	0	0
		35	4	25.9	60	0	0	25.9	60	0	0
TR86	R17	2	7	0	0	0	0	0	0	0	0
		3	7	0	0	0	0	0	0	0	0
		4	7	0	0	0	0	0	0	0	0
TR85	R16	4	4	12.8	64	0	0	12.8	64	0	0
		5	4	25.4	80	0	0	25.4	80	0	0
		6	7	0	0	0	0	0	0	0	0
TR85	R17	1	7	0	0	0	0	0	0	0	0
		12	7	0	0	0	0	0	0	0	0
TR85	R16	7	7	0	0	0	0	0	0	0	0
		8	7	0	0	0	0	0	0	0	0
		9	7	0	0	0	0	0	0	0	0
		16	7	0	0	0	0	0	0	0	0
		17	4	97.0	243	0	0	97.0	243	0	0
		18	4	51.8	120	0	0	51.8	120	0	0
TR85	R17	13	4	24.3	60	0	0	24.3	60	0	0
		24	4	24.3	60	0	0	24.3	60	0	0
TR85	R16	19	4	34.5	172	0	0	34.5	172	0	0
		20	4	67.5	215	0	0	67.5	215	0	0
		21	7	0	0	0	0	0	0	0	0
		28	7	0	0	0	0	0	0	0	0
		29	4	25.9	60	0	0	25.9	60	0	0
		30	4	97.0	240	0	0	97.0	240	0	0
TR85	R17	25	4	48.5	120	0	0	48.5	120	0	0
		36	4	48.5	120	0	0	48.5	120	0	0
TR85	R16	31	7	0	0	0	0	0	0	0	0
		32	4	2.5	19	0	0	2.5	19	0	0
		33	7	0	0	0	0	0	0	0	0

$$\sum_i \sum_j V_{ij} * x_{ij} + d^-_{12} - d^+_{12} = b_{12} \quad (j=10,11) \quad (6.19)$$

Where:

V_{ij} is the habitat value of wetland in unit i;

x_{ij} is defined as in equation 6.18;

d^-_{12} and d^+_{12} are underachievement and overachievement of the habitat value goal respectively;

b_{12} is the target level of habitat value goal.

The overachievement or the positive deviation from the goal target is desirable in this case. Only the underachievement or the negative deviational variable, d^-_{12}, is included in the submodel and is to be minimized in the objective function. Data on the duck population for wetland of the 28 land units in the study region are collected from Ducks Unlimited at Prince George and are presented in Table 6.12. The target level of the duck population is set at the current number of nesting and migrating duck populations.

Duck Hunting Goal

Duck hunting activities are mainly undertaken by local residents. Nonresident hunting of waterfowl is almost nonexistent in the Ft. St. John region (BCMOE, 1988). Residents' utilization of the wetland resources, in terms of economic values of waterfowl hunting, is used as another goal for wetland use assessment. The duck hunting goal is expressed by:

$$\sum_i \sum_j R_{ij} * x_{ij} + d^-_{13} - d^+_{13} = b_{13} \quad (j=10,11) \quad (6.20)$$

Where:

R_{ij} is the average economic value of waterfowl hunting on wetland j in land unit i ($/ha);

x_{ij} is defined as in inequalities 6.18;

d^-_{13} and d^+_{13} are the underachievement and overachievement respectively from target level of the hunting goal;

b_{13} is the target level of the hunting goal ($).

The underachievement or negative deviation of the hunting goal, d^-_{13}, is to be minimized in the objective function of the submodel. The average net economic value of resident hunting, R_{ij}, is provided by the Regional Fish and Wildlife Branch of the Ministry of Environment and Parks in Ft. St. John. R_{ij} wetland values with or without habitat enhancement projects in each land unit are tabulated in Table 6.13. It should be noted that this goal is mainly concerned with the economic value derived from resident hunting of waterfowl on wetlands, rather than considering the total economic value of wetland resources. The costs of implementing habitat enhancement projects and of crop damage by waterfowl are not incorporated in the submodel which does not have an economic return goal. However, these costs are included into the integrated model expressed later. Since soil erosion is not a problem in wetland resource uses, this submodel does not have a soil loss control goal.

Table 6.13: Net Return for Land Use on Wetland ($).

	Section	R_{i10}	R_{i11}
I	2	-65.30	-65.30
	3	-47.55	-47.55
	10	-34.87	-34.87
	11	-38.25	-38.25
	14	-54.73	-54.73
	15	-50.60	-50.60
II	26	-68.05	-68.05
	27	0.00	0.00
	28	0.00	0.00
	29	0.00	0.00
	32	0.00	0.00
	33	-69.66	-69.66
	34	-67.96	-67.96
	35	-68.26	-68.26
	2	-67.57	-67.57
	3	-68.02	-68.02
	4	-68.04	-68.04
	5	0.00	0.00
	8	0.00	0.00
	9	0.00	0.00
	10	-9.04	-9.04
	11	0.00	0.00
III	26	0.00	0.00
	27	0.00	0.00
	28	0.00	0.00
	33	0.00	0.00
	34	0.00	0.00
	35	-67.57	-161.07
	2	0.00	0.00
	3	0.00	0.00
	4	0.00	0.00
IV	4	0.00	0.00
	5	0.00	0.00
	6	0.00	0.00
	1	0.00	0.00
	12	0.00	0.00
	7	0.00	0.00
	8	0.00	0.00
	9	0.00	0.00
	16	0.00	0.00
	17	-28.87	-121.78
	18	-5.19	-98.69
	13	0.00	0.00
	24	0.00	0.00
	19	0.00	0.00
	20	0.00	0.00
	21	0.00	0.00
	28	0.00	0.00
	29	0.00	0.00
	30	0.00	0.00
	25	0.00	0.00
	36	0.00	0.00
	31	0.00	0.00
	32	0.00	0.00
	33	0.00	0.00

Objective Function for Wetland SubModel

The objective function of this submodel is expressed by the following formula:

Minimize: $Z = [P1(d^-_{12}), \ P2(d^-_{13})]$ (6.21)

In equation 6.21, P1 denotes the first priority and P2 denotes the second priority. The habitat value is considered more important than the hunting goal by the officers in B.C. Ministry of Environment. The GP program will seek to find the lexicographic minimum of Z. That is, it is to find first, the smallest value of d^-_{12}, the negative deviation from habitat value goal, then the smallest value of d^-_{13}, the underachievement of resident hunting goal.

6.3.2.4 Integrated Model

The three submodels developed in previous section have so far been limited to the resolution of internal goal conflicts within each resource sector or subsystem of the regional land use system. The analytical framework is built in the absence of any integration among different resource sectors of the land use system. It is now time to consider the multisector dimension of the integrated land assessment system.

An important characteristic of regional resource assessment or evaluation is that the decision makers in different resource sectors or officials in different government agencies possess different objectives and priorities with respect to resource use, and have only a limited

179

range of decision variables under their direct control. Relationships or conflicts among land use sectors are not represented in the submodels. At the regional level, intersectoral relationships and hierarchical relationships (between region and sector) need to be incorporated in the model by a clear articulation and reconciliation of objective functions and decision variables in the model. This integrated model reflects interactions among regional and sectoral agencies. In the integrated resource assessment, each resource use sector must also consider the conflicting interests of other sectors.

Coordination among the three submodels discussed previously is achieved by an integrated model. The basic structure of the integrated model is similar to the one used for the submodels, but contains more variables, constraints and goals. In particular, the integrated model is flexible enough to encompass multidimensional considerations such as multiple goals, conflicting land uses among multiple users, and the land resource transfer between different resource sectors. These considerations can be represented in the model.

The transfer or flow of land resources from one sector to another is an important feature of the integrated assessment model. The intersectoral flow of land resources provides a linkage for the coordination and integration of land use assessments conducted by each of the resource sectors. The distinction between the integrated model and the submodels is that land resources are transferable between sectors in the former, while in the latter land resources are not transferable between sectors.

Land units of this integrated model are the same as those of the submodels. Land-based activities for each sector are also included in this model. Joint constraints which reflect the current rates of land conversion from forest and wetland to agricultural uses are created in the integrated model to coordinate three individual submodels. Furthermore, the objective function of the integrated model is different from those of submodels. This reflects the different concerns of decision makers at different levels. Regional production levels for agriculture and forestry, economic return to land use, soil erosion control and wetland protection are major goals of the assessment system, which reflect the diverse objectives and aspirations which exist among the regional government agencies and various resource sectors.

Land Resource Constraints

These constraints reflect the fact that the land resources available for various uses in each land unit are limited. The total land used by different resource sectors cannot exceed the land availability in each land unit. In order to have the land resource assessment undertaken in a realistic context, it is important to identify conditions of the current land base in the Peace River Region. In the integrated model, land availability in each land unit is separated into three groups based on land suitability and current use. These three land groups are: improved land, woodland, and wetland. It is assumed that improved land resources are currently used for cropping activities and summer fallow, which represents current land use

patterns in the Peace River Region. Woodlands are currently used for forest production, and wetlands are for habitat use and hunting activity. Given the finite nature of the land resource base, conversion of woodland and wetland to the agricultural sector results in losses of opportunities for alternative uses such as timber production, waterfowl habitat, and hunting activity.

To reflect the concern of land resource conversion in the study region, three decision variables, x'_{i2}, x'_{i5}, and x''_{i5}, are incorporated in the integrated model for each land unit. The first two decision variables represent respectively land areas converted from woodland to barley and hay production in land unit i annually. The third decision variable represents land area converted each year from wetland to hay production in land unit i. This is consistent with the land conversion situation in the Peace River Region where most of the lands currently converted from woodlands are used for barley and hay production; and most of the lands drained from wetlands are used for hay production. The mathematical formulation of the land resource constraints are as the follows:

$$\sum_{j} x_{ij} - x'_{i2} - x'_{i5} - x''_{i5} \leq A1_i \quad (j=1,2,\ldots,6) \quad (6.22)$$

$$\sum_{j} x_{ij} + x'_{i2} + x'_{i5} \leq A2_i \quad (j=7,8,9) \quad (6.23)$$

$$\sum_{j} x_{ij} + x''_{i5} \leq A3_i \quad (j=10,11) \quad (6.24)$$

Where:

x_{ij} is the area of land allocated for activity j in land unit i;

$A1_i$, $A2_i$ and $A3_i$ are defined as in inequalities 6.1, 6.11, and 6.18 respectively.

182

Inequalities 6.22 represent the fact that land resources used for agricultural purposes cannot exceed existing improved lands plus lands converted from woodlands and wetlands. Inequalities 6.23 express the fact that lands used for timber production cannot exceed the available woodland resources minus woodlands converted to agricultural sector. Similarly, inequalities 6.24 indicate that lands preserved for waterfowl habitat and hunting activity cannot exceed the existing wetland availability minus wetlands drained for hay production.

Regional Production Goal Constraints

The provision of adequate and secure agricultural products and timber on a continual basis is a major objective of regional resource development. As mentioned previously, the land use activities for regional sectors have been adjusted to reflect land conversion from forestry and wetland sectors to the agricultural sector. The outputs of these land use activities are included in the regional production for agricultural products. The forms of the regional production goal constraints are as follows:

Crop production:

$$\sum_i y_{ij} * x_{ij} + d^-_j - d^+_j = b_j \quad (j=1,3,4) \quad (6.25)$$

$$\sum_i y_{i2} * (x_{i2} + x'_{i2}) + d^-_2 - d^+_2 = b_2 \quad (6.25)'$$

$$\sum_i y_{i5} * (x_{i5} + x'_{i5} + x''_{i5}) + d^-_5 - d^+_5 = b_5 \quad (6.25)''$$

Where:

x_{ij} is defined as in equation 6.1;

y_{ij}, d^-_j, d^+_j, and b_j are defined as in equation 6.4;

x'_{i2}, x'_{i5}, and x''_{i5} are defined in previous section.

183

Timber production:

$$\sum_i y_{ij} * x_{ij} - d^+_j + d^-_j = b_j \quad (j=7,8,9) \quad (6.26)$$

The timber production goal constraint is the same as that in the forestry submodel. But, in the integrated model, target levels or priorities of goals are based on the objectives and aspirations of regional decision makers who are acting as coordinators among different resource sectors.

Economic Return Goal Constraints

One major concern of the regional decision makers is how to allocate a given land base among conflicting land uses to achieve economic efficiency. The net economic returns to land resources are used as a measure of economic efficiency of land resource allocation. The net economic return goal is incorporated into the integrated model by means of a joint goal constraint of the form:

$$\sum_i \sum_j R_{ij} * x_{ij} + \sum_i R'_{i2} * x'_{i2} + \sum_i R'_{i5} * x'_{i5} + \sum_i R''_{i5} *$$
$$x''_{i5} + d^-_{10} - d^+_{10} = b_{10} \quad (j=1,2,\ldots,11) \quad (6.27)$$

Where:

R_{ij} is defined as in equations 6.3, 6.13, and 6.20;

R'_{i2} is net return from converted land (from woodland to cropland) for barley production in land unit i;

R'_{i5} is net return from converted land (from woodland) for hay production in land unit i;

R''_{i5} is net return from converted land (from wetland) for hay production in land unit i;

184

x_{ij} are defined as in inequalities 6.1, 6.11, and 6.18;

x'_{i2}, x'_{i5}, and x''_{i5} are defined in previous section;

d^-_{10}, d^+_{10} are the underachievement and overachievement of regional net economic return goal respectively;

b_{10} is the target level of regional net economic return goal with relation to land resource uses.

In this integrated model, the net economic return derived from wetland use is determined by three factors: economic value from resident hunting of waterfowl, cost of habitat enhancement project, and cost of crop damage by waterfowl. The net economic return coefficients for wetland use activities, R_{i10} and R_{i11}, are simply the results of the economic value of resident hunting less costs of the enhancement project and crop damage by waterfowl.

The net economic returns of converted lands, R'_{i2}, R'_{i5}, and R''_{i5}, are different from those of continuous land uses because the costs of land resource conversion have to be included into the net economic return calculation for converted lands. It is assumed that costs of land conversion from woodland to cropland comprise land clearing and breaking costs, while costs of land conversion from wetland to cropland only include drainage costs. The annual costs of land conversion are calculated by multiplying land conversion costs ($/ha) by the interest rate on land investment. The land clearing, breaking, and drainage costs are provided by the B.C. Ministry of Agriculture and Food (1981), and the 11% interest rate on land investment is applied in Collins and Hadland's study (1988). The net

economic return coefficients, R'_{i2}, R'_{i5}, and R''_{i5}, are listed in Table 6.14. The regional economic return target level is simply the sum of net economic returns of the three submodels.

Erosion Control Goal Constraints

Another goal constraint is formulated to reflect concern over the control of soil loss by water erosion. This goal constraint is to minimize the soil loss to as near the T-value as possible. In the integrated model, the overachievement of soil erosion target level is minimized. The erosion control goal constraint can be expressed as shown in the following formula:

$$\sum_i \sum_j E_{ij} * x_{ij} + \sum_i E_{i2} * x'_{i2} + \sum_i E_{i5} * (x'_{i5} + x''_{i5}) - d^+_{11} + d^-_{11} = b_{11} \quad (j=1,2,\ldots,11) \quad (6.28)$$

Where:

E_{ij} is defined as in equations 6.6 and 6.17;

x_{ij} is defined as in inequalities 6.1, 6.11, and 6.18;

x'_{i2}, x'_{i5}, and x''_{i5} are defined as in inequalities 6.22;

d^+_{11} and d^-_{11} are the overachievement and underachievement of soil erosion control target respectively;

b_{11} is the T-value of regional soil loss (t/yr).

Forest Cover Goal Constraint

The B.C. Ministry of Forest Act requires the forest sector to implement an integrated resource management program which aims to protect, conserve, and develop the forests' nontimber production resources and integrate activities for these resources with the activities for timber production. In accordance with this Act, the

Table 6.14: Net Economic Return For Land Use On Converted Land ($).

