OLD-GROWTH FORESTS FOR WILDERNESS PRESERVATION AND TIMBER PRODUCTION IN BRITISH COLUMBIA: A GOAL PROGRAMMING MODEL

by

SEN WANG

B.A., Beijing Foreign Studies University, 1982

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ABSTRACT

The B.C. government's Protected Areas Strategy (PAS), aimed at protecting 12 per cent of the province's land base, will affect the old-growth forests considerably. Based on the Valhalla proposal, at least 0.65 million hectares of old growth will need to be set aside as wilderness.

Given the nature of multiple uses of the old growth, a Goal Programming approach is appropriate for the assessment of the preservation plan. For model construction, six goal items have been identified: the net benefits from old-growth stands, wilderness expansion, direct forest employment, government stumpage revenue, sustained yield, and current timber harvesting. Targets have been determined for each. On the basis of the results from a survey, goals are ranked in terms of priority, and their achievement is attempted in a sequential order to seek minimal deviations from the specified levels.

The Goal Programming model indicates that old-growth preservation on the scale of the Valhalla proposal will cause reduction in the province's level of direct forest employment, and the magnitude of the adverse effects is variable, depending on the intensity of the goal constraints concerned. The goals of net benefits and Crown revenue from stumpage charges do not appear to be vulnerable, but the conflicts between the preservation plan and the goals of long-run sustained yield and current timber harvest are serious.

Table of Contents

LIST OF TABLES

LIST OF FIGURES

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Chapter 1

Introduction

1.1 Background

British Columbia is territorially the third largest province in Canada. Covering 94.78 million hectares, or 9.51 per cent of Canada's total area, it represents 20.72 per cent of the country's timber-productive nonreserved forest land. As far as mature and overmature forests are concerned, the province accounts for 47.29 per cent of the country's gross standing volume[1]. British Columbia is one of the few places where substantial areas of temperate old-growth forests still exist (Valhalla Society 1988). Of the provincial land base that measures 929,730 square kilometres, around 65 per cent, or 60.57 million hectares, is classified as forest land. The timber-productive nonreserved forest land measures 49.05 million hectares, but the area presently available and suitable for timber harvesting covers 26.6 million hectares[2].

Forest resources are of vital importance to British Columbia in terms of their contribution to the province's economy and environmental quality. They represent a source of timber supply for the forest industry that forms one pillar of the

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[1] The information is from "Canada's Forest Inventory 1991" which is carried, in part, by *Compendium of Canadian Forestry Statistics 1992.*

[2] "Canada's Forest Inventory 1991"; and B.C. *Ministry of Forests Annual Report 1991-92.*

provincial economy, and forest lands are an essential resource base in support of rapidly growing tourism. What makes British Columbia attractive also generates the province's principal wealth (B.C. Wilderness Advisory Committee 1986).

In recent years the province has been faced with conflicting demands of increasing intensity over its forests, in particular with the old growth[3]. The long-standing forest industry relies on a continued supply of timber from the resource base. Meanwhile, rising environmental concerns call for the expansion of wilderness area into the currently operable forest land. Viewed in an economics context, B.C.'s old-growth forests are a scarce resource that is nonrenewable within the lifetime of the present generation. The extraction of timber tends to take place at the expense of many non-timber products, whereas preserving forest land as wilderness is likely to cause economic losses in connection with the reduction in timber harvest.

The issue of old-growth forests in British Columbia is one of land use. The competitive nature of the old growth as a resource for satisfying diverse human needs compels planners to decide upon the choice of land uses with due consideration to the opportunity costs of each. Such a decision is often made within a given institutional framework. Having gone through a variety of studies

[3] Definitions of old-growth forests are varied. Some believe that old growth constitutes stands over 200 years in age. In this study, mature and overmature forests are referred to as old growth. The stand is considered mature when the age reaches 80 for lodgepole pine, white-bark pine and all deciduous species. Other stands of coniferous species are considered mature when their age is greater than 120 years (B.C. Ministry of Forests 1991).

initiated in the past decade by separate government agencies, the old-growth issue finally found its way into the province's Protected Areas Strategy (PAS) that came into being in 1992 (B.C. Ministry of Environment, Lands and Parks; Ministry of Forests 1992a).

The Protected Areas Strategy commits the government to a doubling of B.C.'s park and wilderness areas by the end of this century. Having identified 184 study areas, ranging from less than 10 hectares to more than one million hectares each, the strategy is designed to be an integrated process for coordinating all of B.C.'s protected area programs. It represents a landmark in the transition on the part of the provincial government from traditional piecemeal initiatives towards planning forest land uses in a more holistic fashion. However, a certain amount of productive forest land will necessarily be withdrawn into wilderness with the effect of banning timber harvest activities altogether.

PAS is the result of a lengthy and ongoing process with wide-ranging public involvement and input. Hence, it serves as an established institutional framework that sets both the stage and timetable for specific implementations (B.C. Ministry of Environment, Lands and Parks 1993). Seeking to protect representative ecosystems around the province, the strategy deals with the old-growth issue at its core. Given the proportion of forest lands in the province and the extent to which British Columbians have been dependent on timber extraction for their economic well-being, assessment of the possible effects of the strategy becomes a matter of weighing the benefits and costs of wilderness expansion.

As a forerunner of PAS, the proposal put forward by the Valhalla Society in 1988 mapped out specific geographic sites worthy of protection. Entitled *British Columbia's Endangered Wilderness: A Proposal for an Adequate System of Totally Protected Lands*, the proposal recommended that the amount of protected areas be increased to 13.06 per cent of B.C.'s total area from the then 5.24 per cent. The implementation of the Valhalla proposal was expected to affect 650,459 hectares of mature and overmature forests, involving 226.15 million cubic metres of commercial timber (Valhalla Society 1988; Simon Fraser University 1990).

Originating from pin-points of grass-root opinions, the Valhalla proposal has served as an essential building block on which the unfolding Protected Areas Strategy stands. While PAS is expected to undergo a series of evaluations in determining actual sites for protection, to begin with, the process is preferably a check-and-acceptance verification of existing proposals to avoid duplication of efforts (B.C. Ministry of Environment, Lands and Parks 1993). In view of the apparent similarities and connections between the Protected Areas Strategy and the Valhalla proposal, the latter offers a sensible starting point in evaluating the PAS program for its overall viability and economic implications.

1.2 Problem Statement

The Protected Areas Strategy is aimed at bringing 12 per cent of British Columbia's land area under protection by the turn of the century, namely, expanding the protected areas from the current 6.2 million ha to around 12 million ha. In the hope of developing one of the most comprehensive and systematic plans for protected areas in North America, the provincial government is confronted with a formidable challenge to strike a balance between protecting environment and securing socio-economic stability. B.C.'s high proportion of forest cover justifies the emphasis in PAS on forest land, especially mature and overmature stands. Further, because there are many uses of old growth, the PAS program is, to begin with, a multi-objective undertaking. What is at issue is not whether the PAS target is attainable, but rather, how it may be achieved and at what cost. The real question boils down to how much old growth, and in which areas, is to be affected. An underlying assumption is that the impact of PAS on the provincial economy is a function of the intensity of old-growth withdrawal from timber harvesting into wilderness with variations in respect of specific geographical sites.

In recognition of the multi-purposes of the old-growth forests, land use planning for timber harvesting and wilderness preservation is an economic as well as a political process that involves (1) the identification of the general shape of relevant production possibility curves in order to determine the trade-off functions among various activities, (2) the specification of the range and intensities of conflicts and/or complementarities, and (3) the decision making on plans of actions available and the consequences thereof (van Kooten 1993a). It is a process of specifying problems both qualitatively and quantitatively for the selection of alternatives.

In the context of the Protected Areas Strategy, reducing the area of productive operable forest area is expected to affect timber supply, employment opportunities and Crown revenue in the short run, and has an impact, in the long run, on many aspects of the province's economy, such as industrial restructuring and the competitiveness of B.C's wood products in the international market. The direction and intensity of the effects are determined by the magnitude of the withdrawals and the time horizon over which the adopted program is implemented. Although deletion of forest land in favour of wilderness preservation is not new to British Columbia in that 3,999 square kilometres of prime forest land were turned into parks and conservation areas between 1965 and 1985, the Protected Areas Strategy has an aim that surpasses all previous endeavours in terms of scale and time span (Environment Canada 1987). The distinctive features of PAS makes it all the more necessary to draw up appropriate plans for maximizing the benefits (both present and potential) of the program and minimizing the costs of implementation.

The announcement of the Protected Areas Strategy by the provincial government indicates the establishment of an institutional framework. With a broad objective of doubling protected areas in the province, the framework needs to be filled with contents that correspond to site-specific action plans. The implementation of the strategy is a process of attaining a series of sub-goals that contribute to the ultimate goal of enhancing British Columbians' well-being. The anticipated benefits of PAS will be associated with certain levels of costs that vary from one type of action scheme to another. The adoption of a given plan such as the Valhalla proposal should be based on an understanding of the plan in terms of contents, specific targets or goals, the extent to which each of the goals is achievable, and economic implications of attaining them. An analysis to this effect is needed for the implementation of B.C.'s Protected Areas Strategy, and it is the focus of this study.

1.3 Objective of the Study

The objectives of this study are threefold. The first is to identify existing proposals in regard to the use of old-growth forests for wilderness preservation and timber harvesting. Preliminary goals are defined on the basis of the Valhalla proposal, with the priority rankings of the goals sorted out in accordance with solicited opinions of the general public. The second is to evaluate the goals associated with the given wilderness expansion proposal for their technical viability. And the third is to indicate the possible trade-off functions among the various goals as implied in the plan under investigation.

A goal programming model is constructed to serve as a methodological tool. Results from simulations of different scenarios, using data sets drawn from published sources, are presented. An economic analysis is attempted in the end to discuss the impacts of the proposed wilderness expansion plan on other related goals. The study concludes with tentative recommendations for forest policy changes at the macro-level of the province.

1.4 Methodology Employed in the Study

Goal Programming (GP) is the mathematical modelling approach used in this study. The need to employ a GP approach is dictated by the nature of the problem being addressed and the objectives pursued. To date, Goal Programming has not been used to evaluate province-wide forest land use plans and estimate the trade-offs between timber harvesting and wilderness preservation.

1.4.1 Theoretical Basis of the Study

The theoretical basis of this study is multi-objective planning. In light of the recognition that old-growth forests are capable of multiple uses, the assumption of positive non-timber values from forest resources is implied. Given British Columbia's Protected Areas Strategy, it appears that deletion of old-growth forests from the net operable base is to be a political decision. However, this is an economic problem as well in that choices regarding the use of scarce resources are involved. According to Hartman (1976), a program such as PAS may be accepted only when the values of the non-timber products exceed the timber values forgone. The proof that old-growth forests possess positive non-timber values is not sufficient to justify their withdrawal. The opportunity costs of old-growth preservation are, for the most part, the forgoing of immediate timber revenue and resultant losses of employment related to timber harvesting. Despite the many controversies that remain in measuring the non-timber values of the old growth, in evaluating the feasibility of wilderness expansion plans and estimating trade-offs, this study uses information available on the assumption that existing non-market value estimates are reasonably reliable.

1.4.2 Justification of the Use of GP Approach

Goal Programming is a constrained optimization approach suitable for multi-objective planning. The adoption of the GP approach is justified on the following grounds. First, old-growth forests in British Columbia are capable of multiple uses. Unlike Linear Programming, which addresses one single objective at a time, Goal Programming facilitates the planning of various old-growth uses simultaneously, making it possible to consider issues with different measurement units. Second, as decision makers do not know for sure the viability of their initial plans, the processes of evaluating feasibility and efficiency can be taken care of by GP, which deals with either overachievement or underachievement of preliminary goal levels to avoid the rigidity of the single directional operability characterized by Linear Programming. Third, results from GP may provide decision makers with information about the inherent relationships among the various goal components of a program in terms of economic values and about the rationality of goal structures. The usefulness of Goal Programming as a technique lies in the way problems of a different nature and dimensions may be presented and handled. From the standpoint of British Columbia, the value dimensions of the old growth make much sense in the aggregate (Vertinsky *et al.* 1993). It is, therefore, deemed appropriate to adopt Goal Programming in assessing a province-wide preservation program, with a regional breakdown to the levels of the Ministry of Forests regulated regions. Should the need arise to look at old-growth problems from a local perspective, the information from this study may be decomposed to derive regional implications.

Chapter 2

Theory and Methodology

Forests are complex ecosystems capable of supporting multiple uses. Unlike conventional forest practices whose emphasis was confined primarily to the capture of commercial timber values through logging operations, modern forestry is evolving into a science that recognizes a wide range of services forests can provide in meeting the diversified needs of the present generation and of those yet to come. As an important branch of this science, forest resource management is aimed at the development of a sustainable resource base in such a way that society's socio-political, economic and environmental goals may be satisfied. It is a complex process of decision making before actual operations take place, involving, to a large degree, the identification of desired objectives and, in turn, the evaluation of various alternatives.

As an aid to decision making, mathematical programming encompasses an array of analytical techniques for optimizing some particular objective by placing specific restraints on resources allocated to alternative activities (Bell 1977). In forestry, Linear Programming (LP) is by far the most extensively used approach that seeks optimal achievement of an objective within given economic, physical and/or biophysical constraints. However, the management of forests for multiple purposes such as timber values from logging activities and non-timber values from wilderness preservation requires multi-objective programming. Goal Programming is such an instrument.

2.1 Goal Programming Theory and Literature Review

2.1.1 Origin of Goal Programming

The concept of goal programming was initiated by A. Charnes and W. Cooper in 1961 in a book entitled *Management Models and Industrial Applications of Linear Programming (volume 1)*. They observed the limited capacity of conventional linear programming in addressing only one objective function at a time, pointing out that managers often need to consider a decision package comprised of a variety of goals interrelated with one another.

The solution proposed by Charnes and Cooper to multi-objective problems was to transform the usual linear programming format by treating all goals as a separate category of constraints along with the existing physical constraints, and turning the objective function into a process of minimizing deviations from those specific goals.

The essence of Charnes and Cooper's proposal lies in the alteration of the substance of the objective function. The object to be optimized becomes the sum of deviations from various goals. While preserving the form of linear programming, the new approach adopts an objective function that assembles a series of deviational terms associated with corresponding goals, and the optimization process of the objective function is constrained by goal levels as well as by resource availabilities. The technique is unique in that different goals can be stacked in conjunction with physical constraints, and the goal constraints are linked with the objective function via deviational terms to be minimized. With the assumption that variables in a programming model have linear relationships, the method offers a way of handling management problems with multiple goals of different categories.

2.1.2 Evolution of Goal Programming Techniques

Originating from Linear Programming, Goal Programming is a constrained optimization approach. But unlike LP, which seeks the optimization of a single objective through adding up the commonly measurable contributions of all the activities involved, Goal Programming aims at the fulfilment of an aggregate objective by collectively achieving goals that may or may not be directly compatible and commensurable with one another.

The fundamental difference lies in the composition of the objective function. In form, GP resembles LP in that the objective function has one overall aim, since minimization of deviations from each of the goals contributes to the overall success of the program. But in essence, minimization of the objective function is not necessarily a single-step task. When the goals under consideration happen to be compatible with common units of measurement, a GP problem boils down to an LP case. However, in the event that incompatible and unmeasurable goals have to be dealt with in a decision problem, two things will need to be resolved. One is to order goal items in terms of priority sequence, and the other is to determine the magnitude of the relationships among the goals. Determining ordinal ranking and cardinal weights for goals are considered two essential issues in goal programming modelling.

Y. Ijiri (1965) made a significant contribution to the development of goal programming techniques. In his book *Management Goals and Accounting for Control*, Ijiri introduced "preemptive priority factors" for treating multiple goals according to their respective importance, and he proposed the assignment of weights to goals of the same priority level. It was Ijiri who refined the concept of goal programming and turned it into a distinct mathematical programming technique (Lee 1972).

The first book entirely devoted to goal programming was *Goal Programming for Decision Analysis* written by S.M. Lee in 1972. Lee illustrated the various approaches for constructing GP models, and formalized the graphical and simplex methods for solving GP problems. Lee's chief contribution was his demonstration of the wide applicability of Goal Programming as a tool for decision making in many fields such as production, financial management, academic planning and government services.

The two decades following Lee's works have witnessed debates as to how the ordering and weighting ought to be done in formulating the objective function. A general agreement seems to have been achieved that preemptive ordering suggests the notion of higher-level goals completely dominating lower-level goals in the form of "$>>>$". For instance, if there are goals that are ranked j'th in importance, the preemptive priority factor $P_j >>> nP_{j+1}$ for all values of n, however large it may be (Field 1973). This means that the objective function has to be dealt with in a sequential manner, namely, satisfying goals from the highest ranking downwards.

The determination of priority ordering is not without difficulties. It often is filled with subjectivity that characterizes almost all decision making processes. Ranking priorities is to place goals in a hierarchical structure. In spite of real world evidence demonstrating the advantages of this approach, a drawback is that it poses excessive difficulties for trade-off estimations.

Cardinal weighting is viewed as an alternative approach that seeks to identify the estimated weights as coefficients on each of the goals, allowing possible estimation of trade-offs through the calculation of gains versus sacrifices among different goals. However, one major problem is the difficulty in determining the weights in the first place. Goals, which differ from one another but are measurable with a common yardstick in their respective achievements, make it easy for one to discover their weights when they are grouped into a decision making package. After all, weights are but terms that indicate exchange factors of activities for trade in values. What makes weights assignment difficult is cases where goals do not permit ready measurements of trade-offs due to, for instance, non-market values. Although the source of the non-market valuation problem lies deep in economics, the trouble casts its shadow on Goal Programming, scaring many people away from the use of the weight assigning approach.

There has been a broad consensus on the combined use of ordering and weighting. One common suggestion is to use priority ranking for different categories of goals and, within each class of sub-goals, to employ a cardinal weighting scheme (Lee 1972). In an attempt to rearrange goals by type, this integrated approach helps reduce incompatibility and immeasurability among goals. Nevertheless, controversies over objectively specifying goal levels and weights have persisted, and the principal issue of assigning weights across different priority levels remains unsettled (Dykstra 1984).

J. Buongiorno and J.K. Gilless (1987) appear to favour the cardinal weighting approach. Asserting that few goals in the real world are absolute, they question the usefulness of preemptive priority ranking. In their opinion, most values are relative and goal programming with cardinal weights is more likely to reflect these values. They propose adoption of the relative weighting scheme. In assigning weights, attention is supposed to be given to the relative importance of deviating by one percentage point from the respective goals. In other words, all weights are set equal to unity. In the case of goals expressed in large numbers, the derived weight coefficients can be very small, and serious round-off problems may occur in calculating a solution. To avoid this, all the coefficients may be multiplied by an identical large number, which, of course, will not affect the final solution. The advantage of working with relative deviations from goals is to eliminate the different units of measurement. However, this scheme has to be interpreted in terms of the relative value of the goals. Buongiorno and Gilless (1987) argue that the relative value of any items in a model can be determined from the relationship as implied by the objective function. To be specific, the objective function of a GP model is a summation of deviations from various goal items. Suppose one singles out two of the items while treating the rest as given, then a specific relationship between the two items is established via the objective function. Suppose, further, that the objective function is restricted to zero, any changes in the two items will become relative to one another. Then, dividing the coefficient of one deviational variable by the other will give a quotient that may be seen as the trade-off ratio between the two goal items. In spite of the merits of this approach, there are, at least, two problems. One is that it appears rather restrictive in establishing trade-off relations by choosing two items at a time, which is unrealistic for models with a considerable number of goal items. The other problem is whether assigning unity as the universal weight to all items is justifiable in the first place.

2.2 Algebraic Form of a Goal Programming Model

The general form of a goal programming problem is:

$$\underset{\{d\}}{\text{Minimize}} \quad Z = \sum_{k=1}^{m} p_k(w_k^- d_k^- + w_k^+ d_k^+)$$

$$\text{s.t.} \quad Ax + Id^- - Id^+ = b \qquad (1)$$

$$Bx \leq h \qquad (2)$$

$$x, d^-, d^+ \geq 0 \qquad (3)$$

where d^+ = positive deviational variable;

d^- = negative deviational variable;

w^+ = weighted shares for positive deviational variables;

w^- = weighted shares for negative deviational variables;

p_k = priority factor, with $k = 1,\dots,m$;

A = an m x n matrix, describing the technical relationships between goals;

x = an n x 1 column vector of goal variables;

I = an m x m identity matrix;

b = an m x 1 column vector, representing the target levels;

B = an r x n matrix of technical coefficients;

h = a r x 1 column vector of physical constraints; and

k = a subscript that denotes the goal, with $k = 1,\dots,m$.

Several observations are in place. First, the constraints are as follows: (1) goal constraints, (2) biophysical constraints, and (3) nonnegativity constraints. Another constraint may be added to the model, namely,

$$d^- \cdot d^+ = 0.$$

This means that at least one, if not both, of the deviational variables must be zero. As a matter of fact, it is the task of the objective function to drive the values of d^+ and d^- towards zero, and when d^+ and d^- are minimized to zero, goals will be considered as having been achieved at an optimal value of the decision variables x^*.

Second, the determination of the values of coefficients on deviational variables in the objective function can be the hardest part of any goal programming model formulation. The problem is twofold. On the one hand, the hierarchical structure of the various goals should be identified to indicate the order of importance among the goals, and, on the other hand, the numerical significance for deviations from the goals with identical priority factor should be determined.