Section		Converted Land		
		R'_{i2}	R'_{i5}	R''_{i5}
I	2	-0.26	49.04	50.38
	3	-6.91	20.39	21.73
	10	56.15	135.98	137.32
	11	-6.91	20.39	21.73
	14	-6.91	20.39	21.73
	15	22.96	74.73	76.07
II	26	26.29	83.62	84.96
	27	6.36	48.05	49.39
	28	6.36	48.05	49.39
	29	6.36	48.05	49.39
	32	26.29	83.62	84.96
	33	26.29	83.62	84.96
	34	26.29	83.62	84.96
	35	26.29	83.62	84.96
	2	26.29	83.62	84.96
	3	26.29	83.62	84.96
	4	26.29	83.62	84.96
	5	16.31	60.90	62.24
	8	-10.24	10.51	11.85
	9	-0.26	29.27	30.62
	10	9.69	47.06	48.40
	11	9.69	47.06	48.40
III	26	-69.96	-27.04	-25.70
	27	-30.15	7.54	8.88
	28	-126.40	-46.80	-45.46
	33	-6.91	20.39	21.73
	34	-6.91	20.39	21.73
	35	-36.79	-5.30	3.96
	2	-6.91	20.39	21.73
	3	-6.91	20.39	21.73
	4	-6.91	20.39	21.73
IV	4	-13.5	2.60	3.94
	5	-53.41	-0.36	0.98
	6	-3.60	29.28	30.62
	1	26.29	83.62	84.96
	12	-13.55	3.59	4.93
	7	-21.50	-16.17	-14.83
	8	-20.19	-10.24	-8.90
	9	-26.84	-22.10	-20.76
	16	-26.84	-22.10	-20.76
	17	-69.96	-38.89	-37.55
	18	-69.96	-38.89	-37.55
	13	-46.75	-28.02	-26.68
	24	-46.75	-28.02	-26.68
	19	-89.90	-50.75	-49.41
	20	-46.75	-28.02	-26.68
	21	-26.84	-24.07	-22.73
	28	-30.15	-30.00	-28.66
	29	-46.75	-28.02	-26.68
	30	-113.10	-62.60	-61.26
	25	-69.96	-38.89	-37.55
	36	-69.96	-38.89	-37.55
	31	-23.50	-16.17	-14.83
	32	-23.50	-16.17	-14.83
	33	-30.15	-27.04	-25.70

regional forest office in Ft. St. John develops a plan to provide forage to the ranching industry; to provide recreational opportunities, including wilderness, for public use; and to resolve resource use conflicts among various resource sectors. To accomplish this integrated resource use plan, the Ft. St. John forest office established a guideline to ensure that at least 21% of the total area within each planning cell of the TSA would retain forest cover. The forest cover goal constraint in the integrated model reflects this concern, and is illustrated as follows:

$$\sum_j x_{ij} + d^-_{(i+11)} - d^+_{(i+11)} = .21A_i \quad (i=1-55; \; j=7,8,9) \quad (6.29)$$

Where:

x_{ij} is defined as in inequalities 6.11;

d^-_i and d^+_i are underachievement and overachievement of 21% forest cover target respectively;

A_i is defined as in inequalities 6.12.

The overachievement of 21% forest cover in each land unit is assumed desirable by decision makers in the B.C. Ministry of Forests based on environmental concerns. The model is to minimize the negative deviational variable in order to meet the forest cover requirement.

Habitat Value Protection Goal Constraint

This goal constraint is set to represent a major objective of the wetland use plan developed by the B.C. Ministry of Environment and Parks. That is to protect and manage waterfowl habitat in the Peace River Region. It is thus desirable to maintain or increase the habitat

value of the wetland resources in the study region. Overachievement of this goal from the target level may be desirable. The habitat protection goal constraint is to minimize the underachievement of the goal, and is expressed by:

$$\sum_i \sum_j V_{ij} * x_{ij} - d^+_{67} + d^-_{67} = b_{67} \quad (j=10,11) \quad (6.30)$$

Where:

x_{ij} (j=10,11) is defined as in inequalities 6.18;

V_{ij} is the habitat value for wetland in unit i;

d^+_{67} and d^-_{67} are overachievement and underachievement of habitat protection goal respectively;

b_{67} is the target value for habitat value goal.

Land Resource Flow Relationships

Two coordinating or joint constraints are incorporated in the integrated model to represent the flows or transfers of the land resource from one resource sector to another. The flows of land resources between sectors are important features of a multisector model. The land resource transfer relations in the integrated model take the forms:

Woodland to cropland:

$$x'_{i2} + x'_{i5} = C2*A2_i \quad (6.31)$$

Wetland to cropland:

$$x''_{i5} = C3*A3_i \quad (6.32)$$

Where:

x'_{i2}, x'_{i5}, and x''_{i5} are defined as in inequalities 6.22;

C2 is land conversion rate from woodland to cropland;

189

C3 is land conversion rate from wetland to cropland;

$A2_i$ is defined as in inequalities 6.11;

$A3_i$ is defined as in inequalities 6.18.

Different land conversion rates can be applied to represent various estimates on future land resource conversion from one sector to another. Land use policy on land transfer control can also be represented by these constraints with various conversion rates.

Objective Function and GP Algorithm

The objective function or achievement function of the integrated model is also the minimization of nonattainment of defined target levels. The goals are ranked according to their priorities which represent the preferences and aspirations of decision makers in different government agencies. In solving the integrated model, higher priority goals are satisfied first, then the lower priorities are considered.

The four priority rankings representing preference orderings of different resource sectors and regional agencies are shown in Table 6.15. These priority rankings can be incorporated in the objective function for four separate runs. The results of these separate runs reveal the implications of each set of four preference orderings. Comparisons and contrasts between different results provide information useful for land use decision making. In particular, analyses of the results can indicate whether there are any land use conflicts existing among different resource sectors, or between sectoral and regional

190

Table 6.15: Priority Rankings for 3 Sectors and Regional Agency of Fort St. John.

Priority Ranking	BCMOA	BCMOF	BCMOE	Regional Office
1	Net Economic Return	Net Economic Return	Habitat Value	Net Economic Return
2	Crop Production	Timber Production	Net Economic Return	Crop Production
3	Timber Production	Forest Cover	Crop Production	Timber Production
4	Erosion Control	Crop Production	Erosion Control	Erosion Control
5	Forest Cover	Erosion Control	Forest Cover	Forest Cover
6	Habitat Value	Habitat Value	Timber Production	Habitat Value

Note:
BCMOA: B.C. Ministry of Agriculture
BCMOF: B.C. Ministry of Forests
BCMOE: B.C. Ministry of Environment

agencies with the variance in preference orderings. The analyses can also identify the extent of conflict and trade-offs among different land use prospects. Some interesting expansion of analyses could be undertaken to include some modified priority rankings or modified goals. Based upon the nature of the land use problem to be solved, the structure of the integrated model or the objective function can be further adjusted to provide required information for integrated land resource management.

There are several algorithmic techniques that can be adopted to solve LGP models. The algorithm employed by this study is the Interactive Mathematical Programming System (IMPS) which was written specifically for nonspecialists in operations research. The codes for this algorithm were written in FORTRAN and are available at Simon Fraser University by request. A detailed explanation of this algorithm, and some examples of its application, can be found in a user manual (Love, 1986).

CHAPTER VII

RESULTS AND DISCUSSIONS

7.1 Land Issues Assessed

This chapter illustrates ways in which the assessment system is applied to various land resource problems in the study area. In particular, the applications cover four aspects: identification of the significance of an integrated resource assessment; estimation of the impacts of land use conversion on achieving goals; conflict assessment and trade-offs identification among various land development prospects; and land use policy analysis.

First, this assessment system is employed to identify the significance of integrated land resource analysis for sustainable land development. The specific question to be addressed in this application is: are there differences between single sectoral resource assessments and the integrated assessment? With comparisons between results of an integrated assessment and those of the single sectoral analyses, implications of the integrated land assessment for achieving land use goals can be identified. Second, the analytical framework is used to indicate the impacts of land resource conversion on the attainment of regional goals. This application can provide information on whether land use conversion from one sector to another will affect the achievement of regional land development goals, and to what extent. Third, the assessment framework is used to undertake conflict

assessment. The purpose of this analysis is to examine whether there are conflicts, and to what extent the conflicts are among different goals or between different priority rankings. Conflict assessment also provides information on trade-offs between goals and preferences. The fourth application of the research framework is to assess the impacts of prospective policies on attaining land use goals. The emphasis is on soil erosion control and land conversion policies. This assessment can provide relevant information for the policy making process to ensure sustainability of the land resource systems.

A broad range of land use problems, concerns, or land use policies can be examined by using this integrated land resource assessment framework. These land use issues are all crucial to the development of land resources of the Peace River Region. Many land use plans or policies desirable for the region can be implemented to achieve more or less of any particular goal. However, changing the achievement of one goal often decreases or increases the achievement of other goals. Understanding these land use issues, and identifying the economic and environmental implications of different land use strategies, is facilitated by this integrated land assessment framework.

7.2 Scenarios Developed for Assessment

Several scenarios are set for analysis in this study. These scenarios are based on certain assumptions with respect to the questions to be addressed by the assessment. Scenarios are represented

194

in the model's structure by altering coefficients, rows or columns of the technical matrix, values of the right hand side vector, and the objective function. Different scenarios can also be represented by different models. In such a case, all the variables, rows, columns, and the objective function of the model are changed simultaneously. The three submodels, and the integrated model, are run in turn with different scenarios. The results of different runs with different scenarios indicate the impacts of alternative land use policies or options for achieving sustainable land use goals.

The time horizon for integrated resource assessment can be critical to the results of the assessment. The production cycles of various activities are widely disparate between agriculture and forestry. Forest production is characterized as having a longer cycle and requiring more land. During the tree-growth period, it requires management and other production inputs which are purchased in the early years of the cycle. These costs will not be recovered until the trees are harvested. When discounting is concerned, it makes the assessment more complex.

To make the analysis simpler, one alternative is to use average annual yields and annual economic return from the agricultural and forestry sectors as assessment parameters. Data on average annual yield and economic returns for agricultural activities are available. In the forestry sector Maximum Sustainable Yield (MSY) by a given species of tree is used as the average yield of timber production. Economic returns from timber production are estimated on the basis of stumpage prices, which is conceptually consistent with the sustained yield

management approach expoused by the provincial forest policy (BCMOF, 1984).

The temporal dimension will be represented in the assessment by varying the data base which includes: the land resource availability, the priority ordering, and the target levels of goals. Variation of assessment data reflects different conditions in the future. At any specific future date, there will be estimated data on priority, demand, and resource change which will be used to assess the impacts of future changes on achieving land use goals. Different scenarios can be created to represent short-term or long-term situations.

In total, 12 scenarios were specified and tested for this case study (Table 7.1). Scenarios 1 to 4 were designed to indicate the significance of integrated land resource assessment. These scenarios are based on current land use conditions, land conversion rates, yields, prices, and other biophysical and economic factors. An exception to this are the resource production targets which are based on predictions made by government agencies for the year 1995. Scenario 1 represents an agricultural land use assessment system. Land resource conversion and land use conflict between sectors are not considered in this analysis. Goal target levels and priority ordering of goals are based on decision makers' preferences in the agricultural sector. Similarly, scenario 2 reflects resource assessment with consideration of only the forestry sector. The forestry submodel is employed for assessment with scenario 2. Scenario 3 is designed to evaluate the wetland resources. Habitat and hunting values are goals of the assessment. This single sector

Table 7.1: Scenario specification.

Category	Scenario Number	Resource Sector Or Region	Conditions for Assessment	Model Employed
Significance Assessment of Integrated Approach	1	Agricultural	Current Conditions Plus Future Production Targets	Agricultural Submodel
	2	Forestry	Same as Above	Forestry Submodel
	3	Wetland	Same as Above	Wetland Submodel
	4	Region	Same as Above	Integrated Model
Land Conversion Impact Assessment	5	Region	Current Conditions Plus 10 Years Land Conversion From Forest and Wetland to Cropland	Integrated Model
	5a	Region	Modification Of Scenario 5: Land Conversion Rates Are Determined by The Model	Integrated Model
Conflicts Analysis and Trade-off	6	Region	Goal Preference Based on Decision Making in Ag. Sector	Integrated Model
	7	Region	Goal Preference Based on Decision Making In Forestry	Integrated Model
	8	Region	Goal Preference Based on Decision Making In Wetland	Integrated Model
Identification Among Land Use Goals	9	Region	Varying Target Levels Reflecting Certain Concerns	Integrated Model
Policy Impact Assessment	10	Region	Soil Erosion Control Policy	Integrated Model
	11	Region	Land Resource Conversion Control Policy	Integrated Model

analysis is undertaken by the wetland submodel which delineates impacts in different land units. Scenario 4 differs from the three previous scenarios in current conditions such as land resource conversion and land use conflicts which are not considered in scenarios 1 to 3 but are incorporated in scenario 4. This scenario pursues a number of goals while at the same time integrating agricultural, forestry, and wetland sectors. The integrated model provides a mechanism to represent linkages among these three resource sectors, and reflects a regional perspective. As such, the model provides a basis for determining if the results from the analysis of the whole region differ from those for the individual sectors. Details of the three submodels and the integrated model, and data for analysis, were presented in chapter 6.

Scenario 5 is created for a second type of application. It assesses the impacts of land conversion from the forestry and wetland sectors to agricultural uses on attainment of regional resource development goals. This scenario assumes that the current land conversion rate will continue for ten years, while other conditions remain the same as those for scenario 4. Land resource conversion is an important resource management issue in the Peace River Region. Based on scenario 5 the consideration of the 10-year land resource conversion is represented by the two land resource flow relation equations, 6.31 and 6.32, of the integrated model. Comparisons of the results from scenario 5, with those from scenario 4, indicate the impacts of the transfer of land between uses on achieving land use goals.

In scenario 5, the same land conversion rates are assigned for all land units across the study region. That is, in every land unit, there is a certain proportion of land converted from forest lands and wetlands to farmlands. In this scenario, based on information from government documents, the annual conversion rates for forest land and wetland are set at 1.58% and 5% respectively of the total areas of woodlands and wetlands in each of the land units (BCMOA&F, 1981a; BCMOLP&H, 1985a).

The assumption in scenario 5 is relaxed in scenario 5a to find the best land resource conversion rates with respect to achieving multiple land use goals. With scenario 5a, the exact land conversion for each land unit is not predetermined but determined by the model. More detailed explanation of scenario 5a is presented in section 7.4. Results of scenario 5a are used as a baseline against which the results from scenarios 6 through 11 are compared. Scenarios 6 through 11 differ from scenario 5a in that some conditions are changed to reflect impacts of land use conflicts, different land use options, or land use policies.

Another important function of the integrated research framework is to undertake conflict analysis and to identify trade-offs among different resource sectors. Scenarios 6, 7, and 8 are set for identification of conflicts among land use prospects based on land use decision makers' preferences and aspirations in the agricultural, forestry, and wetland sectors respectively. Under scenario 6, goal preference, or the priority ranking of goals, is based on land use

decision making in the agricultural sector. Scenario 7 refers to land use decision making priorities in the forestry sector. Hence the goal priority ordering for scenario 7 is ranked according to the goal preference of officials in the forestry sector. Scenario 8 reflects the land use preference of decision makers in the wetland sector. Priority ordering of goals in the model reflects decision makers' aspirations in the wetland sector. The three preference orderings for entry into three separate runs of the integrated model have been presented in Table 6.15 of chapter 6.

Scenario 9 is also designed for conflict analysis, but its purpose is slightly different from the three previous scenarios. Analyses based on scenarios 6, 7, and 8 are designed to examine conflicts between land use preferences of different decision makers in the three resource sectors. The conflicts and trade-offs between goals and priority rankings can be identified through comparing the results for scenarios 6, 7, and 8. However, scenario 9 is set to estimate trade-offs between goals by changing the target level for a specific goal, in this case, the net return or the crop production goals, given the priority ordering of scenario 5a. This is relevant in the situation given that decision makers in the agricultural sector had forecast a future increase of grain and oilseed production in B.C. Three scenarios-moderate, optimistic, and pessimistic-were set by Agriculture Canada (1986) for the year 1995.

Still another type of application of the integrated assessment system is for policy analysis. Scenarios 10 and 11 are established for

discussing ways in which the integrated assessment framework can be applied to questions of land use policy. Scenario 10 considers the implementation of a restricted soil erosion control policy. The total soil loss in the study region by water erosion has to be at a level which is below the T-value. With this soil loss control policy, some land use activities which are prone to erosion may be forced out of production. This ultimately affects the achievement of land use goals. The soil erosion control policy is represented in the model by shifting the soil erosion goal to priority 1 in the objective function of the integrated model.

Scenario 11 considers the introduction of a land conversion control policy. With this policy, land conversion from woodland and wetland to cropland is not allowed under any circumstances. This limits the increase of land resource availability for the agricultural sector through land conversion. Attainments of crop production may be affected by this land use policy. Scenario 11 is reflected in the model by adjusting the values of the conversion coefficients, C2 and C3, to zero. All other conditions remain the same as those in scenario 5a.

7.3 Significance of Integrated Land Assessment (Scenarios 1-4)

In scenario 1, crops incorporated for the assessment are wheat, barley, oats, canola, hay, and summer fallow which are major farming practices in the study region (Canada. Agriculture Canada, 1984). Goal target levels for grain production are based on demand predictions of

201

the moderate scenario made by Agriculture Canada for the year 1995. The priority ordering of goals is determined by regional officers in the B.C. Ministry of Agriculture.