The ordinal values of p_k represent the subjective judgement by the planners of goal rankings. Following a preemptive sequence, the ordering gives precedence to higher ranking goals over lower ones. In other words, lower-level goals are considered only after higher-level goals are satisfied. Once the superior goals are achieved, they should not be violated, and they act as new constraints in redefining the feasible regions for subsequent lower-order priorities. Cohon (1978) calls this the "lexicographic" ordering approach, which resembles the way a dictionary lists words. The sequential preemptive attempts at goal achievements are expected to result in an accumulation of constraints.

The numerical values of w_k must be nonnegative. If, for example, $w_k^+ = 0$, it means that only negative deviation needs to be minimized either because positive deviation does not matter or overachievement of the goal would even be welcome. These are known as one-sided goals (Cohon 1978) or one-way goals (Dykstra 1984). Of course, deviations of opposite directions can be minimized at the same time. The effects of positive and negative deviations may not be the same and, to reflect this, one may assign different weights to them.

The weighting approach reflects the degrees to which managers permit the occurrence of production activities. The cardinal is continuous while the ordinal is discrete. When the weighting says 100 per cent for one of the activities, that activity gets elevated to the fullest possible level of that priority order. Trade-off estimation may be obtained more easily with the cardinal approach.

2.3 Applications of Goal Programming

Goal Programming was applied by Charnes (1968) to media planning, while Charnes, Cooper and Nilhaus (1968) used GP techniques in manpower management. During the late 1960s and throughout the 1970s, the approach was applied to many private sector problems. The apparent lack, in the early years, of application to public problems was largely attributed to the difficulties in specifying target levels of social goals (Cohon 1978). One reason for this is that corporate problems are primarily concerned with traded products, whereas public problems involve many nonmarket goods and services.

Due to the nature of Goal Programming, the technique is most suitable for multi-objective planning. Natural resource management is an area where conflicting goals often exist. While Bell (1976) used Goal Programming for land use planning, Bottoms and Bartlett (1975) applied the method to range management, and Miller and Byers (1973) constructed a GP model for water resources projects.

The first application of goal programming to forestry was reported by Field (1973), who demonstrated the potential of goal programming in solving many forest management problems. Important studies using GP models to solve forest problems include the following:

- management of small woodlands (Field 1973);

- timber production (Rustagi 1976; Kao and Brodie 1979; Field *et al.* 1980);

- land use planning (Bell 1976; Dane *et al.* 1977);

- evaluation of alternative logging residue treatments (Bare and Anholt 1976);

- Christmas tree production (Hansen 1977);

- evaluation of trade-offs between timber management, outdoor recreation, grazing and production of game animals for hunting (Schuler *et al.* 1977);

- range management (Bottoms and Bartlett 1975); and

- outdoor recreation planning (Romesburg 1974).

The above-mentioned applications all used linear goal programming. Porterfield (1976) employed a nonlinear goal programming model to evaluate tree improvement programs, and Mitchell and Bare (1981) solved a forest inventory goal programming problem with nonlinear constraints. Buongiorno and Gilless

(1987) highlight GP as one of the most widely used mathematical modelling techniques.

2.4 Some Theoretical Issues of Goal Programming

Aside from the distinctive features of the goal programming approach, issues that have concerned GP scholars include sub-optimality or inferior solutions and inadequate provision of trade-off information. Unlike Linear Programming for which the feasible region is defined by the constraints, the Goal Programming approach is capable of producing a solution in which constraints can be satisfied as closely as possible, but need not all be met completely (Dykstra 1984). This means that, even if some goals turn out to be unattainable within the limits of available resources, with goal programming, we are driven towards the best possible levels of achievements insofar as the constraints and competing goals permit.

The guaranteed solvability of a problem does not ensure the attainment of an efficient solution. As a matter of fact, the flip side of the flexibility of goal programming is the usual phenomenon of sub-optimality.

Generally speaking, a non-inferior goal programming solution is associated with infeasible goal levels. In most cases where goals are all found to have been achieved, it either suggests that the original goals are not high enough or solutions are insensitive to the priority ordering. The manager needs to be suspicious that large production potentials remain untapped, that is, the production possibility curve probably lies far out in the northeasterly direction in an *XY* plane. Sensitivity analysis may be necessary by means of altering the way priorities are placed and resetting the goal levels. Non-inferiority is guaranteed only when strictly positive deviations are obtained (Cohon 1978). To avoid sub-optimality, it appears that we should aim at the infeasible region. However, several problems arise. First, goal programming relies heavily on decision makers' perception of the range of feasibility, but they do not necessarily have sufficient knowledge about the non-inferior region when setting goal levels. The consequences of initially aiming at levels beyond the production possibility curve are that we are likely to end up with corner solutions unless the shape of the production possibility curve indicates complementarity or supplementarity.

According to the theory of production, complementarity and supplementarity only occur within a certain range (van Kooten 1993a). In the case of British Columbia, as activities compete with one another for the use of limited old-growth resources, the production possibility curve has to be negatively sloped. In the case of the old growth, which may be characterized by the two broad groups of timber and non-timber products, the steeper is the production possibility curve, the more likely is the result of a corner solution, favouring the production of one product group at the expense of another. In the event that one goal is initially selected to exceed the production frontier to avoid inferior solutions, the achievement of this target will likely result in complete sacrifice of other goals.

The sacrifices may not be justifiable unless the goal sought has sufficient values to more than offset the losses. For instance, excessive timber harvest expels tourists from logging sites proper and adjacent areas as well. The revenue losses from recreation plus the sacrifices from other relevant non-timber uses may convince decision-makers to restrict timber extraction to reasonable levels. On the other hand, a complete ban of timber felling may be undesirable because the economic losses in terms of reductions in timber supply, forest employment opportunities and community stability can be enormous. Therefore, the horizontal nature of goal level choices, coupled with the usual shape of negative slopes for production possibility curves, tends to rule out attainment of an optimal solution in its pure sense and, consequently, an interior solution rather than one on the production possibility curve often is the case (Dyer *et al.* 1979).

Due to the sub-optimal nature of Goal Programming, while a solution is obtainable, it is often difficult to find the true level of production potential. Repeated parametric trials may help locate the production frontier, but identifying trade-offs between products is difficult as we may not be able to attain the optimal spot on the production possibility curve.

The extent of trade-offs depends largely on the shape of the transformation functions. The greater the competitiveness between two products, the more likely it is for one of the products to be forced towards zero. In GP problems, there is a tendency for lower priorities to be precluded from consideration, especially when conflicts among uses are tense and the higher-priority products are in great demand.

Therefore, ranking priorities and determining goal levels are instrumental for generating sound solutions. But it is, by and large, a subjective judgement and could be unrealistic unless reliable evidence is ascertained in terms of production transformations and value exchanges. Inappropriate ranking of priorities will lead to a wrong sequence, unduly favouring some products at the expense of others. Given a priority ordering, incorrect setting of goal levels will cause non-production of lower ranking products to give way to excessively high-level goals, and inferior solutions will likely occur if goals are lower than optimal levels. Trade-offs between products are meaningful only when priority ordering and weighting are realistic.

In summary, multiple objectives justify the use of goal programming techniques, and the usefulness of the GP approach is dictated by the shape of the production possibility curve. But the subjectivity problem inherent in Goal Programming is serious. The method is merely a tool for aiding decision making. The effectiveness of the approach is as good as the dependability and soundness of the judgements of the planners.

Chapter 3

Formulation of a Goal Programming Model for Wilderness Preservation in B.C.

The essential component of this study is a Goal Programming model. The formulation of such a model depends on identifying (1) the relationships among various goals, and (2) technical coefficients for the activities concerned. Within the general framework of allocating B.C.'s old-growth forests between the two representative land uses of timber harvesting and wilderness preservation, the construction of the GP model follows a procedure of ranking goal items, specifying goal levels, defining physical resource constraints, and forming the objective function.

3.1 Identification of Goals

Before the physical building of a GP model is contemplated, a system of goals needs to be defined, and the pre-requisite to specifying any goals is the identification of issues to be dealt with by the model.

3.1.1 Identifying Goal Items

Despite the diversification of old-growth uses, this study is confined to timber harvesting and wilderness preservation, with an objective of investigating the viability of the Valhalla plan and assessing the implications of the proposed wilderness expansions in terms of timber output reductions, employment losses, and alterations in government revenue. For the purpose of restricting the study to a manageable size and maintaining a realistic focus, the economic objectives of managing old-growth forests as recommended by the Parksville Old-Growth Workshop held in 1989 serve as a basis of consideration (B.C. Ministry of Forests 1989). Regrouping of the workshop findings results in the following goal items that form the core of the GP model:

- Wilderness preservation in terms of withdrawal of old-growth forests from the operable productive forest land;
- Timber harvesting in terms of AAC;
- Government revenue;
- Direct forest employment;
- Maximization of net benefits from all old-growth uses; and
- Sustained timber yield.

Reasons for adopting the above goal items are the following. Preserving old-growth forests for wilderness is the main argument of the study, so it has to be there. Timber harvest at its current level is a *status quo* against which any new program will need to be evaluated since losses in commercial timber values indicate the most obvious opportunity costs of preservation (van Kooten 1993b). As over 20 per cent of British Columbians depend, either directly or indirectly, on the forest industry for employment, any negative effects on job opportunities have to be taken into account when a new program is introduced (Environment Canada

1987). Maintaining Crown revenue at an non-declining level is required in the hope of sustaining social programs at a time of budget deficits. The inclusion of a sustained timber yield goal reflects a philosophy about a stream of services expected of forest resources -- sustainable development. Last, but not least, maximization of net benefits from all old-growth uses is an expression of the desire for economic efficiency in the allocation of B.C.'s scarce resources.

3.1.2 Ranking Goals in Priority Sequence

Decision making is a process of determining the choice of solutions to well defined problems on the basis of established value judgements. Since 95 per cent of the inventoried timber-productive, nonreserved forest land in B.C. is owned by the Crown, decisions regarding changes in the designated use of the forest must come from the general public or be made by appropriate authorities with the public's endorsement (Canadian Council of Forest Ministers 1993). Due to the usual hierarchical nature of decision making and based on the assumption that the stakeholders in B.C. place different values and expectations over the old growth, a survey was conducted to solicit opinions on the ordering of those previously identified goals. Entitled *Identifying Priority Rankings on Old-Growth Uses in British Columbia*, a total of 57 questionnaires were distributed among participants in a socio-economic impacts workshop of the Commission on Resources and Environment (CORE) held in June 1993. The CORE process, which was first introduced in early 1992, is expected to provide guidance for resolving conflicts in the use of publicly-owned land resources (B.C. Ministry of Environment, Lands and Parks 1993). The individuals who completed the questionnaires were representatives of B.C.'s forest industries, academe, environmental groups and government agencies. The response rate was about 25 per cent. The questionnaire is found in Appendix A.

Of the six goals proposed to respondents, maximization of net benefits from all old-growth uses received the first priority status[4]. The second ranking went to wilderness expansion. Employment occupied the third place. The goal of maintaining government revenue came next, followed by the sustained yield goal. Keeping the current level of timber harvesting was considered the least priority.