The forestry submodel is run with scenario 2 representing resource assessment within the forestry sector. Land resource availability, land use activities, goals, and priorities attached to these goals are presented in Table 6.1 under the forest submodel category. The assessment of scenario 3 is undertaken by running the wetland submodel which delineates impacts on different land units. This analysis is based on conditions and concerns within the wetland use system. Habitat and hunting values are the targets for assessment. Integrated land resource assessment based on scenario 4 coordinates the agricultural, forestry, and wetland sectors. The integrated model provides a mechanism to represent linkages among these three resource sectors, and reflects a regional perspective. Under the integrated model category in Table 6.1, land use activities, land base and goal priorities for the integrated assessment are illustrated. The goals and their priority ranking in the integrated model are different from those of the submodels. This reflects the different concerns by decision makers at different levels. It also reflects adopting a broader perspective and incorporating other interests into the equation.

In scenario 4, higher priorities are assigned to agricultural land uses because the Peace River Region is one of the major agricultural areas in B.C. In this regard, the agricultural sector is more important when compared with the forestry and wetland sectors, particularly with

respect to economic returns and employment. Different land conversion rates can be applied to represent various estimates of future land resource conversion from one sector to another. In scenario 4, the average annual land conversion rate in the Peace River Region is adopted for assessment. This assumption can be relaxed if data on land conversion rates for different land units are available. Then, land use conversion can be incorporated into the integrated model as a goal constraint.

In the analyses, the three submodels for the agricultural, forestry, and wetland sectors are run with scenarios 1, 2, and 3 respectively. The integrated model is run with scenario 4. The results of the four runs presented in Table 7.2 illustrate the implications of integrated land resource assessment.

The results of the scenario 1 run (Table 7.2) indicate that, under current conditions and 1995 production target levels, the land base in the agricultural land use system is only able to meet production targets of wheat, barley, and oats, and fails to provide enough land for canola and hay production. The findings also show that the net economic return goal is achieved. Soil loss in the agricultural land use system exceeds the T-value target level by about 18.2 percent because row crop production is usually subject to heavier soil loss by water erosion.

The forestry land use system represented by scenario 2 shows a different picture. Results of the assessment for the forestry sector

Table 7.2: Results of Runs with Scenarios 1 to 5a.

Scenario\Goal:		Wheat	Barley	Oats	Canola	Hay	Spruce	Pine	Deciduous	Net Return	Soil Erosion	Forest Cover	Habitat Value	Hunting Value
Unit:		(t)	(t)	(t)	(t)	(t)	(m^3)	(m^3)	(m^3)	($)	(t)	(ha)	(duck)	($)
1	Target Level:	2000	3550	1070	1620	7020				168061.0	62070.0			
	Deviation:	0.0	0.0	0.0	13.6	7020				0.0	11297.6			
2	Target Level:						1432.2	613.8	2758.7	15702.1	75756.8			
	Deviation:						0.0	0.0	0.0	0.0	0.0			
3	Target Level:												9517.0	4917.2
	Deviation:												0.0	0.0
4	Target Level:	2000	3550	1070	1620	7020	1432.2	613.8	2758.7	195000.0	76615.0	2991.5	9517.0	
	Deviation:	0.0	0.0	0.0	0.0	5613.8	0.0	0.0	1004.5	0.0	2814.4	133.4	0.0	
5	Target Level:	2000	3550	1070	1620	7020	1432.2	613.8	2758.7	195000.0	76615.0	2991.5	9517.0	
	Deviation:	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1031.8	0.0	0.0	161.3	2895.9	
5a	Target Level:	2000	3550	1070	1620	7020	1432.2	613.8	2758.7	195000.0	76615.0	2991.5	9517.0	
	Deviation:	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1001.5	0.0	0.0	133.4	0.0	

illustrate that all the target levels of various goals in the forestry submodel are achieved. It indicates that the forestry land base is adequate to produce enough timber for future demand, to generate net economic return for land resource uses, and to keep soil erosion under the T-value target. The results of the forestry land use are not unexpected because the AAC in this region is relatively low and can be achieved without considerable difficulties. One important benefit of forestry is that it significantly reduces soil loss.

Scenario 3 is run by the wetland submodel which, when compared to the other models, is small in size. Only two goals are considered in this model. Results of this run show that both the habitat value goal and the hunting goal are achieved. From 1981 through 1986 the number of hunters decreased by about 40 percent due to the decline of hunting success (BCMOE, 1988). The results indicate that the declining hunting value can be offset by implementing wetland enhancement projects which will ensure the achievement of the hunting value goal set by the B.C. Ministry of Environment.

The fourth run with scenario 4 is undertaken by the integrated model which represents a regional and multisectoral land resource assessment system. The results of the integrated land resource assessment are quite different from the sum of all the results of the three submodels. In the integrated model, one mechanism of the mathematical structure allows land resources to be converted from forestry uses and wetland activities to agricultural uses. In this scenario, land resource conversion for one year changes the situation

205

of achieving different land use goals. Land resources available for crop production increase through land conversion. Thus it is now possible for the study region to fully achieve the goal of canola production and increase the hay production. On the other hand, land conversion reduces the availabilities of land for forestry and wetland activities. Now the timber production goal cannot be achieved. Most of this underachievement is due to the conversion of land under low value deciduous production. Some wildlife habitats are lost due to land conversion, and the total habitat value decreases. Moreover, the amount of soil loss in the study region has increased significantly. Soil loss from the integrated run is about 4 percent more than the sum of soil losses from the results of scenarios 1 and 2. Thus increasing crop production causes greater soil loss for the region.

The assessment is not intended to identify an appropriate pattern for land resource allocation. Yet the research framework is capable of identifying the resource allocation pattern which best satisfies the given conditions. Hence, the framework can be used for the land use planning purpose. Table 7.3 presents the land allocation patterns in the agricultural sector resulting from runs of scenarios 1 and 4. Differences of land resource allocation between the results of a sectoral analysis (scenario 1) and the results of an integrated analysis (scenario 4) are noticeable. But the general patterns of the crop production in the region derived from the runs of the agricultural submodel and the integrated model still have some similarities. Since the influence of the current land use pattern is reflected in the

Table 7.3: Farmland Allocation Patterns From Scenarios 1 and 4.

Area/Crop	Wheat (ha)	Barley (ha)	Oats (ha)	Canola (ha)	Hay (ha)
(Scenario 1)					
I	414	190	0	568	0
II	437	208	0	772	0
III	102	189	0	64	0
IV	111	1553	659	131	0
Total	1064	2140	659	1535	0
(Scenario 4)					
I	309	113	0	596	172
II	579	301	0	949	36
III	199	134	0	68	5
IV	113	1606	510	133	24
Total	1200	2154	510	1746	237

integrated land assessment framework in the form of a land resource constraint for each of the land types (improved land, woodland, and wetland), the impact of short-term (one year) land use conversion on land allocation is relatively insignificant.

A comparison and contrast of results between the integrated land assessment and those of single sector assessment, illustrate that, to analyse regional land resource use prospects, it is important to adopt an integrated approach. Land use evaluation for each individual sector does not provide an appropriate framework to take into consideration land use conflicts and land use conversion between different resource sectors. By developing an integrated research framework which is flexible enough to encompass components and linkages of a regional land use system, the full set of interrelationships within conflicting resource sectors and between conflicting goals can be assessed.

7.4 Land Conversion Impact Assessment (Scenarios 5 and 5a)

In order to resolve policy conflicts regarding land use and land use conversion, an indepth knowledge of the nature and implications of land use conversion is needed. It is for this purpose that the integrated land use assessment framework developed in this thesis is employed to undertake the impact analysis of land resource conversion. One particular question is addressed in this land use analysis: do current trends in use conversion from forest lands and wetlands to farmlands, threaten sustainable resource production and adequate

economic return to the land base, affect soil loss by erosion, and influence the preservation of waterfowl habitat of wetlands?

Scenario 5 reflects the condition of continued land use conversion from forest lands and wetlands to farmlands for ten years. By running the integrated model with scenario 5, the impacts of land use conversion on the achievements of the region's land resource development targets can be identified. Scenario 5 is represented by the integrated model through multiplying the right hand side values in the land resource flow relationship equations (6.31 and 6.32) by 10. This assumes that woodlands and wetlands will be converted to farmlands at a constant rate continuously for ten years. In order to examine whether this amount of land conversion is necessary to attain land use goals, another run of the integrated model is undertaken by changing equations, 6.31 and 6.32, into inequalities. The equal signs (=) in the two equations now become less than or equal to (≤) signs. These adjusted conditions can be assumed as scenario 5a. This means that, in scenario 5a, the amounts of land conversion are determined by the model. Whereas in scenario 5, land conversion is preset at a given rate. In other words, with scenario 5a, the model finds desirable land conversion rates in order to attain as closely as possible the multiple land use goals.

The model is first solved for scenario 5. The results of this run are presented in Table 7.2. Comparing results of scenario 5 with scenario 4, indicates the impacts of ten-year land conversion, from forestry and wetland sectors to agricultural sector, on the achievement

of land use goals. It illustrates that there are no significant changes in achieving net return and grain production goals. A significant increase in hay production helps the region reaching the hay production goal. Land use conversion also results in a moderate reduction in the attainment of timber production, a decrease of soil loss from erosion, a moderate decline of forest cover, and a loss for the waterfowl habitat value of about 2895 birds. The soil erosion goal is now attainable.

Land use conversion changes the land availability for different sectors and land use patterns. A shift to a condition with more land available for cropping and less for forestry and wetland uses makes the achievement of the hay production goal possible. This shift also generates moderate declines in obtaining timber production and forest cover goals. Loss of wetlands would likely reduce the waterfowl habitat value. The results indicate that about one third of the target level of the habitat value goal cannot be achieved under scenario 5. The results for cropping activities, as a result of land conversion, could help to reduce soil erosion by allocating row cropping activities on lands which are not susceptible to erosion. Land increased in hay production further reduces the total soil loss by water erosion.

Next, the integrated model is rerun with scenario 5a. The results are also summarized in Table 7.2, which indicate that under present conditions, 10 years of land use conversion from woodlands and wetlands to farmlands may not significantly affect the achievement of certain goals. While continued land conversion for ten years at current

210

conversion rates which is given and evenly distributed across all the 55 land units in the study region (scenario 5), creates a problem in sustaining waterfowl habitat values in the study region. Land conversion rates which are not preset but determined by the integrated model (scenario 5a) do not cause the same habitat loss problem. The goal achievement situation in the results for scenario 5a is better than that of scenario 5. The habitat value goal is attained in the results for scenario 5a.

As shown in Table 7.4, the extent of land conversion is much less for scenario 5a. With scenario 5, woodland conversion occurs in all the 55 land units and wetland conversion takes place in all 29 land units where wetland resources are available in the study region. An area of 1069 ha of woodlands and 681.5 ha of wetlands are converted for agricultural uses. When compared with scenario 5a, only 35 land units experience woodland conversion, 64 percent of that for scenario 5 while 18 land units experience wetland conversion, 62 percent of that for scenario 5. The area converted from woodland to cropland is 975.9 ha, 91 percent of the land predicted for scenario 5. About 373.6 ha of wetlands are converted to cropland, 55 percent of that for scenario 5.

The geographical distribution of land conversion for scenario 5a shows an uneven pattern. In the study region, forestry land conversion takes place in all the land units of area II and area III, and in most of the land units of area IV (Figure 6.1). There is no forestry land conversion in area I because forest resources are limited in this area and they also need to meet the forest cover goal. All land units

Table 7.4: Land Conversion Distributions From Scenarios 5 and 5a.

Scenario/Area		Woodland Conversion					Wetland Conversion				
		I	II	III	IV	Sum(%)	I	II	III	IV	Sum(%)
Total Land Units		6	16	9	24	55(100)	6	8	2	13	29(100)
5	Affected Units	6	16	9	24	55(100)	6	8	2	13	29(100)
	Land Converted (ha)	31	298	265	475	1069 (100)	54	356	46	240	682 (100)
5a	Affected Units	0	16	9	20	35(64)	6	7	0	5	18(62)
	Land Converted (ha)	0	298	265	413	976 (91)	54	274	0	46	374 (55)

possessing wetland resources in area I suffer land conversion. In areas II and IV, only part of the land units would experience land conversion. There is no wetland conversion identified in area III.

7.5 Conflict Analysis and Trade-Off Measurement (Scenarios 6-9)

Concerns over sustainable land use and development require information on trade-offs among various development goals and resolution of conflicts between different resource sectors. Three questions are of particular interest in this application: first, do land use conflicts exist among the three resource sectors? Second, if conflict exists between land use activities, what is the extent of these conflicts? Third, what are the trade-offs between goals? The first two questions are discussed and analysed with the case study in section 7.5.1, and the third question is discussed in section 7.5.2.

7.5.1 Land Use Conflicts in the Study Region (Scenarios 6-8)

To answer the first two questions, or to identify the nature of the land use conflicts among resource sectors and to investigate the extent of conflicts in the study region, a set of three scenarios are defined based on the variance in priority ordering of goals. These scenarios represent alternative preferences of decision makers involved with land uses in the region. The integrated model is run for each of the three scenarios, scenarios 6, 7, and 8. Results of each run indicate the extent to which each goal can be achieved under a specific

ranking of goal priorities. Furthermore, comparisons between the results of the three runs identify the nature and extent of land use conflicts among the three resource sectors. If the results of the three runs are identical, it is assumed that no land use conflicts exist among the agricultural, forestry, and wetland sectors. If the variance in the results of three runs is identified, the extent of the conflict between resource sectors can be indicated by comparing the extents of goal achievements under different priority orderings of goals.

The results of three runs for scenarios 6, 7, and 8 are presented in Table 7.5. The three runs are undertaken using the integrated model. In each run, the model is adjusted by changing the priority ranking of the goals according to the goal preference for each resource sector. Three separate sets of solutions are identified for the three runs. The results illustrate that either overachievement or underachievement, or neither, may occur for the goals. In this conflict analysis, only information on goal attainment levels is considered. Comparison of the results of the three runs shows that changes are insignificant when goal priority orderings are changed under scenarios 6, 7, and 8. The shortfall for the forest cover goal is attributed to the fact that woodlands in some land units are less than the required forest cover.

Does this mean that there is no significant conflict among the three alternative land use prospects? What are the underlying reasons which affect the results? First, the target levels of the goals are not high enough to generate conflict. It appears that potential still exists to increase resource production, net economic return, and other

214

Table 7.5: Results of Conflict Analysis.

Scenario\Goal:		Wheat	Barley	Oats	Canola	Hay	Spruce	Pine	Deciduous	Net Return	Soil Erosion	Forest Cover	Habitat Value
Unit:		(t)	(t)	(t)	(t)	(t)	(m3)	(m3)	(m3)	($)	(t)	(ha)	(duck)
Target Level:		2000	3550	1070	1620	7020	1432.2	613.8	2758.7	195000.0	76615.0	2991.5	9517.0
6	Priority	2	2	2	2	3	4	4	4	1	5	6	7
	d-	0	0	0	0	0	0	0	1001.5	0	0	130.3	0
	d+	0	0	0	0	0	0	0	0	40363	0	0	0
7	Priority	4	4	4	4	5	2	2	2	1	6	3	7
	d-	0	0	0	0	0	0	0	1001.5	0	0	130.3	0
	d+	0	0	0	0	0	0	0	0	111885	0	0	0
8	Priority	3	3	3	3	4	7	7	7	2	5	6	1
	d-	0	0	0	0	0	0	0	1001.5	0	0	130.3	0
	d+	0	0	0	0	0	0	0	0	37504	0	0	0

goal targets. Lonergan and Cocklin (1988) applied the maximum values that can be achieved for each goal as the target levels of goals in their study of conflict analysis for energy development in the forest sector. The target levels set in the Lonergan and Cocklin study represent the resource potential for each goal with a long-term perspective. Their study indicates that the results of conflict analysis are sensitive to goal priority ranking in the model. A different approach is adopted in this study in determining the target levels of goals. Instead of using the maximum values for all goals as the target levels, target levels are set, in this study, based on current or short to medium-term conditions. In scenario 9, when target levels are raised to reflect long-term considerations, the results do change markedly. Second, the current land use patterns represented in the integrated model have some restrictions on the interactions between goals from different resource sectors. Even though the interrelationship mechanism between resource sectors is built into the model by virtue of the land use conversion constraints, the ten-year time span for continued land conversion considered in this analysis might allow only a small amount of land to flow between sectors.

In summary, under current conditions and in the near future there is no significant conflict among the three land use activities in the study region. The results of the analyses are consistent with other reports (BCMOLP&H, 1985a; BCMOF, 1986) which also suggest a short-term stability in agricultural and forestry productions in the Peace River Region. Land use conflicts may increase when demands for land resources

increase or target levels of goals are raised. In the long-run situation land use conflict will be different from the current condition. The following discussion will further clarify the nature of land use conflict in the Peace River Region.