The wording of the survey was such that additional information was expected from respondents regarding the scope of old-growth withdrawal in favour of wilderness preservation. The range turned out to vary considerably from the government proposed 12 per cent. Extreme answers were received, on one end, asking for no withdrawal at all and, on the other, demanding that all old-growth forests be preserved as wilderness.

For setting up the priority sequence of the goals, the importance of each item was determined by the number of votes cast by the respondents, with 6 points being awarded to the highest item and 1 point to the lowest. The item that earned the highest scores became the first rank. Both the ordering and scoring are

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[4] Respondents did not provide information about, or a ranking for, the last or "other" category. Hence, six rather than seven goals are used.

summarised in Table 1 to show, in a descending manner, the ordinal importance of the various goal items.

Table 1: **Ranking of the Goals**

Item	Rank	Scores
Maximize net benefits from all old-growth uses	1	71
Permanently withdraw ______ % of the old growth scheduled for future timber harvest	2	63
Secure regional stability by maintaining the current level of employment in forest industries	3	59
Maintain Crown revenue from forest harvesting	4	56
Maintain maximum sustained yield in timber harvest	5	51
Maintain current level of timber harvest in B.C.	6	36

Given the small sample size, the priority ranking may be arguably representative of the perceptions and attitudes of B.C.'s general public. Nevertheless, the results are found consistent with those of the national survey of Canadian public opinion on forestry issues (Environics 1989). Besides, answers to the same questions in a mini survey of 11 individuals conducted on the campus of the University of British Columbia revealed an identical ordering[5]. Therefore, this ranking is adopted for the model, although sensitivity analysis is used at a later stage of model validation.

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[5] This survey was conducted by the author between June 28 and July 3, 1993.

3.1.3 Cardinal Weighting of Goals

If the ordinal ranking of goals is viewed as a step in establishing the hierarchy of various items, it is merely a qualitative expression of the relationships among the goals. The importance of a goal is meaningless when it stands in isolation. Goals make more sense when they are compared in relative terms with one another, and goals as well as physical constraints jointly form the decision environment in a GP problem.

In many instances, the knowledge that one goal is considered more important than another is not adequate. It is desirable to move one step further in discovering the extent to which that goal prevails over the other. The purpose for so doing is to identify the exchange rate, in terms of economic values, between two activities that compete for the same scarce resources. It is implied in production theory that a trade-off relationship exists between two activities as long as they both are sub-elements of a joint production function (Doll and Orazem 1985). This is true of B.C.'s old-growth forests that produce two broad types of products, namely, timber and non-timber products. What makes it hard to reveal the trade-off functions of the old growth is the difficulty in obtaining the values of many non-timber products that are not readily available in the market place. Nevertheless, efforts at quantifying the importance of goals relative to one another are helpful in the efficient allocation of resources, and some insights may be gained by means of determining the cardinal weights of goals that belong to an identical problem package.

Cardinal weights may also refer to decision makers' subjective consideration of the degree of importance one goal possesses over another if the two goals happen to be on the same priority ordering. For instance, the achievement of the revenue plan of the whole province may be considered twice as important as achieving the revenue plan for one specific government agency. Even for an individual goal alone, over-fulfilment of the target, say, by 10 per cent, may carry much more weight than underachievement by the same percentage, and if policy makers should decide that the former be four times as important as the latter, this decision would form a basis in assigning cardinal weights.

The usefulness of weight assignment is matched by a complexity that involves considerable subjective judgement. Given the scope and objectives of this study, weighting of goals is ignored for the sake of simplicity.

3.2 The Goal Programming Model

A Goal Programming model comprises an objective function and constraints that break down to goal constraints, physical constraints, and non-negativity constraints.

3.2.1 Steps in Constructing the GP Model

As a first step in formulating the model, choice variables are determined. In this model, the choice variables are defined as x and q, where x is the area of old-growth forests for commercial timber harvesting and q is the area to be withdrawn into wilderness status.

The second step is to specify constraints. Both goal constraints and physical constraints need to be identified. It is a process of defining the right-hand-side constants that are supposed to indicate goal levels and/or resource limitations.

The objective function is developed as the third step. This is the stage when the ordinal rankings of the goals can be allocated as priority factors on the deviational variables.

3.2.2 Identifying Goal Levels

(1) Wilderness goal

The Protected Areas Strategy attempts to incorporate all major initiatives, including *Parks and Wilderness for the 90s* and the *Old Growth Strategy* that have been launched by various government agencies. Similar to PAS which is aimed at placing 12 per cent of B.C.'s representative land base under protection, the Valhalla proposal indicates the need to protect 13.06 per cent of the province, involving 650,459 hectares of old-growth forests (Simon Fraser University 1990). The most recent information reveals that the mature and overmature stands on provincial Ministry of Forests' regulated productive land are estimated at 26.6 million ha, which is 58 per cent of the total productive forest land of the Timber Supply Areas (TSAs) and Tree Farm Licences (TFLs) in the province (B.C. Ministry of Forests 1992).

The practice of allocating Crown forest land for wilderness preservation dates back several decades. Between 1965 and 1985 alone, 399,900 hectares of prime forest land were designated for parks and recreation purposes (Environment Canada 1987). Since the mid 1980s, deletion of forest land in favour of wilderness preservation picked up in scale, and it peaked in 1990 by 147,010 hectares. By 1991, the amount of forest land primarily used for parks and recreation purposes was believed to have reached two million hectares[6].

During the period from 1983 to 1991, for parks and recreation purposes, deletion of land from provincial forests amounted to nearly one quarter of a million hectares, and almost two thirds of the land use changes occurred on the Coast with much of the rest in the Northern Interior (B.C. Ministry of Forests 1983-91). Review of land use alterations during this period reveals a pattern of response to the call for wilderness preservation and, at the same time, provides information for policy makers in deciding on how much more forest land the inhabitants could afford to set aside and where. Little information is available about the maturity class of the forest land deleted. It is assumed that at least half of the forest land withdrawn consisted of mature stands on account of the special designated use for parks and recreation. If valid, this assumption is of importance for it may have significant bearing on the allocation of targets among different regions as far as the old-growth withdrawal goal is concerned.

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[6] Prior to 1965, 186 parks, both National and provincial, were in existence on 2,864 hectares. It is assumed that half of it was on prime forest land.

Based on the assumption that half of the previous wilderness expansions involved old growth, the Coast seems less capable of handling additional withdrawals of large areas than the Interior in view of resource constraints and opportunity costs of timber values. This belief has found expression in the Valhalla proposal, which spells out the need to assign some 175,000 hectares of the withdrawal task to the Coast and about 475,000 hectares to the Interior over the planning horizon to the end of this century (M'Gonigle *et al.* 1992).

On the provincial level, the withdrawals suggested in the Valhalla proposal indicate a reduction of the Ministry of Forests' regulated mature stands by 4.7 per cent. Effects are expected to vary from one area to another, especially between the generally highly productive Coast area and many less productive areas in the Interior (Binkley *et al.* 1993). The adoption of the Valhalla plan as a basis for the wilderness goal of this study is attributed to its typical comprehensiveness in respect of altering old-growth uses across British Columbia.

(2) <u>Timber goal</u>

It is required by law that sustained timber yield has to be maintained in British Columbia. The allowable annual cut (AAC), which refers to the volume of timber that may be harvested each year, is a proxy for sustained timber yield. During the past decade, B.C.'s levels of timber harvest fluctuated considerably. In the peak year of 1987, the level rose above 90 million cubic metres (Forestry Canada 1992). But the AAC for the province's Timber Supply Areas (TSAs) and Tree Farm Licences (TFLs) fell to around 73 million cubic metres in 1991 (Binkley *et al.* 1993).

Due to the predominance of coniferous species in British Columbia, outputs of hardwoods are ignored in this study, and privately owned forest land, which is merely 4 per cent of the province's total forest area, is excluded from consideration. Given a variable allowable annual cut from one period to another, the average AAC level of 73.33 million cubic metres is used as the timber goal in the model.

M'Gonigle *et al.* (1992) pointed out that implementation of the Valhalla plan would result in an exclusion of 226.15 million cubic metres of commercial timber from the net operable base, which means a reduction of B.C.'s AAC by about 2.6 million cubic metres.

(3) Employment goal

During the decade between 1982 and 1991, B.C.'s forest sector witnessed fluctuations in the levels of employment. The total number of employees in forest industries was 75,138 in 1982, and was pegged to remain around this level in the ensuing few years. Forest sector employment rose above eighty thousand in the mid 1980s and reached 81,375 in 1989. However, the following two years saw a considerable decline.

Consisting of those employed in logging, wood industries and paper and allied industries, the above figures only reflect the levels of direct employment in the forest sector. The indirect and induced employment, or the multiplier effect, is believed to almost double the direct employment level. The provincial Ministry of Forests is convinced that, through economic linkages, each job in the forest industry is associated with two jobs elsewhere in the economy (Council of Forest Industries of British Columbia 1990). In spite of reports that tourism has surpassed the forest industry and become the province's largest employer, it is assumed that any job losses resulting from timber land withdrawal can hardly be offset by employment growth in wilderness tourism due to lack of labour mobility and a lengthy period required for economic restructuring[7]. Therefore, maintaining regional stability by keeping the level of employment in the forest sector is expressed as one of the goals that PAS should be concerned with. To modify effects of annual fluctuations, a ten-year average of 77,600 is viewed as a representation of the level of employment goal for the model.

(4) Revenue goal

Striving for a non-declining revenue for the provincial government has been identified as an important economic objective in the old growth strategy formulation process (B.C. Ministry of Forests 1989). As this study focuses on the use of forest land for timber harvesting versus wilderness preservation, there appears a need to differentiate the Crown revenue from forestry in such a way that only the relevant items are considered. For the sake of simplicity and pertinence, stumpage charges are singled out for analysis. This is assumed appropriate because stumpage is a particular source of revenue to which the Crown has legitimate entitlement. From the standpoint of the provincial

[7] The definition of tourism is so broad-based that it includes travel for business purposes.

government, the principal opportunity costs of withdrawing old-growth forests into wilderness are the forgoing of stumpage fees that would otherwise be available for collection.

It must be made very clear that taking stumpage receipts as a goal is purely for the purpose of measuring government revenue so as to assess given wilderness expansion programs. The reason for caution is that variations in stumpage levels during the past 10 years have been substantial. For instance, in October 1987, significant changes were introduced in B.C.'s stumpage system. In lieu of the 15 per cent tax on softwood lumber exports to the United States, forest industries were confronted with sharp increases in stumpage charges (Price Waterhouse 1988). The rise in stumpage levels coincided with accelerated withdrawal of old-growth forests for parks and recreation. The increase in forest land deletion was possible partly because a 5-percent reduction in the AAC accompanied the policy change in the stumpage system (Price Waterhouse 1988). Nevertheless, it is inadequate for one to draw an inference that shrinking AAC induced price rises and, in turn, resulted in higher stumpage values for the Crown. In the model, the level of average stumpage charges for the recent few years is used as the government revenue goal.