7.5.2 Trade-Offs Between Land Use Goals (Scenario 9)

In this section, the integrated model is employed to analyse the trade-offs among goals. Analysis of the trade-offs is undertaken by varying the target level of the highest priority goal. The effects of changing the goal target level on the relative levels of achievement for other lower priority goals can be identified, which provides trade-off values among various land use goals given a certain priority ordering. This sort of trade-off analysis is applied to two different problems. The first application is to examine the effects of Agriculture Canada's optimistic and pessimistic objectives for regional grain production on achievement of other land use goals. The second application is to identify the impacts on the attainment of goals to an increase of the target level of the goal with the highest priority. The results of this type of analysis show the trade-offs between goals.

Figure 7.1 illustrates the results of the first analysis. The priority ordering of goals reflects goal preference of decision makers at the regional level. In this case, net economic return and grain production are assigned as the first and second order priorities. Varying the target levels of achievement for the two goals (target levels being predetermined initially) in accordance with Agriculture

Figure 7.1: Goal Attainment Levels (%) for Three Scenarios.
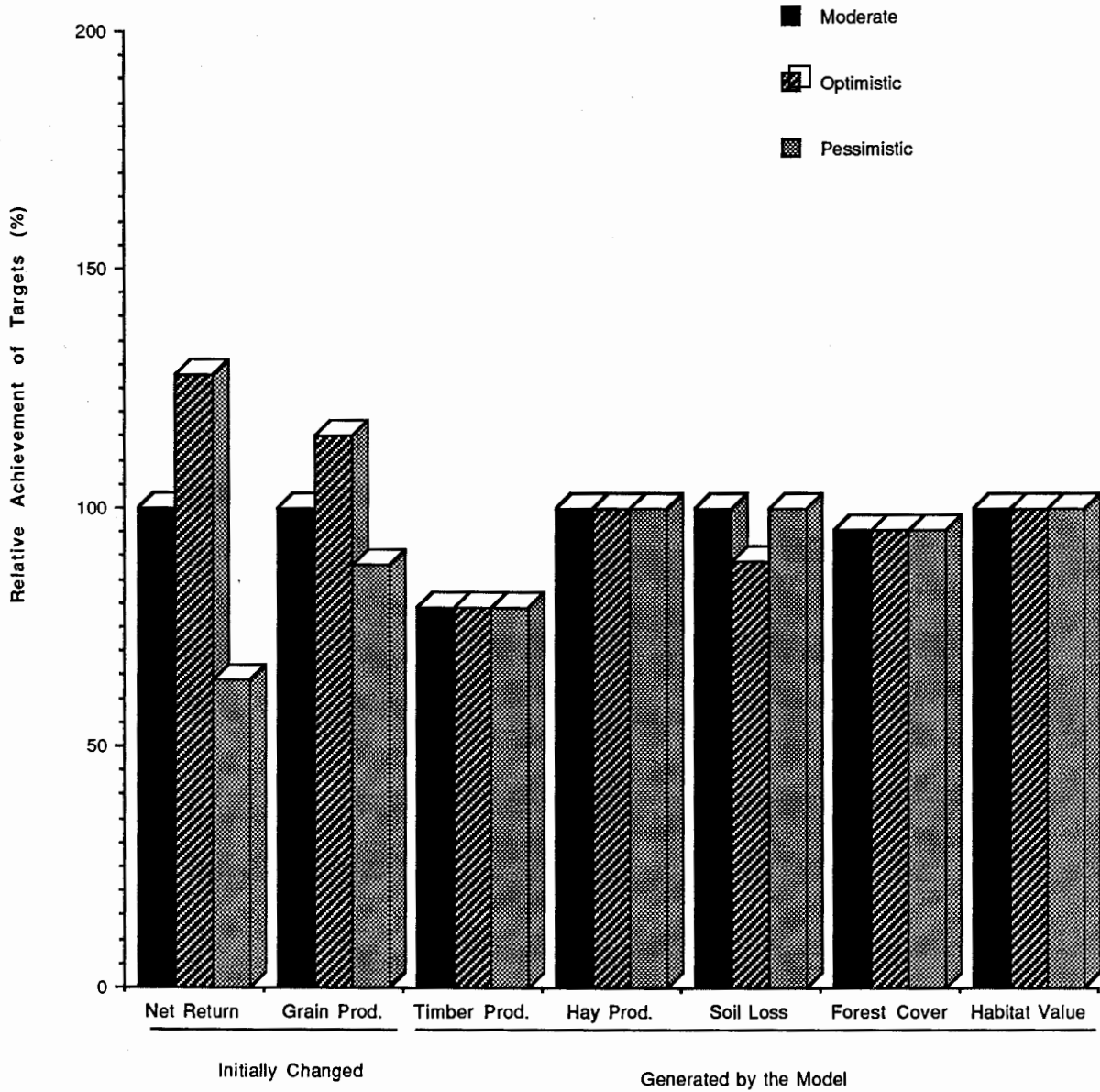
Note: Target levels for moderate scenario are considered as 100%

Canada's pessimistic and optimistic predictions on crop production and thus net return (Canada. Agriculture Canada, 1986), results in changing levels with respect to the percentage of achievement of targets for other goals. In Figure 7.1, the pessimistic, moderate, and optimistic target levels of various goals are placed on the horizontal axis. The relative degrees of achievement of these goals are measured in terms of the percentage achievement of their respective target levels as indicated by the vertical axis.

These results indicate that both Agriculture Canada's optimistic and pessimistic grain production targets can be accomplished without significantly affecting the achievement of other land use goals. Only a slight decline in the relative achievement of the soil erosion control goal is identified in the results. The results can be interpreted as that the study region still has potential to simultaneously increase grain production and to meet other demands for land resources given appropriate land resource allocation and management.
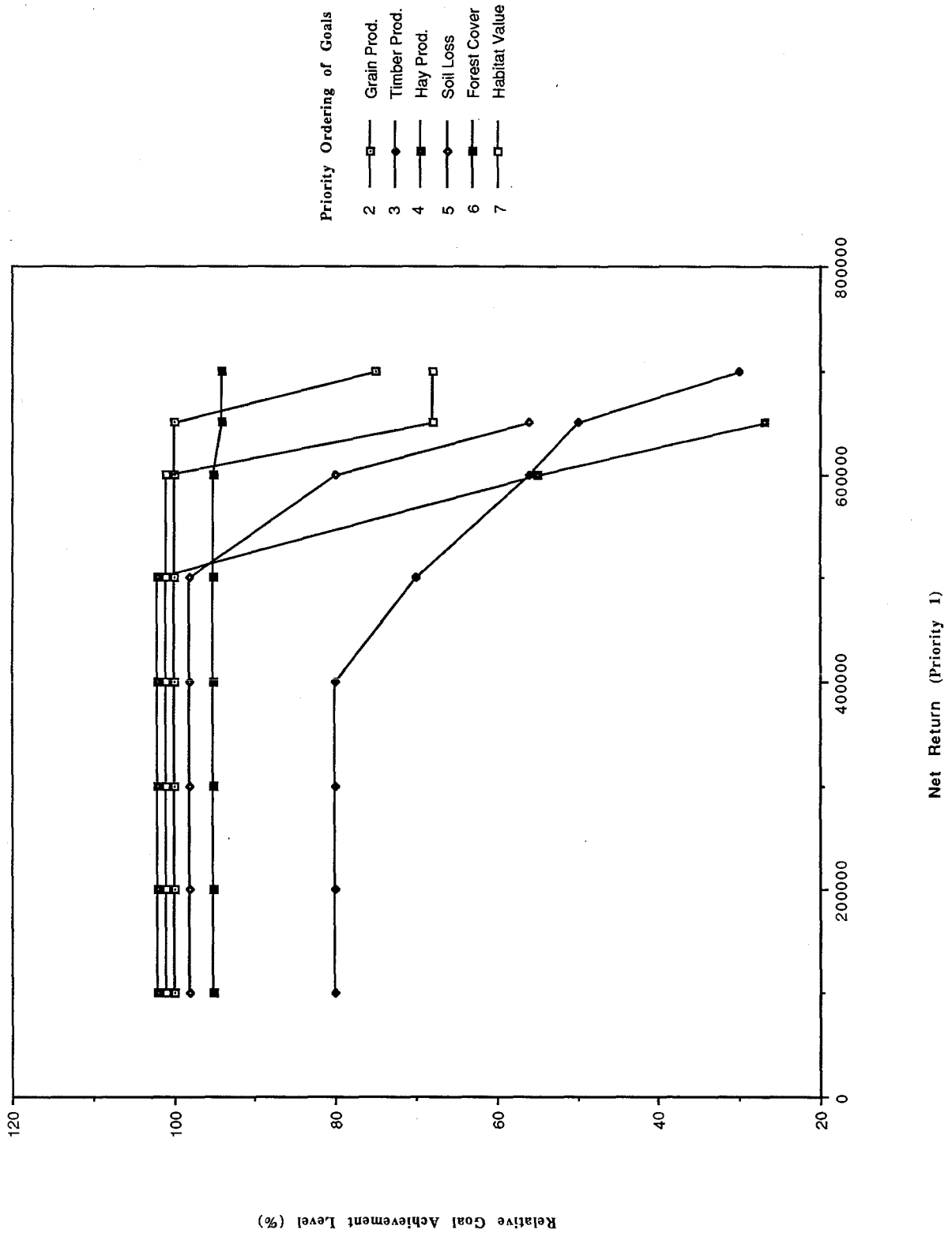
Lonergan and Cocklin (1988) show a special procedure to identify trade-offs among various goals in the development of forest energy plantations in Eastern Ontario. The second conflict analysis employs their style of assessment. In this analysis, the target level of net return goal, the highest priority, is increased incrementally from $160,000, $250,000, $450,000 to $650,000. The priorities of other goals are ranked in order and are presented in Figure 7.2. The integrated model is run repeatedly with each of the target levels for the net economic return goal. The results of the percentages of target level

219

achievements for all other goals under these runs are plotted in Figure 7.2. At the beginning, goal achievement levels are insensitive to an increase in the target level for the net return goal. With an increase of the target level for the net return goal beyond $450,000, there are noticeable changes in attainment levels for other goals. Higher economic return targets force land resources to be allocated for wheat, canola, and spruce timber production. Thus, achievement levels for other goals start to decline. Increasing wheat production, coupled with decreasing hay production, causes an increase of soil loss by water erosion. More land resources are converted from woodland and wetland to cropland, which reduces the achievement levels for forest cover and habitat value goals. It is also noted that the curves in Figure 7.2 demonstrate an important feature: all the curves remain constant with increasing target level for net return goal until a threshold level is reached. In this analysis, after the target level of the net return goal is raised beyond $450,000, the curves start to drop dramatically. This information could be useful for land resource management.

7.6 Assessment of Land Use Policy (Scenarios 10-11)

An ex ante evaluation of land use policy is a prerequisite for implementation of land policy. Such an assessment provides a basis for estimating the likely impacts of a policy on achieving various land development goals. It also provides a basis for decision makers to determine whether the land use policy should be implemented given certain economic, social, and environmental criteria.

220

Figure 7.2: Goal Relationships at Alternative Target Levels for the Net Return Goal.

Priority Ordering of Goals

2	□	Grain Prod.
3	●	Timber Prod.
4	■	Hay Prod.
5	◆	Soil Loss
6	■	Forest Cover
7	□	Habitat Value

Net Return (Priority 1)

Relative Goal Achievement Level (%)

221

The effects of two hypothetical land use policies, a soil erosion control policy and a land conversion control policy, on the achievement of goals are assessed under the conditions specified for scenarios 10 and 11 respectively. For scenario 10, the soil loss control goal is shifted to the highest priority in the objective function of the integrated model to reflect concern of the soil erosion control policy which restrains soil loss from exceeding the T-value. Adjustments of both the land conversion coefficients C2 and C3 to zero value under scenario 11 reflect restriction of land use conversion from one sector to another as the aim of the land conversion control policy.

The results for the two policy analysis scenarios are summarized in Table 7.6. The soil erosion control policy simulated for this analysis does not lead to a significant change in goal achievement. This result is most likely related to the fact that the low levels of soil erosion rates for forest and wetland have offset high erosion rate for cropping activities. The effects of a soil erosion control policy on the agricultural sector would be more significant than that on forestry and wetland sectors should separated erosion control targets be set for each of the three sectors. It is not difficult technically to disaggregate a soil erosion constraint goal for the whole study region into individual goal constraints for each land type in each land unit. By doing so, however, it would significantly increase variables and constraints of the integrated model, and thus would exceed the capacity of the IMPS software which can deal with up to 999 variables and 300 constraints respectively.

Table 7.6: Results of Policy Analysis.

Scenario\Goal:		Wheat	Barley	Oats	Canola	Hay	Spruce	Pine	Deciduous	Net Return	Soil Erosion	Forest Cover	Habitat Value
Unit:		(t)	(t)	(t)	(t)	(t)	(m3)	(m3)	(m3)	($)	(t)	(ha)	(duck)
Target Level:		2000	3550	1070	1620	7020	1432.2	613.8	2758.7	195000.0	76615.0	2991.5	9517.0
10	Priority	3	3	3	3	5	4	4	4	2	1	6	7
	d-	0	0	0	0	0	0	0	1001.5	0	0	130.3	0
	d+	0	0	0	0	0	0	0	0	40363	0	0	0
11	Priority	2	2	2	2	4	3	3	3	1	5	6	7
	d-	0	0	0	13.6	7020	0	0	100.5	0	0	130.3	0
	d+	0	0	0	0	0	0	0	0	105670	0	0	0

If land conversion policy were implemented as simulated by scenario 11, there would be a significant impact on goal achievement in the analysis. The results indicate that the achievement for canola production may be 13.6 tonnes short of the target level. No land resources would be available for hay production. As restraints are placed on land conversion from one sector to another, the land resources available for crop production are reduced sizably. Other policy alternatives of land conversion control representing various levels of land conversion restraints, can also be analysed to evaluate the impacts on achievements of different land use goals. Information provided by the policy analysis can be used to expore the economic and environmental impacts of these proposed policies before they are enacted.

CHAPTER VIII

CONCLUSION

Integrated resource management, by its nature and complexity, must recognize four major groups of factors and their interrelations.

1. a biophysical aspect: land use patterns reflect natural constraints inherent in the physical and biological environments.

2. an economic aspect: land uses are also economically based. The economic factors of market, production, demand, supply, and transportation costs are important for land resource management.

3. an institutional aspect: the establishment of adaptable institutions and policies can provide a necessary direction and control to ensure sustainable development.

4. a behavioral aspect: there are further sets of behavioral influences which affect land use planning, including values, aims, motives, and attitudes of planners, policy makers, and the public.

It is the interactions among the biophysical, socio-economic, institutional, and behavioral factors, which affect the patterns of land resource uses.

Rural land resource studies are hampered by a lack of conceptual and methodological innovation. Methodological development in land use evaluation is still in an early stage (Cocklin et al., 1987). Some endeavours in developing methodologies for land resource analysis have focused on a specific aspect of land use planning with the consideration of only one sector. There has been a lack of study on

225

integrated land resource analysis. In this thesis an integrated approach, which provides a systematic and comprehensive research framework for land resource analysis, has been developed and applied to a case study in the Peace River Region. The case study deals with some important questions in relation to integrated land use. The specific questions being addressed are:

1. What are the implications of land use conversion from one resource use or one sector to another with respect to achieving multiple land use objectives?

2. How critical are the threats of land degradation in terms of achieving multiple land use objectives?

3. Do land use conflicts exist among different resource sectors?

4. If conflicts exist between different uses or users in pursuing integrated land development, how serious are they and how can compromises be reached?

5. What are the possible trade-offs for different land use objectives or alternatives?

8.1 Contributions of the Thesis

This thesis has contributed to four aspects of the development of an integrated land resource assessment. First, a systematic survey and evaluation of a range of methods has been undertaken to identify an appropriate approach for integrated land resource assessment. Second, the establishment of an integrated data base for land use assessment in the Peace River Region of B.C. provides a basis for incorporating

biophysical and socio-economic information from various information sources. Third, an integrated analytical system has been developed for assessing the implications of land use prospects for achieving multiple land use goals. This integrated approach coordinates the resource assessment made by the various resource use sectors and accommodates the interactions between resource sectors. And finally, the application of this integrated assessment system to the Peace River Region in B.C. has illustrated that an integrated approach to land resource analysis is practicable and can be useful in examining a wide range of land use problems, options, and land use policies.

A review and appraisal of many methods or techniques which have been applied frequently to natural resource management reveals that while highly useful for specific tasks they do not fulfill the requirements and guidelines necessary to achieve integrated land assessment. Most of these methods are based on one dimension of the resource use system, and thus are only desirable for the assessment of single impact such as ecological, social, or economic. Another important constraint of these methods is that they often deal with one resource sector in isolation, failing to recognize the importance of intersectoral relations. Land resource management is highly complex and involves several interest groups, and has to consider multiple objectives which are often in conflict. The integrated and interdependent nature of the land use issues requires an approach to integrate a wide range of objectives, preferences, resource sectors, and intersectoral relations into the assessment framework.

An integrated data base was developed for this study. It is a necessary step for integrated resource assessment to establish a common data base which incorporates various data from different sources such as agriculture, forestry, and the environment. The region considered in the case study is represented as a set of land units of equally sized squares or map sections. Each land unit is assumed to be a homogenous entity having similar biophysical and socio-economic conditions, such as productive potential, economic performance, land use patterns, and management level. Based on this type of spatial land unit, information about land resource availability, land use, and land conversion from a wide range of sources, which often was inconsistent in scale and coverage, was transferred to a data base for integrated assessment using a superimposition technique.

An integrated land assessment framework (ILAF), possessing a hierarchical structure and containing a multiplicity of assessments by several resource sectors, has been designed and applied in this study. This integrated analytical system provides a framework for the coordination of resource assessments made by three resource use sectors representing different components and processes of a land use system. It consists of three submodels and an integrated model. The three submodels represent the agricultural, forestry, and wetland use sectors, while the integrated model represents the regional integration of these land use systems.

The ILAF system was applied to the Peace River Region of B.C. for testing purpose. The results of the Peace River case study illustrate

228

that it is practicable to assess systematically various impacts of land use change and policy. A broad range of land use problems, concerns, and land policies have been incorporated into, and analysed by, the integrated land assessment framework. These include land use conversion, intra and inter-sectoral land use competition, soil erosion, crop damage by waterfowl, waterfowl habitat protection, and sustainable resource use. In particular, the applications cover four specific types of analyses: (1) identification of the significance of integrated land assessment for sustainable land development; (2) estimation of the impacts of land use conversion on achieving land development goals; (3) conflict assessment and trade-off identification among various land use alternatives; and (4) land policy impact analysis.

This study provides guidelines and information for those interested in pursuing integrated land use analysis. For example, it illustrates how various dimensions of land use (economic, environmental) and multiple land use perspectives (perspectives from a broad range of agencies or other interest groups) can be represented in the research framework through interaction with concerned agencies.

This study is also of significance in terms of contribution to the development of geographical studies. Kates (1987) indicates that there is a great need for geographers to provide analysis and integration in dealing with challenges related to human-environment interactions. Moreover, geographers have an interest in solving problems of competing land use, complex land management and integrated natural resource development which are multiobjective and multisectoral in nature (CAG,

1987). Having studied the principles and concepts of both physical and social sciences, and having been equipped with tools or methods of the physical and social sciences, geographers alone are likely trained in a range of disciplines required to handle many pressing problems in human-environment interactions (Bennett and Chorley, 1978; Boulding, 1983; Kates, 1987).

Surprisingly, however, geographers show a relative lack of awareness of the development and application of integrated analytical frameworks to problems related to natural resource management and planning, and further, to global changes and sustainable economic development (Cocklin et al., 1987). Despite many accomplishments made by geographers in resource analysis, research problems and difficulties are still encountered. In many aspects, the research work in resource analysis is still in the early stages and needs improvement in understanding the basic relationships and processes of the resource use system. Macmillan (1989) claims that geography at large, is simply not facing up to the challenges of exploring the new research areas regarding some emerging global issues. The discipline's modelling expeditions are ill-equipped and short-handed. Thornes (1989) and Openshaw (1989) see the possibility that if geographers are not prepared to address human-environment interactions by reorientating their modelling work, then other scientists will be willing and able to take it up. Given the inadequate knowledge as to how environmental and socio-economic systems function, much remains to be done by geographers on this subject (Macmillan, 1989; Mitchell, 1989).

In the absence of integrated assessment frameworks, land use problems will be difficult to analyse and understand. This study shows that through the use of mathematical programming methods, particularly goal programming, it is possible to achieve a better level of understanding of the complex functioning of land use systems. These methods provide research frameworks for the resolution of problems involving multiple and conflicting objectives and for systematic investigation of various alternatives. Thus, they are useful tools which assist geographers, as well as other analysts, in getting a better insight into the implications of particular land resource development strategies and for the stock and flow characteristics of the resource base generally.

In summary, the chief contribution of this study is much less to provide information or solutions for land use planning and much more to provide procedures for integrating multiple resource use objectives and a range of resource sectors, in order to systematically investigate a set of land use prospects. In this sense the model developed is for heuristic purposes. The integrated land assessment framework possesses characteristics of a learning tool and a means of communication. As such, the results presented in the case study should not be viewed as a final analysis of the land use issues. If more reliable data are available, this analytical framework is flexible enough to generate a more accurate analysis. The integrated land assessment provides better insight into the trade-offs and conflicts between goals which are the key information for decision making in sustainable resource development.

Also, the research framework can serve as a forum for interaction and communication among decision makers from different government agencies, and among policy makers, the public, and analysts. For the aforementioned reasons, this framework can have a positive contribution to facilitate public participation in resource use decision making.

The need for involvement of the public in a policy process is based on the presupposition that the results of the assessment may be biased toward the views of analysts. Public participation is a process which provides a cooperative opportunity for different individuals and interest groups to present different values, goals, concerns, and perceptions to each other, and to discover the potential impacts of alternative development options or policies. Liebman (1976) suggests that programming models should be applied to provide insight and understanding, and to facilitate informed decisions. For this purpose, the analyst seeks to communicate effectively to policy makers and the general public the insights, structure, and understanding available from the models and the results. To provide more reliable information to improve public understanding and achieve compromise among different interest groups is one of the main concerns in this type resource analysis.

The above discussion raises questions as to the importance of public participation and as to the role of analytical methods within the overall policy making context of resource management. The ILAF system can be integrated with other assessment tools and specific mechanisms for involving public opinion to form a comprehensive

assessment framework. Such a framework coupled with an interactive element will ensure more active participation of and input from the general public and policy makers. Inclusion of public opinion will help to avoid the use of unrealistic scenarios and assumptions, and will provide an educational value in informing the public and policy makers of the implications of alternative courses of action when viewed within the context of the 'stake holders'. The interactive component of the analytical framework is further discussed in section 8.2.6.

8.2 Limitations of the Assessment and Means for Improvement

A variety of applications previously outlined indicate the usefulness and flexibility of the integrated analytical framework as a tool for the assessment of alternative land use prospects for achieving sustainable land development. Although an extensive endeavour has been made in data compilation and in modelling technology development, there are limitations in the integrated assessment system and thus there is room for improvement.

The purpose of this section is to identify limitations in the study and to suggest some potentially important research directions with respect to integrated resource assessment. The limitations of the case study, once identified, are accompanied with suggestions for improvements. Land resource analysis encompasses a great variety of different issues or problems which need to be assessed from many different perspectives. Keeping this in mind, the following issues are

discussed in this section: measuring model reliability, data improvement, the aggregation issue, scenario setting, and additional aspects in the assessment system.

8.2.1 Measuring Model Reliability

The integrated model has hundreds of equations and constraints, and thousands of variables and parameters. It is obvious that the reliability or usefulness of the model depends on the accuracy of these parameters and equations. Model testing and validation is critical to provide potential users with confidence in model results. In this study, many efforts have been made in the model construction and application phases to detect possible errors and unreliable aspects in the model. In the model building process, model functions and structural relations were modified frequently until the overall model does not seem inconsistent with the general assumptions about how the system works. The Peace River Region case study provided a good opportunity for testing the ILAF system. When inconsistent results were generated from a model run, structural relations and parameters were checked carefully and mistakes were corrected. In addition, partial sensitivity analysis was undertaken when the model was applied for conflict analysis. These model tests helped to find some flaws, and thus enhanced the confidence in the model.

Having said this, the study has not tested the model systematiclly and comprehensively with respect to model sensitivity. Model evaluation often relies on the purpose of the model. The purpose of this study, as

mentioned before, is to develop an integrated framework for achieving a better understanding of the behavior of land use systems. The ILAF system brings the structure and interactions of the land use system into a 'laboratory' where various experiments can be practised. The case study was designed for testing the ILAF system rather than for generating precise information for final land use decision making. Furthermore, severe constraints of time, resources, and money inhibited this study from having a thorough model testing.

In order to realize the potential of ILAF system as a means to provide meaningful and reliable guidelines for land policy making and planning, the model must be further tested. Many approaches can be adopted for model evaluation, among which sensitivity analysis and calibration are presented briefly here.

Sensitivity Analysis

An extensive sensitivity testing can indicate how sensitive various measures of the model output are to changes in parameter values, individually and in combination. More effort should be allocated to check and refine the values that have significant effects on the output. The question of whether sensitivity is or is not a desirable property of the model needs to be judged with regard to the problem being specified. It is important to know if the model is sensitive where the real land use system is sensitive, and insensitive where it is stable.

235

Calibration

The model can be validated against historical data to ensure that the model did correspond to reality. The ability of the model to reproduce past behavior may enhance the credibility of the model. One difficulty for model calibration is that the data for model testing must be independent of the data for model building. This is the dilemma that analysts have to face in the model calibration process: use all of the data to build a better model or save some already insufficient data for testing the model.

8.2.2 Data Improvement

Owing to the complex nature of land use problems, the data base required for the integrated land use assessment of the Peace River Region is extensive. Although certain data sources are relatively accurate, others are less so. The data base developed for the Peace River Region case study is characterized by a lack of consistency among various data sources for different land use activities, particularly between different resource sectors. Updated and complete time series data sets would improve studies in integrated land management.

Improvements of the existing integrated data base for this study can be made to increase the confidence of the results generated. Data from various sources may need to be checked by field survey. Attention should be given to data collection for other land resource activities such as recreation, tourism, fish, wildlife, settlement, and minerals,

such that the integrated land resource assessment can also take these land use activities into consideration.

A preventative measure for the future to resolve the problem of the persistent separation of data collection and land analysis is to have a database administrator which is responsible to all data users. By doing so, data gathered for one resource sector will be compatible with, and useful to, other sectors. Data acquisition and maintenance will follow a common format or set of rules covering some aspects of the data base--classification scheme, land unit, index, and so forth.

8.2.3 Aggregation Issue

In applying the methodology to assess the implications of various land use proposals in the Peace River Region, the spatial land units for assessment are based on map sections. It is assumed that various factors within each map section are homogeneous. However, the map section used in the case study may not be as homogeneous as assumed. Within a map section, there are variations in soil types, microclimates, land use patterns, yields, erosion rates, and so on. Even though a regional analysis based on 1x1 mile square will not lose too much local detailed information, bias due to this type of aggregation may still influence the relevance of the results.

The scale of aggregation is related to the purposes of different models. For example, at a global level, the United Nations model developed by Leontief and others (1977) only has 15 regions. At the

national scale, a sector model developed by Adams, Hamilton, and McCarl (1985) divides the U.S. into 58 'homogeneous' regions. There are 29 crop regions in the Canadian Regional Agricultural Model (CRAM) (Klein and Graham, 1985). In general, it is easier to fine-tune a model for a farm or a small area than for a broad region at the same level of detail.

If information on integrated land use for subareas within the map sections is available, a more disaggregated approach for the integrated land use assessment could be made. Instead of relying on land resource data for the map units, this alternative approach defines land use activities which best suit the biophysical and socio-economic conditions for each disaggregated subarea. Such a disaggregated approach may introduce more accuracy into the results of the assessment. However, as scale becomes finer, data requirements, mathematical structure, and computer time increase at a rapid rate. Data collection at this scale for a broad region will be very expensive, and represents a major challenge for scientists in many disciplines.

8.2.4 Alternative Scenario Setting

Another important aspect of the study which can be improved is the approach for scenario setting. Generally, the scenario specifications in this study are based upon parametric adjustments to certain selected coefficients under given assumptions. These assumptions basically involve extrapolations from data of the preceding years. A scenario set by this approach represents only one possible future condition.

Moreover quite often many conditions change through time. In view of the limitation of the parametric adjustment approach in scenario setting, it appears that the use of an economic forecasting mode. or simulation model would be helpful in developing better scenarios (Brklacich, 1989). Economic forecasting and simulation models utilize a variety of statistical and empirical techniques to project a set of future conditions relative to a specified set of assumptions, and provide a basis for designing scenarios (Brklacich, 1989).

8.2.5 Improvement of the Integrated Assessment Framework

The integrated land use assessment system developed in this study has involved the incorporation of multiple goals, multiple land use activities, and multiple land use prospects. It integrates three resource sectors and deals with a number of land use problems. Even so, certain aspects of the land use system have not been addressed in the integrated land resource assessment framework. For example, recreation, range, and forestry wildlife activities were omitted from the model because required information is unavailable at present. Further improvements of this research framework might be advanced in a number of ways.

Adjustments to the integrated assessment system could be undertaken by adding livestock activity to the agricultural sector, and adding wildlife habitat, recreation, and range use to the forestry and wetland sectors in the models. At this point, data for these land use activities are either not available or insufficient for analysis. There

239

are other mechanisms or marketing relationships which could be incorporated into the modular structure of the analytical framework. It may be desirable to consider crop and tree rotation alternatives in the models. The present structure of the assessment system consists of only land resource constraints. Labor and capital resource constraints are not considered in the assessment. Thus, it is assumed that labor and capital are not scarce resources in the study region. The incorporation of labor and capital resource constraints in the models would be helpful in studying land use problems from a different perspective. Variability of prices and values affect land resource allocation and land use conversion. If the models are to be employed for more complicated policy analysis or conflict assessment, the price factor could be incorporated in these models as endogenous variables. With the above adjustments, the research framework could be used to assess effectively the impacts of the changing price of agricultural products as a result of the changes of agricultural policies such as international trade or free trade with the U.S.

8.2.6 Improving Interaction with Decision Makers

Integrated land resource assessment needs to incorporate diverse values or preferences of a variety of interest groups or government agencies, and to deal with conflicts and disagreements among them. In this respect, the goal programming modelling possesses some characteristics which limit its performance in resource assessment. For example, the requirement of precise quantification lends GP to exclude

some important qualitative data from analysis. Also, GP needs fairly detailed *a priori* information on decision maker's preferences, aspiration levels, and values. It is obvious that reliable and explicit specification of goal levels and priority orderings is a prerequisite for achieving sound assessment results. The difficulty and reluctancy of decision makers in setting goal levels and priority orderings, may result in some problems for assessment. Consequently, significant interaction between model analysts and decision makers representing various government agencies and interest groups may be required to improve the integrated resource assessment.

The interactive approach is usually composed of several steps to exchange information between resource analysts and decision makers (Grauer and Wierzbicki, 1984). During the interaction process, the decision makers from different agencies and interest groups are asked to identify goals, target levels and preferences of goals. This, in turn, determines the parameters and priority ranks of the models. After the first run of the models, the solutions are presented to these decision makers for their response by indicating new changes in parameters or goals. These interactive processes are then repeated until a satisfactory solution is identified. The interactive approach assists decision makers to obtain greater insight in the trade-offs among different alternatives. It also provides a mechanism for coordination among various government agencies, and cooperation between analysts and decision makers.

In the case study, extensive discussions were held with specialists and officials in a variety of government and research agencies at both the provincial and regional levels. Interactions with these decision makers were carried out for data collection, goal setting, priority ranking, and land use problem defining. Some follow up interactions with decision makers in different agencies also took place after the analysis was completed. The results of the assessment were presented at several conferences where several government officials attended. People at the B.C. Ministry of Agriculture were contacted. Response to this study was generally positive.

However, no attempt was made to conduct a formal interactive analysis. It is beyond the capability of this study in terms of time and resources to have a comprehensive follow up communication with the decision makers and to give them an opportunity to review the results and provide feedback. The results of the case study could have been improved had the officials and specialists of these agencies, and other representatives of different public groups been contacted extensively for their comments on the results once the model runs were completed. The failure to consider the public opinion and to undertake a systematic post-evaluation communication impedes the process of providing policy makers and the local people with some general insights into land use problems. This is not a reflection of the weakness of the ILAF system, but rather of time and financial constraints which would largely be eliminated if a larger study group were to be involved.

8.3 Extension of the Research

Rapid population growth and a rising standard of living have increased the derived demand for natural and environmental resource use. Economic growth and human activities are disturbing earth's life support system (Clark and Munn, 1986). Several natural resource and environmental problems have pushed global change and sustainable development issues to the center stage. These crucial resource and environmental issues include: greenhouse warming, the disappearance of tropical forests, the depletion of stratospheric ozone, desertification, the increased rate of soil erosion worldwide, and damage to lakes and forests by acid rain (Brundtland, 1989). The emergence of concerns on global changes and sustainable economic development present a fundamental challenge to scientists across various disciplines.

Research on global change or sustainable development is immensely complex. Any study on global change related problems must deal with an interrelated array of physical, biological, social, and economic systems. In the search for an understanding and assessment of these problems, it is necessary to adopt approaches which encompass large scale and interactive processes. Sustainable resource development must be considered globally but action must be locally.