(5) Goal of maximizing net benefits from all old-growth uses

One assumption of the model is that old-growth stands possess, on the one hand, timber values that may be captured through extraction and, on the other hand, non-timber values that exist through recreational uses and persist when the stands are left in the state of wilderness. Although market prices are available for most timber products, non-timber values embodied in wilderness preservation are not easily measurable and obtainable. The levels of non-timber values of B.C.'s old growth in the forms of recreation values and preservation values adopted in this study are adapted from van Kooten (1993b). As timber values comprise a significant portion of the total values of the old-growth forests, it is decided that the contributions of forest industries to the provincial gross domestic product (GDP) at factor costs are taken as the level of net benefits goal. It serves as a yardstick against which PAS may be evaluated in terms of overall economic profitability despite apparent non-commensurability problems between GDP and non-timber values (van Kooten 1993b).

(6) Sustained yield goal

Forest industries have been a driving force for British Columbia's economy thanks to the province's natural endowments of productive forests. Maintaining the share of the forest sector's contribution to the provincial economy depends, to a large extent, on sustaining timber yield over a long period of time. The long run sustainable yield (LRSY) is a representation of this goal to which the AAC is supposed to converge. However, declaring old-growth stands as wilderness status will exert downward pressure on the allowable annual cut. It is believed that the Valhalla plan is likely to remove some 3.52 per cent of the AAC on a provincial scale (Simon Fraser University 1990). New AAC calculations, with relevant effects being netted out, are adopted to serve as physical constraints against which the sustained yield goal may be evaluated. A summary of the goals and their levels is presented in Table 2.

Table 2: **Goal Items and Their Levels**

Goal	Unit	Level	Priority ranking
Maximization of total net benefits from all uses	\$	1,244.4 million	1
Old-growth withdrawal	ha	650,459	2
Employment security	job	77,600	3
Non-declining government stumpage revenue	\$	408.73 million	4
Sustained timber yield	m^3	58.94 million	5
Maintain current timber harvest	m^3	73.33 million	6

3.2.3 Mathematical Expressions of Goal Constraints

(1) Wilderness expansion goal

$$\sum_{j=1}^{6} q_j + d^- - d^+ = 650{,}459 \text{ ha} \qquad \text{(GC1)}$$

where q_j is the number of hectares of old growth affected by wilderness expansion in region j, with $j = 1,\ldots,6$ to denote the six B.C. Ministry of Forests' regulated regions of Cariboo, Kamloops, Nelson, Prince George, Prince Rupert, and Vancouver; d^- is negative deviation from goal level, and d^+ for positive deviation.

The provincial authorities have placed study areas for withdrawal evaluation into four categories. The first two categories are areas to be designated by the end of 1993, the third by 1995, and the last by 2000 (B.C. Ministry of Environment 1992). Obviously, this is necessary because of the enormous amount of work involved, and besides, an even allocation of tasks is conducive to minimizing negative effects of the program.

(2) Timber harvesting goal

$$\sum_{j=1}^{6} x_j \cdot V_j + d^- - d^+ = 73.33 \text{ million m}^3 \qquad \text{(GC2)}$$

where x_j is the number of hectares of timber harvest in region j, with $j = 1,2,\ldots,6$; and V_j is the weighted average of timber stock volume, measured in m^3/ha, in region j, taking into account species compositions and site qualities. The allowable annual cut reflects B.C.'s legislative requirement that sustained timber yield should be achieved on a provincial scale. This goal is synonymous with the objective of an even flow of timber supply.

(3) Employment goal

$$\sum_{j=1}^{6} r_j \cdot x_j + d^- - d^+ = 77{,}600 \qquad \text{(GC3)}$$

where r_j is the level of direct forest employment in region j in terms of jobs provided by one hectare of timber harvesting. To calculate this coefficient, one needs to convert the usually used job generation level per thousand cubic metres of timber cut into a basis of job/ha. Since the withdrawal of old growth from timber production will likely cause job losses in the forest industry, the employment goal may be unattainable. However, one wants to get as close to the goal as possible in order to minimize any adverse effects of old-growth withdrawals on employment in the forest sector.

(4) Revenue goal

$$\sum_{j=1}^{6} c_j \cdot x_j \cdot V_j + d^- - d^+ = \$\ 408.73 \text{ million} \qquad \text{(GC4)}$$

where c_j is the rate of stumpage charges, measured in dollars, per cubic metre of timber in region j. The coefficient c is calculated from the provincial Ministry of Forests' annual reports of the past few years. The level of this goal represents an annual average of stumpage charges by the provincial government from 1988 onwards. Revenues from wilderness expansions are deliberately ignored in the model on the assumption that the government will be unable to immediately derive net revenues from expanded wilderness areas due to considerable costs associated with the PAS program in the beginning years.

(5) Total net benefits goal

$$\sum_{j=1}^{6} (x_j \cdot V_j \cdot PT_j + q_j \cdot PW_j) + d^- - d^+ = \$1{,}244.4 \text{ million} \qquad \text{(GC5)}$$

where PT_j are the net timber benefits per cubic metre, in dollars, in region j; and PW_j are the non-timber values on a hectare in region j. The right-hand side denotes the contribution of forestry to the province's GDP at factor costs. In this equation, the intention is to maximize the values of combined benefits from timber harvesting and wilderness expansion. The average level of GDP at factor costs over the past 10 years is used as a target.

(6) Sustained yield goal

$$\sum_{j=1}^{6} x_j \cdot V_j + d^- - d^+ = 58.94 \text{ million } m^3 \qquad \text{(GC6)}$$

The right-hand side reflects the long-run sustainable yield (LRSY) for all TSAs and most TFLs in British Columbia (Binkley *et al.* 1993) . This level is both a target and a constraint in the long run.

3.2.4 Identifying Physical Constraints

The mature and overmature stands constitute a resource base that may be used either for timber production or for non-timber purposes, or for both. At the provincial level, the availability of old-growth forests is a physical constraint on the designation of various uses (Ludwig and Conrad 1991). Specifically, the total area of old-growth forests amounts to 28.77 million ha.

Wilderness preservation is viewed, in this model, as a proxy for all non-timber uses. Basically, two resource constraints are identified for the model.

(1) The constraint of net operable productive mature stands:

$$\sum_{j=1}^{6} (x_j + q_j) \leq 26.6 \text{ million ha} \qquad \text{(PC1)}$$

(2) AAC constraint:

$$\sum_{j=1}^{6} x_j \cdot V_j + q_j \cdot U_j \leq 73.33 \text{ million m}^3 \qquad \text{(PC2)}$$

where U_j is the amount of AAC to be affected by old-growth withdrawal per hectare in region *j*.

The first physical constraint is redundant because, in any given year, the allowable annual cut is not supposed to be exceeded, and the AAC may be translated into harvestable area based on established volume tables. The breakdown of the AAC constraints by B.C. Ministry of Forests' regulated regions is as follows:

(1) Cariboo $x_1 \cdot V_1 + q_1 \cdot U_1 \leq 8.56$ million m^3

(2) Kamloops $x_2 \cdot V_2 + q_2 \cdot U_2 \leq 8.14$ million m^3

(3) Nelson $x_3 \cdot V_3 + q_3 \cdot U_3 \leq 6.1$ million m^3

(4) Prince George $x_4 \cdot V_4 + q_4 \cdot U_4 \leq 17.77$ million m^3

(5) Prince Rupert $x_5 \cdot V_5 + q_5 \cdot U_5 \leq 9.44$ million m^3

(6) Vancouver $x_6 \cdot V_6 + q_6 \cdot U_6 \leq 23.32$ million m^3

Sources and explanations about the AAC are found in the chapter on data.

3.2.5 Identifying Nonnegativity Constraints

By definition, all choice variables and deviational variables are nonnegative.

3.2.6 Formulating the Objective Function

$$\text{Minimize} \quad Z = \begin{aligned}[t] & p_1 (d_1^-) + \\ & p_2 (d_2^-) + \\ & p_3 (d_3^-) + \\ & p_4 (d_4^-) + \\ & p_5 (d_5^- + d_5^+) + \\ & p_6 (d_6^- + d_6^+) \end{aligned}$$

where Z is the value of the objective function to denote the sum of deviations; p_k is the priority factor associated with goal item k, with $k = 1,...,6$.

In accordance with the priority rankings that have already been established, maximization of net benefits from both timber harvesting and wilderness preservation on mature stands is the first priority. Hence, we assign p_1 to this item. For p_1, it is a minimum target to achieve. By assumption, the planners should not be concerned with overachievement, so d_1^+ is omitted from the objective function. Only negative deviations are minimized.

Withdrawal of old-growth forests from timber harvesting is the second highest priority, which is denoted by p_2. Similarly, the planners are assumed to be concerned only with underachievement of the goal. Therefore, d_2^+ is omitted.

The employment goal has been identified as the third priority. For p_3, over-achievement is actually welcome, so it can be safely ignored. We only minimize underachievement in order to get as close to the specified goal level as possible.

The fourth priority goes to the Crown revenue goal. For p_4, the average stumpage level of recent years is taken as the basis from which any underachievement is to be minimized.

Sustained yield is the fifth priority. For p_5, the planners are assumed to utilize available capacity of timber harvesting to the full, while avoiding the tendency to hasten the liquidation of old-growth resources. Therefore, both positive and negative deviations from the goal level are minimized.

The timber production goal happens to be the last priority. For p_6, exact achievement of the goal level is preferred and, therefore, neither positive nor negative deviations are encouraged.

3.2.7 The Complete Model

$$\text{Minimize:} \quad Z = p_1(d_1^-) + p_2(d_2^-) + p_3(d_3^-) + p_4(d_4^-) + p_5(d_5^- + d_5^+) + p_6(d_6^- + d_6^+)$$

Subject to:

(A) Goal constraints:

$$\sum_{j=1}^{6} (x_j \cdot V_j \cdot PT_j + q_j \cdot PW_j) + d^- - d^+ = \$1{,}244.4 \text{ million} \qquad \text{(GC1)}$$

$$\sum_{j=1}^{6} q_j + d^- - d^+ = 650{,}459 \text{ ha} \quad \text{(GC2)}$$

$$\sum_{j=1}^{6} r_j \cdot x_j + d^- - d^+ = 77{,}600 \quad \text{(GC3)}$$

$$\sum_{j=1}^{6} c_j \cdot x_j \cdot V_j + d^- - d^+ = \$408.73 \text{ million} \quad \text{(GC4)}$$

$$\sum_{j=1}^{6} x_j \cdot V_j + d^- - d^+ = 58.94 \text{ million m}^3 \quad \text{(GC5)}$$

$$\sum_{j=1}^{6} x_j \cdot V_j + d^- - d^+ = 73.33 \text{ million m}^3 \quad \text{(GC6)}$$

(B) Physical constraints:

$$\sum_{j=1}^{6} x_j \cdot V_j + q_j \cdot U_j \leq 73.33 \text{ million m}^3 \quad \text{(PC)}$$

$$x_1 \cdot V_1 + q_1 \cdot U_1 \leq 8.56 \text{ million m}^3 \quad \text{(PC1)}$$

$$x_2 \cdot V_2 + q_2 \cdot U_2 \leq 8.14 \text{ million m}^3 \quad \text{(PC2)}$$

$$x_3 \cdot V_3 + q_3 \cdot U_3 \leq 6.1 \text{ million m}^3 \quad \text{(PC3)}$$

$$x_4 \cdot V_4 + q_4 \cdot U_4 \leq 17.77 \text{ million m}^3 \quad \text{(PC4)}$$

$x_5 \cdot V_5 + q_5 \cdot U_5 \leq 9.44$ million m^3 (PC5)

$x_6 \cdot V_6 + q_6 \cdot U_6 \leq 23.32$ million m^3 (PC6)

(C) Nonnegativity constraints:

$d_1^-, d_2^-, d_3^-, d_4^-, d_5^-, d_5^+, d_6^-, d_6^+ \geq 0$

$x_j, q_j, d_k^-, d_k^+ \geq 0$ for $j = 1,...,6$; and $k = 1,...,6$;

$d_k^+ \cdot d_k^- = 0$ for $k = 1,...,6$.