Continued progress in understanding global changes and sustainable development requires, among other things, the development and application of various mathematical models which can simulate and integrate various systems and their interactions (Meadows, Richardson

243

and Bruckmann, 1982; NASA, 1988). The integrated research framework developed in this study allows for local or regional evaluation, and is appropriate for impact assessment of economic-environmental changes. It is more realistic in its consideration of multiple objectives and multiple resource sectors. The integrated framework can be adapted and extended to examine certain issues relating to global changes or sustainable development. To achieve this type of research goal, it is necessary to extend the research framework by incorporating other mathematical models to simulate the processes and the complex interactions that characterize physical and biological systems.

In the assessment process, many objectives must be considered. These may include economic efficiency, environmental quality, regional or intergenerational equity, and so on, all of which represent preferences and aspirations of different interest groups. There are several dimensions to the understanding process (Parry and Carter, 1987). The first is identification and anticipation of the impacts of human activities on global changes. That is, the influence of industrial, agricultural, and other human activities on ecosystems. The second addresses the interactions between variables of physical or biological systems. For example, climatic change may affect the intensity of soil erosion, desertification, or salinization. Climatic change in the form of higher temperature or lower precipitation may threaten crop or forest growth. The third involves a systematic assessment of the implications of various global changes for achieving societal development objectives, along with a need to understand the

interactions between the biophysical system and the socio-economic system. The fourth is concerned with policy analysis to identify appropriate public policies to adapt to global changes and to protect the public interest.

Key insights must come from a broad area of knowledge about various physical, biological, and economic systems, and the processes and interrelationships both within and among these systems (Brown and Sandra, 1987). These can be simplified and represented by physical and biological simulations, as well as other conceptual or numerical models (Annino and Russell, 1979; Putman and Dyke, 1987). Various simulation models can be used as effective means to examine issues related to global changes and sustainable economic development (Williams et al., 1983; Schlesinger and Mitchell, 1985; Strain and Cure, 1985)

These physical and biological simulation models can be linked with the ILAF system developed in this study to form a comprehensive and systematic research framework. Implications of various environmental or resource changes, or policy responses to these changes, for sustainable resource development can be examined by applying the potential research framework. Output of these physical and biological simulations will be treated as inputs to the scenario mode of the ILAF system. The extended integrated research framework will be able to improve our understanding of the relationships between various components across all the biophysical and socio-economic systems. It can provide information to identify those land use prospects or land use policies which will improve living conditions associated with acceptable resource depletion,

environmental degradation and social instability.

REFERENCES

Adams, R.M., Hamilton, S.A. and McCarl, B.A. 1985. <u>The Economic Effects of Ozone on Agriculture.</u> EPA-600/3-84-090. Corvallis, Ore.: Oregon State University.

Anderson, J.R. 1974. "Simulation: methodology and application in agricultural economics." <u>Review of Marketing and Agricultural Economics</u> 42(1): 3-55.

Annino, J.S. and Russell, E.C. 1979. "The ten most frequent causes of simulation analysis failure and how to avoid them." <u>Simulation</u> 32(6): 137-140.

ASA. 1982. <u>Determinants of Soil Loss Tolerance.</u> American Society of Agronomy, Soil Science Society of America. Madison, Wis.

Baehr, B.E. and Dobb, J.L. 1985. <u>Provincial Development Plan Cereals, Oilseeds, and Seed Crops.</u> Peace River Region, B.C. Ministry of Agriculture and Food.

Barbier, E.B. 1987. "The concept of sustainable economic development." <u>Environmental Conservation</u> 14(2): 101-110.

Barbier, E.B. 1989a. <u>Economics, Natural-Resource Scarcity and Development.</u> London: Earthscan Publications Limited.

Barbier, E.B. 1989b. "The global greenhouse effect: economic impacts and policy considerations." <u>Natural Resource Forum</u> (Feb.): 20-32.

Barlowe, Raleigh. 1972. <u>Land Resource Economics.</u> 2nd ed. Englewood Cliffs, N.J.: Prentice-Hall.

Barnett, H.J. and Morse, C. 1963. <u>Scarcity and Growth: The Economics of Natural Resource Availability.</u> Baltimore: The Johns Hopkins Press.

Bartlett, D. and Clawson, W.J. 1978. "Profit, meat production or efficient use of energy in ranching." <u>J. of Animal Science</u> 46: 812-818.

Bartlett, E.T., Bottoms, K.E. and Pope, R.P. 1976. <u>GOAL -- Multiple Objective Programming.</u> Range Science Series No. 21. Range Science Department, Colorado State University.

Batten, D.F. 1984. "Adaptive learning and multistage compromises for multilevel decision making in macroeconomic systems." In: M. Despontin et al., (eds.). <u>Macro-Economic Planning with Conflicting Goals.</u> Berlin: Springer-Verlag.

BCMOA&F. 1979. B.C. Land Inventory Report: Volume 1&2. B.C. Ministry of Agriculture and Food. Victoria.

BCMOA&F. 1981a. Agriculture Region Report: Peace River. Peace Agriculture Regional Office. Ministry of Agriculture and Food. Victoria.

BCMOA&F. 1981b. Agriculture Statistics Yearbook. B.C. Ministry of Agriculture and Food. Victoria.

BCMOA&F. 1984. Agriculture Profile: Fort St. John District. Victoria, B.C.

BCMOA&F. 1985. Waterfowl Damage to Grain Crops in the Peace River Region, B.C.: A Summary Report and Suggested Damage Mitigation Program. Crop Protection Branch, Cloverdale, B.C.

BCMOA&F. 1988. Risk Identification & Measurement in The Grain Crop Insurance Program. Draft. Farm Income and Crop Insurance Branch. Victoria, B.C.

BCMOE. 1985-86. 85-86 Photography. Serveys and Resource Mapping, Victoria, B.C. Scale 1:50,000.

BCMOE. 1988. Fort St. John Regional Wildlife Plan. Fish and Wildlife Branch. Fort St. John, B.C.

BCMOF. 1971. Forest Cover Map. Forest Service. Fort St. John, B.C. Scale 1:50,000.

BCMOF. 1978-89. Ministry of Forests Annual Report. Forest Service. Victoria, B.C.

BCMOF. 1980a. Forest and Range Resource Analysis: Technical Report. Volume 1&2. B.C. Ministry of Forests. Victoria.

BCMOF. 1980b. Catalogue of Output Statements. Forest and Range Statistics Section, Inventory Branch. Victoria, B.C.

BCMOF. 1981a. Peace Timber Supply Area Yield Analysis Report. Forest Service. Prince George Forest Region, B.C.

BCMOF. 1981b. Site Index Equations and Curves For the Major Tree Species in British Columbia. Inventory Branch. Victoria, B.C.

BCMOF. 1984. Forest and Range Resource Analysis. B.C. Ministry of Forests. Victoria.

BCMOF, 1985a. 1984 Forest and Range Resource Analysis: Background Report, Volumes 1&2. Victoria, B.C.

BCMOF. 1985b. Peace Timber Supply Area Statement of Issues, Options and Procedures. Forest Service. Prince George Forest Region, B.C.

BCMOF. 1985c. Timber Supply Analysis Data Package Peace Timber Supply Area. Forest Service. Prince George Forest Region, B.C.

BCMOF. 1986. Peace Timber Supply Area Options Report. Forest Service. Prince George Forest Region, B.C.

BCMOF. 1987. Draft Fort St. John TSA Plan #1. Forest Service. Prince George Forest Region, B.C.

BCMOF. 1988. Five Year Forest and Range Resource Program 1988-1993. B.C. Ministry. Victoria.

BCMOLP&H and BCMOF. 1981. Provincial Forest – Crown Land Administration, Deferred Area Planning Program, General Policy Framework. B.C. Ministry of Lands, Parks and Housing, and B.C. Ministry of Forests. Report. Victoria.

BCMOLP&H. 1982. A Methodology for Including Economic Criteria In the Crown Land Forestry/Agriculture Allocation Process. Williams Lake, B.C.

BCMOLP&H. 1983. Fort St. John North Area Sub-District Crown Land Planning Report. Peace Region, Fort St. John, B.C.

BCMOLP&H. 1985a. An Inventory of Crown Land Suitable for Agricultural Development in the Peace Region. Draft. Peace Region, Fort St. John, B.C.

BCMOLP&H. 1985b. Lower Peace River Valley Land Use Options. Ministry of Lands, Parks and Housing. Victoria, B.C.

B.C. Standing Committee on Agriculture, 1978a. Land Productivity in British Columbia. Victoria, British Columbia.

B.C. Standing Committee on Agriculture, 1978b. Inventory of Agricultural Land Reserves in British Columbia, Phase I Research Report. Legislative Assembly, B.C.

Bell, E.F. 1977. "Mathematical programming in Forestry." J. of Forestry (June): 317-319.

Bennett, R.J. and Chorley, R.J. 1978. Environmental Systems. Princeton, N.J.: Princeton University Press.

Berry, B., Conkling, E.C. and Ray, D.M. 1987. Economic Geography. Englewood Cliffs, N.J.: Prentice-Hall, Inc.

Bolin, B., Doos, Bo R., Jager, J. and Warrick, R.A. 1986. The Greenhouse Effect, Climatic Change, and Ecosystems. SCOPE 29. New York, N.Y.: John Wiley & Sons.

Boothroyd, P. 1978. "Issues in social impact assessment." Plan Canada 18(2): 118-134.

Bornford, L. 1988. Policy Branch, B.C. Ministry of Agriculture and Fisheries. Communication.

Boulding, E. 1983. "Setting new research agendas: a social scientist's view." In: R.S. Chen, E. Boulding, and S.H. Schneider, (eds.) Social Science Research and Climate Change: An Interdisciplinary Appraisal. Dordrecht, Holland: D. Reidel Publishing Company.

Braat, L.C. and Van Lierop, W.F.J. (eds.) 1987. Economic-Ecological Modeling. Amsterdam: North-Holland.

Brklacich, M., Smit, B. and Phillips, T. 1984. "Long-term prospects for sustainable agricultural production in Ontario, Canada." Paper presented to the Eighth Annal Meeting of the Canadian Regional Science Association. Guelph.

Brklacich, M. 1989. A Framework for Evaluating the Sustainability of Food Production System in a Changing Environment. PhD Thesis. University of Waterloo, Ontario.

Bromley, D.W. (ed.) 1986. Natural Resource Economics: Policy Problems and Contemporary Analysis. Boston: Kluwer-Nijhoff Publishing.

Brouwer, F.M. 1989. "Determination of broad-scale land use changes by climate and soils." J. of Environmental Management 29: 1-15.

Brown, L.R. and Sandra, L.P. 1987. "Thresholds of change." The Futurist (Sept.-Oct.): 9-14.

Browning, B. 1949. "The muskingun story." Journal of Soil and Water Conservation 13-16, 20.

Brundtland, G.H. 1989. "Global change and our common future." Environment 31(5): 16-20, 40-43.

Bryant, C.R. and Russwurm, L.H. 1982. "North American farmland protection strategies in retrospect." Geojournal 6(6): 501-512.

Buongiorno, J. and Gilless, J.K. 1987. Forest Management and Economics. New York: Macmillan Publishing Company.

Cable, T.T., Brach, Jr. V. and Holmes, V.R. 1989. "Simplified method for wetland habitat assessment." Environmental Management 13(2): 207-213.

CAG, 1987. The Skills of Geography. Canadian Association of Geographers.

Canada. Agriculture Canada. 1983. The Land Potential Data Base for Canada: User's Handbook. Land Resource Research Institute, Research Branch. LRRI Contribution No. 82-68. Ottawa.

Canada. Agriculture Canada. 1984. Agricultural Land Degradation in Western Canada: A Physical and Economic Overview. Development Policy Directorate, Regional Development Branch. Ottawa.

Canada. Agriculture Canada. 1985. Self-sufficiency Trends in Canadian Agriculture: 1960-1990 and Future Prospects. Working Paper 5/85. International Trade Policy Division, Marketing and Economic Branch. Ottawa.

Canada. Agriculture Canada. 1986a. Soils of the Fort St. John-Dawson Creek Area, British Columbia. Report No. 42. British Columbia Soil Survey, Research Branch. Vancouver. Scale 1:100,000.

Canada. Agriculture Canada. 1986b. Development of the Agri-Food Sector in British Columbia. Agriculture Development Branch. New Westminster, British Columbia.

Canada. DREE. 1970a. Towards Integrated Resource Management Report of The Sub-Committee on Multiple Use, National Committee on Forest Land. Department of Regional Economic Expansion. Ottawa: Queen's Printer for Canada.

Canada. DREE. 1970b. Land Capability for Wildlife - Waterfowl. Canada Land Inventory. Scale 1:250,000. Ottawa: Department of Regional Economic Expansion.

Canada. Environment Canada. 1972. Land Capability Analysis. Ottawa: Lands Directorate. Scale 1:250,000.

Canada. Environment Canada. 1973. Land Capability for Forestry. Ottawa: Lands Directorate. Scale 1:125,000.

Canada. Environment Canada. 1974. Soil Capability for Agriculture. Ottawa: Lands Directorate. Scale 1:125,000.

Canada. Environment Canada. 1976. Land Capability for Wildlife-Waterfowl. Ottawa: Canada Land Inventory. Scale 1:1,000,000.

Canada. Environment Canada. 1983. Land Use Change on Wetlands in Southern Canada: Review and Bibliography. Working Paper No. 26. Ottawa: Lands Directorate.

Canada. Environment Canada. 1984. Land Use Monitoring on Wetland in the Southwestern Fraser Lowland, British Columbia. Working Paper No. 34. Ottawa: Lands Directorate.

Canada. Environment Canada. 1985a. The Agriculture-Forest Interface: An Overview of Land Use Change. Working Paper No. 38. Ottawa: Lands Directorate.

Canada. Environment Canada. 1985b. Feasibility of Constructing A Multisector Land Evaluation System: The New Brunswick Pilot Study. Working Paper No. 42. Ottawa: Lands Directorate.

Canada. Environment Canada. 1985c. Preliminary Assessment of Wetland Alienation in the South Thompson-Okanagan and Peace River Fort St. John Areas of B.C. Canadian Wildlife Service. Delta, B.C.

Canada. Environment Canada. 1986. Wetland in Canada: A Valuable Resource. Fact Sheet 86-4. Ottawa: Lands Directorate.

Carpenter, R.A. (ed.) 1983. Natural Systems For Development: What Planners Need to Know. New York, N.Y.: Macmillan Publishing Company.

Chang, S.J. and Buongiorno, J. 1981. "A programming model for Multiple use forestry." J. of Environmental Management 13: 45-58.

Chankong, V. and Haimes. Y.Y. 1983. Multiobjective Decision Making: Theory and Methodology. Series Volume 8. North-Holland.

Chapman, G.R., Smit, B. and Smith, W.R. 1984. "Flexibility and criticality in resource use assessment." Geographical Analysis 16(1): 52-64.

Charnes, A., Haynes, K., Hazleton, J., and Ryan, M. 1975. "A hierarchical goal-programming approach to environmental land use management." Geographical Analysis 7(2): 121-130.

Chen, K. 1983. "Using alternative future scenarios for integrating impact assessment." In: F.A. Rossini, and A.L. Porter, (eds.) Integrated Impact Assessment. Boulder, Colo.: Westview Press

Chiang, A.C. 1984. Fundamental Methods of Mathematical Economics. New York, N.Y.: McGraw-Hall.

Chorley, R.J. 1973. "Comments on systems modelling and analysis in resource management, by J.N.R. Jeffers" _J. of Environmental Management_ 1: 29-31.

Christensen, K. 1976. _Social Impacts of Land Development._ Washington, D.C.: The Urban Institute.

Clark, M. 1988. Ducks Unlimited, Prince George, B.C. Communication.

Clark, W. and Muun, R. (eds.) 1986. _Sustainable Development of the Biosphere._ Worcester, Mass.: Cambridge University Press.

Clayton, J.S., Ehrlich, W.A., Cann, D.B., Day, J.H. and Marshall, I.B. 1977. _Soils of Canada, Vols. 1 and 2_ Ottawa, Canada: Department of Agriculture.

Cocklin, C., Lonergan, S. and Smit, B. 1984. "A goal programming model to assess options in resource use for renewable energy: the case of poplar development in Eastern Ontario." _Modeling and Simulation_ 15(1): 561-566.

Cocklin, C., Smit, B. and Johnston, T. (eds.) 1987. _Demands on Rural Lands: Planning for Resource Use._ Westview Press, Inc.

Cocklin, C. 1988. "Environmental values, conflicts and issues in evaluation." _The Environmentalist_ 8(2): 93-105.

Cocklin, C., Lonergan, S. and Smit, B. 1988. "Assessing conflicts in the use of rural resources: an analytical framework." _Journal of Rural Studies_ 4(1): 9-20.

Cocklin, C. 1989a. "Methodological problems in evaluating sustainability." _Environmental Conservation_ 16(4): 343-351.

Cocklin, C. 1989b. "Mathematical programming and resources planning I: the limitations of traditional optimization." _Journal of Environmental Management_ 28: 127-141.

Coffey, W.J. 1981. _Geography-Towards a General Spatial Systems Approach._ New York, N.Y.: Methuen.

Cohon, J.L. and Marks, D. 1975. "A review and evaluation of multiobjective programming techniques." _Water Resource Research_ 11(2): 208-220.

Cohon, J.L. 1978. _Multiobjective Programming and Planning ._ New York, N.Y.: Academic Press, Inc.

Collins, J. and Hadland, A. 1988. Forestry or Agriculture: A Case for Diversification of British Columbia Peace River Farms. Fort St. John, B.C.

Conklin, H.E. 1959. "The Cornell system of economic land classification." J. of Farm Economics 41: 548-557.

Conner, D.M. 1985. Constructive Citizen Participation: A Resource Book. (Revised Edition). Victoria, B.C.: Development Press.

Conway, G.R. 1983. Applying Ecology. London: Centre for Environmental Technology, Imperial College.

Conway, G.R. 1985. "Agroecosystem analysis." Agricultural Administration 20: 31-55.

Cooper, W. and Vlasin, R.O. 1973. "Ecological concepts and applications to planning." In: D.M. McAllister, (ed.) Environment: A New Focus for Land-Use Planning. Washington, D.C.: National Science Foundation.

Crain, I.K. and MacDonald, C.L. 1984. From Land Inventory to Land Management: The Evolution of an Operational Geographic Information System. Proceedings, Autocarto Six. Ottawa.

Crosson, P. (ed.) 1982. The Cropland Crisis: Myth or Reality? Resources For the Future. Baltimore: Johns Hopkins University Press.

Crosson, P. and Stout, A.T. 1983. Productivity Effects of Cropland Erosion. Baltimore: Johns Hopkins University Press.

Crosson, P. 1989. "Climate change and mid-latitudes agriculture: perspectives on consequences and policy responses." Climatic Change 15(2,3): 51-73.

Crosson, P. and Rosenberg, N.J. 1989. "Strategies for agriculture." Scientific American (Sept.): 128-135.

Cumberland, J.H. and Stram, B.N. 1974. "Empirical results from application of input-output models to environmental problems." Paper presented to Sixth International Conference on Input-Output Techniques, Vienna.

Czamanski, S. 1972. Regional Science Techniques in Practice: The Case of Nova Scotia. Toronto: D.C. Health & Co.

Daly, H.E. 1984. "Report on report." Environment 26(7): 25, 27-28.

Daly, H.E. and Cobb, Jr. J.B. 1989. For the Common Good. Boston: Beacon Press.

Dane, C.W., Meador, N.C. and White, J.B. 1977. "Goal programming in land-use planning." J. of Forestry (June): 325-329.

d'Arge, R.C. 1972. "Economic growth and the natural environment." In: A.V. Kneese, and B.T. Bower, (eds.) Environmental Quality Analysis. Baltimore: Johns Hopkins University Press.

Dawson, A.H. 1984. The Land Problem in the Developed Economy. London: Croom Helm.

Day, J.C. et al. 1977. "A strategy for hintsight evaluation of environmental impacts." In: M. Plewes, and J.B.R. Whitney, (eds.) Environmental Impact Assessment in Canada: Processes and Approaches. Institute for Environmental Studies, University of Toronto.

deGroot, R. 1987. "Environmental functions as a unifying concept for ecology and economics." The Environmentalist 7(2): 105-109.

Dee, N., Drobny, N.L., Baker, J.K., Duke, K.M. and Fahringer, D.C. 1973. "An envirnomental evaluation system for water resource planning." Water Resources Research 9(3): 523-535.

de Neufville, J.I.(ed.) 1981. The Land Use Policy Debate in the United States. New York, N.Y.: Plenum Press.

de Souza, A.R. and Foust, J.B. 1979. World Space-Economy. Columbus, Ohio: Merrill Publishing Company.

Despontin, M., Nijkamp, P. and Spronk, J. 1984. "Conflict analysis in macroeconomic planning models." In: M. Despontin, et al. (eds.) Macro-Economic Planning With Conflicting Goals. Proceedings, Brussels, Belgium. Berlin: Springer-Verlag.

Dobbins, C.L. and Mapp, H.P. 1983. "A recursive goal programming model of intergenerational transfers by farm firms." In: K.H. Baum, and L.P. Schertz, (eds.) Modelling Farm Decisions for Policy Analysis. 310-331. Boulder, Co. Westview Press.

Douglass, G. 1984. "The meanings of agricultural sustainability." In: G. Douglass (ed.) Agricultural Sustainability in a Changing World Order. Boulder: Westview Press.

Dumanski, J. and Stewart, R.B. 1981. Crop Production Potentials for Land Evaluation in Canada. Ottawa: Research Branch, Agricultlure Canada.

Dyer, A.A., Hof, J.G., Kelly, J.W., Crim, S.A. and Alward, G.S. 1979. "Implications & goal programming in forest resource allocation." Forest Science 25: 535-543.

Fabos, G. and Caswell, S. 1977. Composite Landscape Assessment Procedures for Special Resources, Hazards and Development Suitability. Part II of the METLAND Model. Amherst: University of Massachusetts Press.

FAO, 1977. The Fourth World Food Survey. FAO Statistics Series No. 11, FAO Food and Nutrition Series No. 10. Rome.

FAO, 1971-81. FAO/Unesco Soil Map of the World, 1:5 Million. Vols. 1-10. Paris.

FAO, 1978-81. Reports of the Agro-Ecological Zones Project. World Soil Resources Report No. 48. Rome.

FAO, 1983. Potential Population Supporting Capacity of Lands in the Developing World. Rome.

FAO, 1984. "Erosion and productivity: a review of its effects and research with suggestions for further investigation." Rome

FEARO, 1984. Beaufort Sea Hydrocarbon Production and Transportation. Final Report of the Environmental Assessment Panel. Hull, Quebec: Federal Environmental Assessment Review Office.

FEPA, 1989. Work Plan 1989-90. Forest Economics and Policy Analysis Research Unit, University of British Columbia.

Field, D.B. 1973. "Goal programming for forest management." Forest Science 19(2): 125-135.

Finsterbusch, K. 1985. "State of the art in social impact assessment." Environment and Behavior 17(2): 193-221.

Flaherty, M. and Smit, B. 1982. "An assessment of land classification techniques in planning for agricultural land use." J. of Environment Management 15: 323-332.

Forgionne, G.A. 1986. Quantitative Decision Making Belmont, California: Wadsworth Inc.

Forman, R.T. and Godron, M. 1986. Landscape Ecology. New York, N.Y.: John Wiley & Sons, Inc.

Found, W.C. 1971. A Theoretical Approach to Rural Land Use Patterns. Toronto: Macmillan.

Frankena, M.W. and Scheffman, D.T.(1980). Economic Analysis of Provincial Land Use Policies in Ontario. Toronto: University of Toronto Press.

Gates, W.L. 1985. "The use of general circulation models in the analysis of the ecosystem impacts of climatic change." Climatic Change 7(3): 267-284.

Gelinas, R., Bond, D. and Smit, B. 1986. Perspectives on Land Modelling. Workshop Proceedings. Toronto, Ontario. November 17-20. montreal: Polyscience Publications Inc.

Gleick, P. 1987. "Regional hydrologic consequences of increases in atmoshperic CO_2 and other trace gases." Climatic Change 10(2): 137-161.

Goldman, D. 1981. "Land use: the multiple use concept." Environment 23(8): 4-5.

Graham, J.D. and Lopez, R. 1976. Farm Planning Under Uncertainty - An Application of MOTAD Programming to the Peace River Block of British Columbia. University of British Columbia.

Grauer, M. and Wierzbicki, A.P. (eds.) 1984. Interactive Decision Analysis. Berlin: Springer-Verlay.

Harper, F. 1988. Fish and Wildlife Branch, B.C. Ministry of Environment. Fort St. John. Communication.

Hassan, Z.A. and Huff, H.B. (eds.). 1985. Agricultural Sector Models for Policy Analysis. Ottawa: Commodity Markets Analysis Division, Agriculture Canada.

Hazell, P.B.R. and Norton, R.D. 1986. Mathematical Programming for Economic Analysis in Agriculture. New York, N.Y.: Macmillan Publishing Company.

Heal, G.M. 1981. "Economics and resources." In: J.A. Butlin, (ed.) The Economics of Environmental and Natural Resources Policy. Boulder, CO.: Westview.

Helmer, O. 1977. "Problems in futures research: delphi and causal cross-impact analysis." Futures 9: 17-31.

Hill, K.Q. and Fowles, J. 1975. "The Methodological worth of the delphi forecasting technique." Technological Forecasting and Social Change 7: 179-192.

Hill, M.A. 1968. "Goals-achievement matrix for evaluating alternative plans" J. of the American Institute of Planners 34: 19-28.

Hoffman, D.W. 1971. The Assessment of Soil Productivity for Agriculture. Report No. 4. Ottawa: ARDA.

Hoffman, K. 1981. "Remarks on Wood and Greenberger papers." In: S.I. Gass (ed.) Validation and Assessment of Energy Models. Washington, D.C.: U.S. Government Printing Office.

Holling, C.S. (ed.) 1978. Adaptive Environmental Assessment and Management. Chichester: John Wiley.

Hufschmidt, M., James, D.E., Meister, A.D., Bawe, B.T. and Dixon, J.A. 1983. Environment, Natural Systems, and Development: An Economic Valuation Guide. Baltimore: The Johns Hopkins University Press.

Hwang, C.L. and Masud, A.S.M. 1979. Multiple Objective Decision Making -- Methods and Applications: A State-of -the-Art Survey. Berlin: Springer-Verlag.

Hwang, C.L. and Yoon, K. 1981. Multiple Attribute Decision Making, Methods and Applications. Berlin: Springer-Verlag.

IFIAS, 1988. Human Response to Global Change: Prospectus for an International Programme. 2nd Edition. Toronto: The International Federation of Institutes for Advance Study.

Ignizio, J.P. 1976. Goal Programming and Extensions. Lexington, Mass.: Lexington Books.

Ignizio, J.P. 1982. Linear Programming in Single - & Multiple - Objective Systems. Englewood Cliffs, N.J.: Prentice-Hall, Inc.

Ilbery, B.W. 1985. Agricultural Geography: A Social and Economic Analysis. New York, N.Y.: Oxford University Press.

Isard, W. 1960. Methods of Regional Analysis: An Introduction to Regional Science. Boston: The MIT Press.

Isard, W. 1972. Ecological-Economic Analysis for Regional Development. New York, N.Y.: The Free Press.

Jain, R.K., Urban, L.V. and Stacey, G.S. 1977. Environmental Impact Analysis: A New Dimension in Decision Making. New York, N.Y.: Van Nostrand Reinhold.

Jeffers, J.N.R. 1973. "Systems modelling and analysis." J. of Environmental Management 1: 13-28.

Jeffers, J.N.R. (ed.) 1988. Practitioner's Handbood on the Modelling of Dynamic Change in Ecosystems. SCOPE 34. New York, N.Y.: John Wiley & Sons.

Kate, R.W. and Burton, I. (eds.) 1986. Geography, Resources, and Environment: Volume I. Chicago: the U. of Chicago Press.

Kate, R.W. 1987. "The human environment: the road not taken, the road still beckoning." Annals of the Association of American Geographers 77(4): 525-534.

Keeney, R.L. and Raiffa, H. 1976. Decision With Multiple Objectives: Preferences and Value Tradeoffs. New York, N.Y.: Wiley.

Killen, J.E. 1983. Mathematical Programming Methods for Geographers and Planners. London: Croom Helm Ltd.

Klein, K.K. and Graham, J.D. 1985. "A Canadian agricultural regional programming model." In: Z.A. Hassan, and H.B. Haff, (eds.) Agricultural Sector Models for Policy Analysis. Ottawa: Agriculture Canada.

Kok, W. 1988. Ministry of Forests. Fort St. John Forest District. Communication.

Koopmans, T.C. 1951. Activity Analysis of Production and Allocation. New York, N.Y.: Wiley.

Krueger, R.R. 1978. "Urbanization of the Niagra Fruit Belt." Canadian Geographer 22(3): 179.

Kuhn, H.W. and Tucker, A.W. 1951. "Nonlinear programming." In: J. Neyman, (ed.) Proceedings Second Berkeley Symposium on Mathematical Statistics and Probability. Berkeley: University of California Press.

Lang, R. and Armour, A. 1980. Environmental Planning Resourcebook. Ottawa: Lands Directorate, Environment Canada.

Lang, R. (ed.) 1986a. Integrated Approaches to Resource Planning and Management. Resource Management Programs, The Banff Centre School of Management.

Lang, R. 1986b. "Achieving integration in resource planning" In: R. Lang, (ed.) Intgrated Approached to Resource Planning and Management. Resource Management Programs, The Banff Centre School of Management.

Lave, L.B. and Epple, D. 1985. "Scenario analysis." In: R.W. Kates, J.H. Ausubel and M. Berberian, (eds.) 1985. Climate Impact Assessment SCOPE 27. New York, N.Y.: John Wiley & Sons.

Lecomber, R. 1979. The Economics of Natural Resources. London: Macmillan Press Ltd.

Lee, Jr. D.B. 1981. "Land use planning as a response to market failure." In: J.I. de Neufville, (ed.) The Land Use Policy Debate in the United States. New York, N.Y.: Plenum Press.

Lee, N. 1983. "Environmental impact assessment: a review." Applied Geography 3: 5-27.

Lee, S.M. 1972. Goal Programming for Decision Analysis. Philadelphia: Auerbach Publishers.

LEG, 1983. "An overview of the LEM2 system - Volume I." Report No. 6/81-83. Land Evaluation Group, University of Guelph.

Leistritz, F.L. and Ekstrom, B.L. 1986. Social Impact Assessment and Management: An Annotated Bibliography. New York, N.Y.: Garland Publishing, Inc.

Leontief, W., Carter, A.P. and Petri, P.A. 1977. The Future of the World Economy. A United Nations Study. New York, N.Y.: Oxford University Press.

Liebman, J. 1976. "Some simple-minded observations on the role of optimization in public systems decision making." Interfaces 6(4): 102-108.

Lonergan, S.C. and Cocklin, C. 1985. "The use of input-output analysis in environmental planning." J. of Environmental Management 20: 129-147.

Lonergan, S.C. and Cocklin, C. 1988. "The use of lexicographic goal programming in economic/ecological conflict analysis." Socio-Economic Planning Sciences 22(2): 83-92.

Love, C.E. 1986. IMPS: Interactive Mathematical Programming System User's Manual. Simon Fraser University.

Maclaren, V.W. 1985. "Multicriteria evaluation methods." In: V.W. Maclaren and J.B.R. Whitney, (eds.) New Directions in Environmental Impact Assessment in Canada. Agincourt, Ontario: Methuen.

Maclaren, V.W. and Whitney, J.B.R. (eds.) 1985. New Directions in Environmental Impact Assessment in Canada. Agincourt, Ontario: Methuen.

Macmillan, Bill (ed.) 1989. Remodelling Geography. Cambridge, Mass.: Basil Blackwell Ltd.

MacNeill, J. 1989. "Strategies for sustainable economic development." Scientific American September: 155-165.

Malone, T.F. and Corell, R. 1989. "Mission to Planet Earth Revisited." Environment 31(3): 7-11, 31-35.

Manning, E.W. 1986. "Towards sustainable land use: a research agenda for Canadian land resource issues." Paper presented at the Canada-China Bilateral Symposium on Territorial Development and Management. Beijing, China.

Manning, E.W. 1988. "The analysis of land use determinants in support of sustainable development." Ottawa: Environment Canada.

McAllister, D. (ed.) 1973. Environment: A New Focus for Land-Use Planning. Washington, D.C.: National Science Foundation.

McAllister, D. 1980. Evaluation in Environmental Planning-Assessing Environmental, Social, Economic, and Political Trade-offs. Cambridge, Mass.: The MIT Press.

McConnell, K.E., Daberkow, J.N. and Hardie, I.W. 1983. "Planning timber production with evoluing prices and costs." Land Economics 59(3): 292-299.

McGrew, J. 1975. Goal Programming and Complex Problem Solving in Geography. Pennsylvania State University, Paper in Geography No. 12.

McHarg, I. 1969. Design With Nature. New York, N.Y.: Natural History Press.

Meadows, D., Richardson, J. and Bruckmann, G. 1982. Groping in The Dark: The First Decade of Global Modelling. New York, N.Y.: John Wiley & Sons.

Mendoza, G.A. 1988. "A multiobjective programming framework for integrating timber and wildlife management." Environment Management 12(2): 163-171.

Miller, R.E. and Blair, P.D. 1985. Input-Output Analysis: Foundations and Extensions. Inglewood Cliffs, N.J.: Prentice-Hall.