3.3 Assumptions in the Model

The basis of the Goal Programming model is a Linear Programming model that seeks the optimal values of x^* and q^* for timber and non-timber products, respectively. Once the optimal levels of annual timber harvesting and old-growth withdrawal are established, they become rules to abide by in planning processes. Given the market timber prices and estimates of non-market values for wilderness preservation, when the single goal of net benefits maximization is considered subject to some specific constraints, an LP problem may be formulated as follows:

$$
\begin{aligned}
\text{Max } Z &= x \cdot PT + q \cdot PW \\
\text{s.t. } & x + q \leq b1 \\
& x \leq b2 \\
& q \geq b3 \\
& x, q \geq 0
\end{aligned}
$$

where x = level of timber harvesting (ha);

q = level of old growth preservation as wilderness (ha);

b_1 = net operable productive mature stands available (ha);

b_2 = operable mature stands for timber harvesting (ha);

b_3 = proposed area for withdrawal (ha);

PT = net benefits from timber harvesting ($/ha); and

PW = non-timber values ($/ha).

The LP problem can also be set up to minimize the opportunity costs of a given withdrawal plan. The latter approach better fits the needs in calculating the optimal levels of timber harvesting and wilderness expansion in the conviction that comparison of opportunity costs clearly reveals the advantages and/or disadvantages of specific management programs concerning old growth. Nevertheless, the two approaches are inherently related because they are the primal and the dual of essentially the same problem.

In Linear Programming, finding an optimum is to locate the intersection point of all the production functions concerned in conjunction with the ratios of product values, which is indeed the slope of the objective function. In the case of the old-growth problem under analysis, what is needed is information regarding (1) resource availability and goals, (2) input requirements in producing certain products, and (3) unit value terms. Some data are readily available whereas others have to be generated based on assumptions. For instance, timber production is known in terms of technical rates and product values. But the picture for non-timber products is not so clear due to difficulty in quantifying the many services they provide and in measuring their dollar values. As the two types of products originate from the same resource base, knowledge of their relationship in terms of exchange rates for economic valuation and resource equivalence is important in providing a basis on which sensible decisions rest. It appears that the allowable annual cut can serve as a yardstick for measuring both biophysical resources and economic values. Although wilderness preservation on mature stands is not easily quantifiable in terms of benefits and costs, the effects of a given withdrawal plan may be traced by looking at the resulting changes in the AAC, which can, in turn, be translated into dollars on the basis of prevailing market prices of timber products. Of course, the strength of the linkage is open to debate, and it tends to make more sense along with improved accuracy in measuring the values of non-market goods.

In this study, the optimal values for the levels of timber harvesting and wilderness expansion are derived from timber harvest adjustments, taking into account the proposed old-growth withdrawal plan. Based on the assumption that an increase in protected areas is competitive with existing timber harvest operations, reduction in the AAC is unavoidable, and this effect can be converted into an area measure. In short, an essential assumption is that wilderness expansion and protection of old-growth forests has to take place at the expense of reduced timber supply from the net operable forest land in British Columbia.

Chapter 4

Data Used in the Model

Data are fabrics, weaving decision variables into a model according to predetermined relationships. In this study, data of essentially two types have been gathered. One category are figures that help identify the right-hand-side (RHS) constants for fixing various goal targets and resource availabilities, and the other category are those that specify the technical coefficients indicative of resource requirements in the transformation from inputs to outputs. However, given the nature of the problem under analysis, the existing data are inadequate. For instance, non-timber values of the old growth for wilderness preservation are neither available at the provincial level nor at regional levels. Therefore, necessary data are generated on the basis of existing data (perhaps for other regions) and assumptions.

4.1 Data Sources

The data used in the model are drawn from various publications. The major sources include the following:

(1) *Selected Forestry Statistics Canada 1991* (Forestry Canada);

(2) *Economic Forestry Statistics 1992* (Forestry Canada);

(3) *Canada's Timber Supply: Current Status and Outlook* (Runyon 1991);

(4) *Compendium of Canadian Forestry Statistics 1992* (Canadian Council of Forest Ministers);

(5) *British Columbia Land Statistics* (B.C. Ministry of Lands, Parks and Housing 1985 & 1989);

(6) *British Columbia Forest Industry Fact Book 1990-1992* (Council of Forest Industries of British Columbia);

(7) *B.C. Ministry of Forests Annual Reports 1982-1992*;

(8) *Parks and Conservation Areas on Prime Forest Land in B.C., 1965-1985* (Environment Canada 1987);

(9) *Canadian Forestry Statistics* (Statistics Canada 25-202);

(10) *The Forest Industry in Canada* (Price Waterhouse);

(11) *British Columbia Economic & Statistical Review 1991-1992* (B.C. Ministry of Finance and Corporate Relations);

(12) *Opportunity Cost of Preservation of Old Growth and the Present Value of Silviculture* (Ludwig and Conrad 1991);

(13) *British Columbia's Endangered Wilderness: A Proposal for an Adequate System of Totally Protected Lands* (The Valhalla Society 1988);

(14) *Wilderness and Forestry: Assessing the Cost of Comprehensive Wilderness Protection in British Columbia* (Simon Fraser University 1990);

(15) *Economics of Protecting Wilderness Areas and Old-Growth Timber in British Columbia* (van Kooten 1993b); and

(16) *The Economic Impact of a Reduction in Harvest Levels in British Columbia:*

A Policy Perspective (Binkley *et al. 1993*).

4.2 Data Classification

The data extracted from the above sources are classified into two broad groups, namely, the right-hand-side constants and technical coefficients. They centre around the six goal items that have been identified as the elements of the model. Some of the data are shown in the form of tables and figures wherever they appear fit, and others are presented at the end of this chapter.

4.2.1 Right-hand-side Constants

In Goal Programming modelling, the right-hand-side constants fall into two categories, namely, the levels of goals and availability of resources.

Constants for Goal Levels

a) The annual contribution of forestry and logging to B.C.'s real GDP at factor costs is $1,244.4 million at 1986 constant prices for an average level of a ten-year period from 1982 to 1991 (B.C. Ministry of Finance and Corporate Relations 1992).

b) The levels of the old-growth withdrawal goal are based on the Valhalla proposal and the Simon Fraser University study report on B.C.'s wilderness protection. Details are presented in Table 3.

c) Information on the levels of employment by B.C.'s forest industry sector is shown in Table 4. The data for the years 1982-89 are from *Selected Forestry Statistics Canada* (Forestry Canada 1991), and figures for 1990 and 1991 are derived from *Statistics Canada 1990* and *British Columbia Forest Industry Fact*

Book 1992, respectively. The annual average of 77,611 is rounded off to 77,600 which is adopted for the model.

d) Crown stumpage revenue data are drawn from B.C. Ministry of Forests annual reports. The level of $408.73 million is an average of the four years of 1988-1991, reflecting a considerable increase in stumpage charges as a result of government policy changes introduced in 1987 (Price Waterhouse 1988).

e) The level of maximum sustained yield is represented by the long run sustainable yield (LRSY) for all of the TSAs and most TFLs in British Columbia. The most recent LRSY estimates for the whole province are 58.94 million cubic metres (Binkley *et al.* 1993).

f) The AAC level of 73.33 million cubic metres is taken both as a target and a constraint for timber harvesting in the province. Break-downs by region are presented in Table 5.

Table 3: <u>Wilderness Expansion in the Valhalla Proposal by Region</u>

Region	Area (ha)	Volume affected (000 m^3)	m^3/ ha	Reduction in AAC (000 m^3)	Effect on AAC in the region (%)	AAC effect (m^3/ha)
Cariboo	109866	27960	254	448	-5.2	4.08
Kamloops	47965	13587	283	173	-2.1	3.61
Nelson	49249	17214	350	253	-4.1	5.14
Prince George	155217	35801	231	337	-1.9	2.17
Prince Rupert	142852	43679	306	394	-4.2	2.76
Vancouver	145310	87908	605	972	-4.2	6.69
Province	650459	226149	348	2578	-3.52	3.96

Source: SFU-NRM Report No.6 "Wilderness and Forestry," 1990

Table 4: **Level of Employment Supported by Timber Harvesting in B.C.**

Region	m^3/ha	Job/ha
Cariboo	243	0.25
Kamloops	256	0.26
Nelson	297	0.30
Prince George	273	0.28
Prince Rupert	342	0.35
Vancouver	737	0.75
Province	341	0.35

Source: B.C. Ministry of Forests Annual Report 1991-92; and Forestry Canada. "Selected Forestry Statistics."

Note: Price Waterhouse and COFI indicate an employment coefficient of 1.2 per thousand cubic metres of timber harvesting. But B.C. Ministry of Forests figures show a ten-year average of 1.02 per thousand cubic metres.

Table 5: **Net Operable Mature Stands and AAC Levels in B.C.**

Region	Area (ha)	Stock (000 m^3)	m^3/ha	AAC level (000 m^3)
Cariboo	2235849	544084	243	8560
Kamloops	1829048	469002	256	8139
Nelson	934582	277972	297	6099
Prince George	5081986	1388844	273	17768
Prince Rupert	1950078	667734	342	9435
Vancouver	1911276	1409433	737	23324
Province	13942819	4757069	341	73325

Source: SFU-NRM Report No.6. "Wilderness and Forestry," 1990.

Resource Availability

As mentioned above, the AAC by region is identified as a resource constraint in the model. As a matter of fact, two AAC levels are involved. In the equations which do not take old-growth withdrawal plans as given, the provincial total AAC is used; but when the wilderness expansion program enters into consideration, a new level of AAC that nets out the relevant effects are adopted.

4.2.2 Revenue/Cost Coefficients

The values of old-growth forests lie in the services they are capable of providing. The quality of these services may be indicated by means of valuation in dollar terms. Basically, two types of products are involved in the study, namely, timber and non-timber products. Determination of their values is necessary for two reasons. One is for understanding the opportunity costs of a program like PAS through product values comparison because, given the AAC constraint, withdrawing old growth into wilderness will lead to reductions in timber harvest and the timber benefits forgone constitute the opportunity costs of the old-growth protection scheme. The other reason is an extension of the first. The values of timber and non-timber products are needed in calculating benefit ratios that serve to measure the slope of iso-profit lines in a linear programming model concerning production functions with joint products such as timber and non-timber goods and services. Knowledge of the slopes is crucial in finding optimal solutions that are supposed to occur at points where iso-profit lines touch the frontiers of feasible regions (Dowling 1980).

In this study, timber benefits are represented by average net returns from harvesting mature and overmature stands (Ludwig and Conrad 1991). The net returns are expressed algebraically as follows:

$$NB = (PT - CH) * V - CR$$

where *NB* is net benefits ($\$/m^3$);

PT is market price of timber ($\$/m^3$);

CH is harvesting cost ($\$/m^3$);

V is the volume per hectare (m^3/ha); and

CR is the restocking cost ($/ha).

As site quality in British Columbia varies considerably from one region to another, it is desirable that site classes be taken into account when calculating timber volumes. Species type is another important factor affecting the values of timber products. Table 6 is a summary of weighted average net timber benefits by region. The non-timber values of B.C.'s old growth for recreation use and preservation are presented in Table 7, which covers all six regions regulated by the Ministry of Forests. The calculations are based on van Kooten (1993b). The second table of van Kooten's paper provides the basis for calculating the weights for recreation use values and preservation values for old growth. Under the assumption that recreation values account for 25 per cent and preservation values for the remaining 75 per cent of the total non-timber values, a combined weight for both recreation and preservation values can be worked out. Van Kooten (1993b) estimates that the non-timber benefits on a provincial scale are around $1,000 per hectare at the pre-1992 levels of old-growth protection. The combined weights of non-timber values of old-growth protection by region may be used in computing sub-total non-timber values for each of the six regions. The results of calculations are presented in Table 8.

Table 6: **Average Timber Values of Old Growth by Species**

($/ha)

Species	Coast	Southern Interior	Northern Interior
Douglas fir	16470	5842	7689
Cedar/Hemlock	28978	23635	31512
Pines	11991	2057	2395
Balsam	12886	7906	9675
Spruce	22104	10647	8026

Source: Ludwig and Conrad 1991. *Opportunity cost of preservation of old growth and present value of silviculture.*

Timber values refer to the net return defined as:
market price - harvest cost - restocking cost

Table 7: **Timber *vs* Non-timber Benefits of Mature Stands in B.C.**

($/ha)

Region	Timber	Non-timber
Cariboo	5002	312
Kamloops	6905	915
Nelson	8106	1641
Prince George	5778	247
Prince Rupert	14080	429
Vancouver	22803	4304

Source: Based on van Kooten 1993b. "Preservation Benefits - Table 2", and SFU-NRM Report No.6 "Wilderness and Forestry," 1990, the calculation of the non-timber values is done by the following formula:

net mature area x 1000 x weights ÷ area of each region;

The figure 1000 is the approximate level of non-timber benefits per hectare estimated by van Kooten (1993b).

Table 8: **Weights of Recreation Use and Preservation Values**

Region	Weights for recreation value	Weights for preservation value	Combined weights for both values
Cariboo	0.13	0.02	0.05
Kamloops	0.25	0.08	0.12
Nelson	0.21	0.07	0.11
Prince George	0.17	0.06	0.09
Prince Rupert	0.13	0.03	0.06
Vancouver	0.11	0.75	0.59

Source: Adapted from van Kooten (1993b) "Preservation benefits - Table 2".
For combined weights, it is assumed that recreation values account for 25% and preservation values for 75% of entire non-timber values. This weighting seems to make more sense for old growth which tends to have higher preservation values. On stands with less stock, recreation values tend to be high. Another way is to assign half weights to both.

4.2.3 Technical Coefficients

Another important category of data involves the input requirement coefficients. Again, all the coefficients are related with the identified goal items, and the unit area stock volume serves as a common linkage among different coefficients.

(1) The timber values and non-timber values are used as coefficients for the net benefits goal.

(2) Withdrawal of old growth into wilderness is bound to reduce the AAC in the forest region concerned. The coefficients that indicate the reduction in AAC in terms of cubic metre per hectare are included in Table 3.

(3) B.C. Ministry of Forests data on timber harvesting and employment suggest that, on the provincial scale, 1.02 is the average level of employment provided from harvesting 1,000 cubic metres of timber over the past decade. In the model, however, different coefficients are used, as shown in Table 4, to reflect regional variations in terms of stock volumes and species compositions.

(4) The levels of stumpage charges, by region, are derived from B.C. Ministry of Forests annual reports and presented in Table 9.

(5) The per hectare stock volume figures are shown in Table 5.

Table 9: <u>Average Levels of Stumpage Charges on MOF Regulated Lands</u>

Region	$/m^3	$/ha
Cariboo	4.93	1198
Kamloops	6.13	1569
Nelson	4.91	1458
Prince George	8.54	2331
Prince Rupert	5.11	1748
Vancouver	9.49	6994
Province	7.23	2465

Source: B.C. Ministry of Forests Annual Reports 1989-1992

4.3 Other Data

In order to better illustrate the model, additional information of relevance is provided in Appendix B in the form of tables and graphs.

Chapter 5

Discussion of the Results of the Model

The results of the Goal Programming model for planning old-growth uses for wilderness preservation and timber production in British Columbia are provided in this chapter. Upon brief explanation of the computer software adopted for the model, the levels of goal achievements are presented. Although the objective function of the model is to minimize deviations from various established goals, the ultimate purpose of assessing the deviations is to determine what implications the wilderness expansion proposal at hand may have. In order for the model to provide relevant information, sensitivity analysis is carried out in such a way that priority rankings are rearranged in the hope of revealing changes in terms of goal attainments. Trade-offs between different goals are discussed at the end of the chapter.

5.1 Description of the Computer Software Employed

The computer software used in the study is called General Algebraic Modelling System (GAMS). Developed at the World Bank in the 1980s, GAMS is a mathematical programming software package (Brooke, Kendrick, and Meeraus 1988). Designed to handle a wide range of modelling problems, the software has been successfully employed in research projects of diverse disciplines (Jefferson and Boisvert 1989). One distinctive feature of the software is its accommodation of linear, nonlinear, and mixed integer optimization problems.

The adoption of GAMS as the computer software for this study is attributed to its design characterized by a programming language in making standard algebraic statements. This straightforward feature of model construction, complemented by the way data are supposed to be organized and solutions reported, offers considerable credit to the software for, after all, a good mathematical programming software is expected to facilitate the description of a problem and to provide effective means of solving it.

The several GAMS manuals available have no mention as to how goal programming may be handled. Nevertheless, GAMS is adopted in the belief that the software is capable of handling the GP model in such a way that goal constraints are isolated to allow sequential treatment of goal items according to their respective ordering. This piecemeal approach requires separate computer runs in generating solutions, which are subsequently put together for interpretation. The full GAMS command file is provided in Appendix C.

5.2 Optimal Goal Levels and Their Achievements

The main computer simulation results are summarised in Table 10. Recall that decision variables x and q stand for the levels of timber harvesting and wilderness expansion, respectively. The variables are denoted by subscripts from 1 to 6, referring to the six B.C. Ministry of Forests regions, namely, Cariboo, Kamloops, Nelson, Prince George, Prince Rupert and Vancouver. Negative deviations from corresponding goals are represented by $D_1^-,\ldots,D_6^-$, and the fifth and sixth goals are the only ones that are permitted to acquire positive deviations, denoted by D_5^+ and D_6^+.

The solution of the goal programming model provides the following results. First, a pattern of goal item grouping is discernable. Second, given the specific constraints in the model, negative deviations occur for the employment goal and the goal of maintaining current timber harvest, while a positive deviation results for the sustained timber yield goal. Third, the rankings of the goal items have been such that goal constraints tend to build up progressively.

As is revealed in Table 10, the six goal items may be classified into four groups. (1) The goals of net benefits and stumpage revenues form one group since they both are expressed in dollar terms. (However, the two goals are not commensurable in an economic sense since the first measures economic efficiency, while the second is an income transfer). (2) The employment goal stands on its own and is judged by the number of jobs. (3) The sustained timber yield and current timber harvesting goals share an identical measurement of cubic metres. (4) Viewed as an institutional constraint, the wilderness expansion goal is a distinctive category measured in hectares. In the optimal solution, for items of the first group, one observes over-fulfilment of goal targets. In the case of the employment goal, negative deviations occur the moment it is introduced. The two timber related goals are found to be binding constraints on direct forest employment in the province.

5.3 Interpretation of the Results

As Table 10 indicates, the first and fourth goal items do not register any undesirable negative deviations. As far as the total-net-benefits goal is concerned, the target represents an average annual level of contribution by the forestry and logging sector towards the GDP of the province. According to Table 10, if the AAC is fully exploited and maximization of timber benefits is the only consideration, the total net benefits from timber harvesting can reach $2,050 million, or $810 million higher than the target. But this result should not be interpreted as saying that the original target was set too low, because in this model that item happens to have been ranked as the first priority. Setting excessively high targets is likely to result in corner solutions, often leading to complete sacrifice of lower ranking goal items. Likewise, the stumpage revenue goal poses no difficulty for accomplishment because, as Table 10 shows, that the maximum stumpage revenue can be up to $525 million which is $116 million higher than the target. These results lend support to a wilderness expansion plan of a scale similar to that of the Valhalla proposal on the argument that total net benefits tend to be positive and government stumpage revenues are non-declining.

The computer work file has been constructed in such a way that the wilderness expansion component is submitted for two separate solutions. On one occasion, the scheme is not site specific, and on the other it is made to conform with the given plan precisely. When wilderness expansion is evaluated in terms of provincial acreage only, that is, without reference to particular sites, preservation takes place in the Cariboo Forest Region. The reason is that the per hectare stock volume in Cariboo is the lowest in the six regions (see Table 5). But, as has been explained earlier, the Valhalla proposal enters into the model as an institutional goal constraint and, therefore, wilderness expansion targets have to be allocated to identified areas in each of the six B.C. Ministry of Forests' regions.

Direct forest employment is negatively affected by wilderness expansion on old growth. Table 10 reveals that it is impossible to achieve the goal because attainment falls short by 5,384 jobs the moment the goal is introduced. In accordance with goal programming rules, once deviations from a certain goal have been brought to a minimal level, they would be treated as a fresh constraint and should not be violated thereafter. Therefore, when it comes to pursue the sustained timber yield goal, retaining the minimal deviation levels from the employment goal turns out not to be possible without breaking the sustained yield ceiling by 2.58 million cubic metres each year. In spite of this rigid feature, information is generated from computer runs about the changes in the levels of timber harvesting in each of the regions.