Mitchell, B. 1986. "The evolution of integrated resource management." In: R. Lang, (ed.) Integrated Approaches to Resource Planning and Management. Resource Management Programs, The Banff Centre School of Management.

Mitchell, B. 1989. Geography and Resource Analysis. Second Edition. Essex, U.K.: Longman Scientific & Technical.

Moss, M.R. 1983. "Land synthesis, landscape processes and land classification, some theoretical and methodological issues." Geojournal 7(2): 145-153.

Munn, L.C. 1986. "The Canada Land Inventory." In: Institute of Terrestrial Ecology. Proceedings of the NATO Semiar on Land and Its Uses. Scotland: Midlothian.

Myers, N. 1987. "The environmental basis of sustainable development." The Annals of Regional Science 21(3): 33-43.

NASA, 1988. Earth System Science: A Program for Global Change. National Aeronautics and Space Administration. Washington, D.C.

Neely, W.P., Sellers, J. and North, R.M. 1980. "Goal programming priority sensitivity analysis: an application in natural resource decision making processes." Interfaces 10(5): 83-88.

Nijkamp, P.P. and Rietveld, P. 1976. "Multi-objective programming models--a new way in regional decision-making." Regional Science and Urban Economics 6: 253-274.

Nijkamp, P.P. and Spronk, J. 1979. "Interactive multiple goal programming: an evaluation and some results." In: G. Fandel, and T. Gal, (eds.) Multiple Criteria Decision Making Theory and Application. Proceedings of the Third Conference Hagen/Konigswinter, West Germany. Berlin: Springer-Verlag.

Nijkamp, P.P. 1980. Environmental Policy Analysis: Operational Methods and Models. New York, N.Y.: John Wiley & Sons.

Nijkamp, P.P. and Rietveld, P. 1986. "Conflicting objectives in environmental management, an introduction." The Annals of Regional Science 20(3): 1-9.

Norton, R.D. and Solis, L.M. (eds.) 1983. The Book of CHAC: Programming Studies for Mexican Agriculture. Baltimore: Johns Hopkins University Press.

Norton, G.A. 1984. Resource Economics. London: Edward Arnold Ltd.

Novak, M.D. and Van Vliet, L.J.P. 1983. "Degradation effects of soil erosion by water and wind." In: B.C. Ministry of Agriculture and Food. Proceedings of the 8th B.C. Soil Science Workshop: Soil Degradation in British Columbia. Victoria.

Openshaw, S. 1989. "Computer modelling in human geography." In: Macmillan, Bill (ed.) Remodelling Geography. Cambridge, Mass.: Basil Blackwell Ltd.

O'Riordan, T. and Turner, K. (eds.) 1983. An Annotated Reader in Environmental Planning and Management. Oxford, England: Pergamon Press Ltd.

Owen, M. 1973. The Tennessee Valley Authority. New York, N.Y.: Praeger.

Page, T. 1977. Conservation and Economic Efficiency: An Approach to Materials Policy. Baltimore: Johns Hopkins University Press.

Parry, M.L. and Carter, T.R. 1987. "The assessment of effects of climatic variations on agriculture: aims, methods and summary of results." In: M.L. Parry, T.R. Carter, and N.T. Konijn, (eds.) An Assessment of Climatic Variations on Agriculture. Volume 1. Assessment in Cool Temperate and Cold Regions. The Netherlands: Reidel, Dordrecht.

Pearce, D.W. and Turner, R.K. 1990. Economics of Natural Resources and the Environment. New York, N.Y.: Harvester Wheatsheaf.

Pearce, D.W., Barbier, E. and Mardandya, A. 1990. Sustainable Development: Economics and Environment in the Third World. Aldershot, U.K.: Edward Elgar.

Pearse, A. 1980. Seeds of Poverty, Seeds of Want: Social and Economic Implications of the Green Revolution. Oxford, U.K.: Clarendon Press.

Peret, N.G. 1975. "Canadian wildlife service." In: USDI. Proceedings of the National Wetland Classification and Inventory Workshop Fish and Wildlife Service.

Pierce, J.T. and Furuseth, O.J. 1982. "Farmland protection planning in British Columbia." GeoJournal 6(6): 555-560.

Pierce, J.T. and Furuseth, O.J. 1983. "Assessing the adequacy of North American Agricultural land resource." Geoforum 14(4): 413-425.

Pierce, J.T. 1983. "Resource and economic considerations in the allocation of agricultural land in Peri-urban areas: A Canadian perspective." Landscape Planning 10: 363-368.

Pierce, J.T. and Stathers, R.J. 1988. "Environmental impacts on cereal grain production in the Canadian prairie provinces: a growth constraint model." Agriculture, Ecosystems & Environment 21: 225-243.

Pierce, J.T. 1990. The Food Resource. Essex, U.K.: Longman Scientific & Technical.

Putman, J.W. and Dyke, P.T. 1987. The Erosion-Productivity Impact Calculator as Formulated for the Resource Conservation Act Appraisal. U.S. Department of Agriculture, Economic Research Service, Natural Resource Economics Division.

Randall, A. 1986. "Valuation in a policy context." In: D.W. Bromley, (ed.) <u>Natural Resource Economics: Policy Problems and Contemporary Analysis.</u> Boston: Kluwer-Nifhoff Publishing.

Rees, J. 1985. <u>Natural Resources: Allocation Economics and Policy.</u> London: Methuen.

Rees, W.E. 1977. <u>The Canada Land Inventory in Perspective.</u> Ottawa: Lands Directorate, Environment Canada.

Rohe, W.M. 1982. "Social impact analysis and the planning process in the United States." <u>Town Planning Review</u> 53(4): 637-682.

Romero, C. and Rehman, T. 1984. "Goal programming and multiple criteria decision-making in farm planning: an expository analysis." <u>J. of Agricultural Economics</u> 35: 177-190.

Romero, C. and Rehman, T. 1985. "Goal programming and multiple criteria decision-making in farm planning: some extensions." <u>J. of Agricultural Economics</u> 36: 171-186.

Romero, C. and Rehman, T. 1987. "Natural resource management and the use of multiple criteria decision-making techniques: a review." <u>Euro. R. Agr. Eco.</u> 14: 061-089.

Rosenzweig, C. 1985. "Potential CO_2 - induced climate effects on North American wheat - producing regions." <u>Climatic Change</u> 7: 367-389.

Rossini, F.A. and Porter, A.L. (eds.) 1983. <u>Integrated Impact Assessment.</u> Social Impact Assessment Series, No. 8. Boulder, CO.: Westview Press.

Saygideger, O. and Heady, E. 1977. <u>A Multigoal Linear Programming Analysis of Trade-offs Between Production Efficiency and Soil Loss Control in U.S. Agriculture.</u> CARD. Report 76. Iwoa State University.

Sampson, R.N. 1981. <u>Farmland or Wasteland - A Time to Choose.</u> Rodal Press.

Schamberger, M.L., Short, C. and Farmer, A. 1979. "Evaluation wetlands as wildlife habitat." In: P.E. Greeson, J.R. Clark and J.E. Clark, (eds.) <u>Wetland Functions and Values: The State of Our Understanding.</u> American Water Resource Association

Schlesinger, M.E. and Mitchell, J.F.B. 1985. "Model projections of the equilibrium climatic response to increased carbon dioxide." In: M.C. MacCracken and F.M. Luther, (eds.) <u>The Potential Climatic Effects of Increasing Carbon Dioxide.</u> (DOE/ER-0237) U.S. Department of Energy. 81-148.

Schuler, A., Webster, H.H. and Meadows, J.C. 1977. "Goal programming in forest management." J. of Forestry 75(6): 320-324.

Sewell, W.R.D., Davis, J., Scott, A.D. and Ross, D.W. 1970. Guide to Benefit-Cost Analysis. Ottawa: Queen's Printer for Canada.

Sewell, W.R.D. 1973. "Broadening the approach to evaluation in resource management decision making." Journal of Environmental Management 1: 33-60.

Simon, D. 1989. "Sustainable development: theoretical construct or attainable goal?" Environmental Conservation 16(1): 41-48.

Simon, H.A. 1969. Science of the Artificial. Cambridge, Mass.: MIT Press.

Simon, H.A. 1978. Rational Decision-Making in Business Organizations. Nobel Foundation.

Smit, B. and Johnston, T. 1983. "Public policy assessment: evaluating objectives of resource policies." Professional Geographer 35: 172-178.

Smit, B., Rodd, S., Bond, D., Brklacich, M., Cocklin, C. and Dyer, A. 1984a. "Implications for food production potential of future urban expansion in Ontario." J. of Socio-Economic Planning Sciences 17(3): 109-119.

Smit, B., Brklacich, M., Dumanski, J., MacDonald, K.B. and Miller, M.H. 1984b. "Integrated land evaluation and its application to policy." Canadian Journal of Soil Science 64(4): 467-479.

Smit, B., Ludlow, L. and Brklacick, M. 1988. "Implications of a global climatic warming for agriculture: a review and appraisal." Journal of Environmental Quality 17(4): 519-527.

Smit, B. and Brklacich, M. 1989. "Sustainable development and the analysis of rural systems." J. of Rural Studies 5(4): 405-414.

Smith, V.K. and Krutilla, J.V. 1979. "Resource and environmental constraints to growth." American Journal of Agricultural Economics 61: 395-408.

Sparrow, Hon. H.O. (Chairman). 1984. Soil at Risk-Canada's Eroding Future. A Report on Soil Conservation by the Standing Committee on Agriculture, Fisheries, and Forestry, to the Senate of Canada. Ottawa.

Stamp, D. 1940. "Fertility, productivity and classification of land in Britain." Geographical Journal 96: 389-412.

Strain, B.R. and Cure, J.D. 1985. Direct Effects of Increasing Carbon Dioxide on Vegetation. DOE/ER-0238. Washington, D.C.: U.S. Department of Energy.

Swartzman, G.L. and Kaluzny, S.P. 1987. Ecology Simulation Primer. New York, N.Y.: Macmillan.

Talisman, 1982. Fort St. John North Deferred Planning Area. Vancouver, B.C.: Talisman Land Resource Consultants.

Tate, D. 1981. "River basin development in Canada." In: B. Mitchell and W.R.D. Sewell, (eds.) Canadian Resource Policies: Problems and Prospects. Toronto: Methuen.

Thompson, M.A. 1990. "Determining impact significance in EIA: a review of 24 methodologies." J. of Environmental Management 30: 235-250.

Thornes, J. 1989. "Geomorphology and grass roots models." In: Macmillan, Bill (ed.) Remodelling Geography. Cambridge, Mass.: Basil Blackwell Ltd.

Tisdell, C. 1988. "Sustainable development: differing perspectives of ecologists and economists, and relevance to LDCs." World Development 16(3): 373-384.

Tisdell, C. 1989. "Environmental conservation: economics, ecology, and ethics." Environmental Conservation 16(2): 107-112.

USDA, 1978. Regional Development and Plan Evaluation: The Use of Input-Output Analysis. Agriculture Handook. No. 530. The U.S. Department of Agriculture. Economics, Statistics, and Cooperatives Service.

Van Vliet, L.J.P. 1989. Water Erosion Prediction for Soils in the Peace River Region of British Columbia. Technical Bulletin 1989-3E. Ottawa: Research Branch, Agriculture Canada.

Victor, P.A. 1972. The Economics of Pollution. London: Mehtuen.

Von Gadow, K. 1978. "Setting goals in forest management." South African Forestry Journal 106: 2-9.

Wagner, H.M. 1969. Principle of Operations Research. Englewood Cliffs, N.J.: Prentice-Hall, Inc.

Walker, N. and Monypenny, R. 1976. "Linear Programming as a tool for agricultural sector analysis." Review of Marketing and Agricultural Economics 44(4): 165-178.

Wall, G. 1981. "Research in Canadian recreational planning and management." In: B. Mitchell and W.R.D. Sewell, (eds.) Canadian Resource Policies. Toronto: Methuen Publications.

Warner, M.L. and Preston, E.H. 1974. A Review of Environmental Impact Assessment Methodologies. EPA 600/5-74-002. Washington, D.C.: U.S. Environmental Protection Agency.

WCED. 1987. Our Common Future. The World Commission on Environment and Development. New York, N.Y.: Oxford University Press.

Weithman, A.S. and Ebert, R.J. 1981. "Goal programing to assist in decision-making." Fisheries 6: 5-8.

Wetstone, G. and Foster. S. 1983. "Acid precipitation: what is it doing to our forests?" Environment 25(4): 1983.

Whitney, J.B.R. 1985. "Integrated economic-environmental models in environmental impact assessment." In: V.W. Maclaren and J.B. Whitney, (eds.) New Directions in Environmental Impact Assessment in Canada. Agincourt, Ontario: Mehtuen.

Wierzbicki, A. 1982. A Critical Essay on the Methodology of Multiobjective Analysis. (Internal IIASA Communication).

Williams, J.R., Dyke, P.T. and Jones, C.A. 1982. "EPIC - a model for assessing the effects of erosion on soil productivity." Paper Presented at the Third International Conference on State-of-the-Art in Ecological Modelling. Colorado State University.

Wilson, A.G. and Kirkby, M.J. 1980. Mathematics for Geographers and Planners. Oxford: Clarendon Press.

Wilson, A.G. 1981. Geography and the Environment: Systems Analytical Methods. New York, N.Y.: John Wiley & Sons.

Wilson, E.O. 1989. "Threats to Biodiversity." Scientific American (Sept.): 108-116.

Wischmeier, W.H. and Smith, D.D. 1978. Predicting Rainfall Erosion Losses: A Guide to Conservation Planning. U.S. Department of Agriculture, Science and Education Administration. AH-537.

Wolf, C.P. 1983. "Social impact assessment: a methodological review." In: K. Finsterbusch et al. (eds.) Social Impact Assessment Methods. Beverley Hills, CA.: Sage.

Woodcock, C.E., Sham, C.H. and Shaw, B. 1990. "Comments on selecting a geographic information system for environmental management." Environmental Management 14(3): 307-315.

World Conservation Strategy. 1980. World Conservation Strategy: Living Resource Conservation for Sustainable Development. Gland: IUCN-UNEP-WWF.

Yeates, M. and Garner, B. 1978. The North American City. Toronto: Macmillan Company.

Zeleny, M. 1982. Multiple Criteria Decision Making. New York, N.Y.: McGraw-Hill, Inc.

Zeleny, M. (ed.) 1984. MCDM: Past Decade and Future Trends: A Source Bood of Multiple Criteria Decision Making. Decision Research, Volume 1. London: Jai Press Inc.

Zionts, S. 1980. "Methods for solving management problems invloving multiple objectives." In: G. Fandel and T. Gal, (eds.) Multiple Criteria Decision Making Theory and Application. Proceedings of the Third Conference Hagen/Konigswinter, West Germany. Berlin: Springer-Verlag.

APPENDIX I: LIST OF PEOPLE INTERVIEWED

Victoria

Gary Falk

Program Analyst, Farm Income and Crop Insurance

Ministry of Agriculture and Fisheries

Harvey Sasaki

Statistics, Farm Land Resource Branch

Ministry of Agriculture and Fisheries

Larry Bornford

Director, Policy Branch

Ministry of Agriculture and Fisheries

Imre Spandli

Supervisor, Inventory Section, Planning and Inventory Branch

Ministry of Forests

Ray Addison

Manager, Range Resources, Integrated Resource Branch

Ministry of Forests

Viggo Holm

Industry, Development and Marketing Branch

Ministry of Forests

Roger Hunter

Habitat Conservation Fund Coordinator

Ministry of Environment

Eric Gunderson

Regional Development Officer, Northeast Region

Ministry of Regional Development

Northeast Region

Wim Kok

Resource Officer, Fort St. John Forest District

Ministry of Forests

Darrell Robb

T.S.A. Planning Forester, Prince George Forest Region

Ministry of Forests

Jack Dobb

Provincial Specialist

Cereal, Oilseed and Seed Crops, Dawson Creek

Field and Special Crop Branch

Ministry of Agriculture and Fisheries

Paul Modahl

Crop Insurance Representative

Farm Income and Crop Insurance Branch, Dawson Creek

Ministry of Agriculture and Fisheries

Charles Littledale

B.C. Lands Peace Region, Fort St. John

Ministry of Lands, Parks and Housing

John Turner

Manager of Development and Marketing, Fort St. John

Ministry of Lands, Parks and Housing

Fred Harper

Regional Habitat Biologist

Fish and Wildlife Branch, Fort St. John

Ministry of Environment

Murray Clark

Area Manager, Prince George

Ducks Unlimited

Vancouver

L. Van Vliet

Land Resource Research Center

Agriculture Canada

Daniel Schroeter

Principal, Talisman Land Resource Consultants

Sean Bord

Candian Wildlife Service

Environment Canada

D.K. Redpath

Senior Researcher, Lands Directorate

Environment Canada

Doug Wilson

Fish and Wildlife Branch, Surrey

Ministry of Environment