Finally, maintaining the current timber harvesting level is not feasible because to insist on achieving that goal will necessarily disturb the immediately higher-ranking item, namely, the sustained timber yield goal. However, by now, the even higher wilderness expansion goal rules out such a possibility by having reduced the AAC already through wilderness designation of certain old-growth stands. This means that negative deviations from the sixth goal are unavoidable.

Table 10 shows the results of evaluating goals at the upper bound of resource constraints, and this approach tells about the obtainability of various goals. For comparison, Table 11 indicates the results when the lower bound of resource availabilities are adopted in goal evaluation.

The additional information provided by Table 11 is the following.

(1) Achieving the minimum level of the first goal does not have to involve timber cut in the Cariboo forest region at all, and logging only needs to occur in the Vancouver forest region on a small scale. Since the concern now is to reach the specified goal level with minimal use of resources, it is economical not to include Cariboo because it is at the bottom among all six regions in terms of timber values per hectare and its unit area stock volume is the lowest as well. The moderate level of timber harvest in the Vancouver forest region is attributable to the region's high stock volume on a hectare basis. The computer algorism is such that one wants to save as much resource as possible in meeting given goals.

(2) Wilderness expansion in the order of 0.65 million hectares can take place entirely in Prince George. The reason is that the region's forest land identified by the Valhalla plan for preservation is of the lowest quality (see Table 3). Besides, achieving the two specific goals makes it unnecessary for logging to occur either in Cariboo or in the Vancouver forest region on account of resource saving principles.

(3) The employment goal is particularly vulnerable to constraint build-up in that negative deviations are hardly avoidable, and it can be tripled should the goal of sustained timber yield be pursued.

(4) The consideration of the sustained yield goal is likely to diminish timber harvesting in the Southern Interior because, as Table 11 shows, logging may fall to zero for Nelson and it can drop to 7,845 hectares from the usual level of 31,117 hectares per year.

5.4 Implications of the Results

The above results indicate that the real conflicts between timber harvesting and wilderness preservation rest with the level of employment being directly provided by the forest industry in the province. Given the fact that old-growth forests are input factors common to both timber harvesting activities and wilderness preservation, review of changes in the levels of resource use may throw some light on various listings of goal items.

As indicated by Table 12, given the current timber prices and non-timber values used in the model, the total-net-benefits goal may be accomplished without ever reaching the upper limit of B.C.'s old-growth resources. The last column of the table suggests that a considerable amount of resources can be left untouched in the Ministry of Forests' Cariboo and Vancouver regions. A wilderness expansion program of the scale such as the Valhalla plan, but not site specific, is unlikely to hinder attainment of the first goal. The situation would probably be such that available mature stands are subjected to fuller use in the Southern Interior and Prince George, where the wilderness expansion scheme could concentrate. However, in view of the Valhalla plan which is identified with specific geographical sites, the old-growth resources become a real constraint everywhere in the province in conjunction with employment considerations. As shown in Tables 10 and 11, even if all the AAC is utilized, there is still a shortfall of 5,384 jobs. The adoption of the sustained yield goal favours relieving pressure on old-growth resources in the Southern Interior, but the cost in terms of job losses in forest-dependent communities would rise to a high level because negative deviations from the average annual employment level would widen by 17,339 instead of 5,384.

In order to validate the model, various tests are necessary in the hope of revealing as much information as possible about the impacts of wilderness expansion on other goal items concerned. A sensible thing to do is to alter priority rankings.

5.5 Priority Ranking Tests

As the employment and sustained timber yield goals have stood out as the ones that witness large deviations, they are singled out for priority ranking alteration tests.

Test 1

During this test, the employment goal is upgraded to the first priority status, while the remaining items maintain their positions relative to one another. The purpose of doing this is to isolate the effects of the proposed wilderness expansion plan on direct forest employment. Table 13 provides information about the level of forest employment losses associated with various goal item packages. It shows that the current timber harvesting level is unable to support the average level of 77,600 jobs and the shortfall amounts to 2,747. This is important for evaluating the Valhalla proposal because the negative effects of the wilderness expansion plan on forest employment is actually not as high as suggested in Table 10. Another interesting thing about this table is the revelation that, without site specifications, all of the wilderness expansion task would go to Prince George where the average opportunity costs are lower than other regions for old-growth preservation.

Test 2

When the sustained yield goal is allowed to assume the first ranking, significant changes would occur with regard to the allocation of old-growth resources among different regions to satisfy the new ordering of various goal items. As can be seen from Table 14, if the sustained yield goal is the first priority, as many as 2.15 million hectares of old growth may be protected as wilderness, occurring entirely in the Vancouver forest region. In the event that a wilderness expansion plan of the Valhalla scale is implemented without site specifications, Vancouver would still be the region for concentrated wilderness preservation. The reason is that non-timber values are much higher in this region than elsewhere, although it is true of timber values as well.

5.6 Different Scenarios of Harvesting Levels

The results of the priority sequence tests indicate that the levels of annual timber harvesting can vary from one ranking scheme to another. For instance, given the original ranking of the GP model, annual timber cut is likely to start off with 149,300 hectares each year to achieve the net benefits goal, and it slides to 137,191 hectares to accommodate the need of preserving 650,000 hectares of forests that are not geographically specific. But, in the framework of the Valhalla plan which serves as an institutional constraint, timber harvesting needs to be maintained at around 204,800 hectares, and retreating from this level on account of long-run sustainable yield will have to cause decline in direct forest employment. This result is shown by Figure 1, which also indicates two other scenarios, one having the employment goal as the first priority and the other adopting sustained yield as the first ranking. These two scenarios start off with higher amounts of timber cut, but both level off as goal constraints pile up. In spite of the differences, the three scenarios show a common feature of conflicts between employment and timber harvesting goals.

5.7 Trade-offs among various goals

Goal Programming is known to be deficient in generating trade-off information (Field, Dress and Fortson 1980). This is particularly the case when only the preemptive approach is used in ordering goal items. Nevertheless, the ranking alteration tests as shown in Table 13 and Table 14 provide information on the trade-offs between the proposed wilderness expansion plan and the reduction in employment for B.C.'s forest industry. Expressed in terms of trade-off ratios as summarized in Table 15, the indications are that additional goal constraints produce adverse effects on the level of direct forest employment given the Valhalla proposal. It appears that adding goal items in the decision package is associated with additional job losses. In other words, the accumulation of goal elements tends to reduce the exchange rate between wilderness expanded area and the lowering of forest related employment.

For instance, when the decision package consists of a plan to expand wilderness by about 650,000 million hectares without specific requirements about site conditions, the number of jobs lost would be (4194 - 2747) = 1447, and the ratio of expanded wilderness area versus job losses would work out to be -450, meaning that losing one forest job is the price for protecting 450 hectares of old growth. However, when site specification is required in accordance with the Valhalla proposal, the absolute value of the ratio would drop to 247, indicating that the disappearance of one forest job is now worth 247 hectares. By the same token, by the time the sustained yield constraint is included in the decision package, loss of one forest job could exchange for merely 45 hectares of wilderness. Therefore, inclusion of goal considerations in decision making processes will likely shrink the resource base of mature stands for timber harvesting, and the most obvious price that British Columbians have to pay, and at an increasing rate, is in terms of forest related employment.

Given the ranking and target levels of the goals, the results of the model demonstrate a serious conflict between timber harvesting and wilderness preservation. Strictly speaking, the conflict originates because the forest base is not unlimited. Wilderness protection (e.g., the Valhalla proposal) merely exacerbates the resource scarcity problem since, even without the proposed protection program, the current AAC is inadequate in supporting the current average level of employment, as shown by Table 13. Yet implementing the Valhalla proposal will incur a greater degree of job losses. The magnitude of the losses can vary considerably, depending on site specification and intensity of constraints. Whether or not to accept the losses is ultimately a political decision.

Table 10: Goal Targets and Attainments at Upper Bound of Resource Constraints

Goal Item	Target	Achievement	Deviation	Wilderness expansion (ha)***	Annual cut (ha)***
- 1st	1.24×10^{9}	2.05×10^{9}	$D_1^-=0$	Total 0	x1 35226 x2 31797 x3 20539 x4 65092 x5 27602 x6 31642 Total 211898
- 1st - 2nd*	1.24×10^{9} 6.5×10^{5}	2.2×10^{9} 6.5×10^{5}	$D_1^-=0$ $D_2^-=0$	q1 650459 Total 650459	x1 24305 x2 31797 x3 20539 x4 65092 x5 27602 x6 31642 Total 200977
- 1st - 2nd** - 3rd	1.24×10^{9} 6.5×10^{5} 77600	1.97×10^{9} 6.5×10^{5} 72216	$D_1^-=0$ $D_2^-=0$ $D_3^-=5384$	q1 109866 q2 47965 q3 49249 q4 155217 q5 142852 q6 145310 Total 650459	x1 33383 x2 31117 x3 19682 x4 63849 x5 26436 x6 30327 Total 204794
- 1st - 2nd** - 3rd - 4th	1.24×10^{9} 6.5×10^{5} 77600 4.09×10^{8}	1.97×10^{9} 6.5×10^{5} 72216 5.25×10^{8}	$D_1^-=0$ $D_2^-=0$ $D_3^-=5384$ $D_4^-=0$	same as above	same as above
- 1st - 2nd** - 3rd - 4th - 5th	1.24×10^{9} 6.5×10^{5} 77600 4.09×10^{8} 5.89×10^{7}	1.97×10^{9} 6.5×10^{5} 72216 5.25×10^{8} 5.89×10^{7}	$D_1^-=0$ $D_2^-=0$ $D_3^-=5384$ $D_4^-=0$ $D_5^-=0$ $D_5^+=1.18\times10^{7}$	same as above	same as above
- 1st - 2nd** - 3rd - 4th - 5th - 6th	1.24×10^{9} 6.5×10^{5} 77600 4.09×10^{8} 5.89×10^{7} 7.33×10^{7}	1.97×10^{9} 6.5×10^{5} 72216 5.25×10^{8} 7.07×10^{5} 7.33×10^{5}	$D_1^-=0$ $D_2^-=0$ $D_3^-=5384$ $D_4^-=0$ $D_5^-=0$ $D_5^+=1.18\times10^{7}$ $D_6^-=2.58\times10^{8}$ $D_6^+=0$	same as above	same as above

* not area specific;
** area specific

*** regions: 1 -- Cariboo; 2 -- Kamloops; 3 -- Nelson; 4 -- Prince George; 5 -- Prince Rupert; 6 -- Vancouver

Table 11: **Goal Targets and Attainments at Lower Bound of Resource Constraints**

Goal Item	Target	Achievement	Deviation	Wilderness expansion (ha)***	Annual cut (ha)***
- 1st	1.24×10^9	1.24×10^9	$D_1^- = 0$	Total 0	x1 0 x2 31979 x3 20539 x4 65092 x5 27602 x6 4088 Total 149300
- 1st - 2nd*	1.24×10^9 6.5×10^5	1.24×10^9 6.5×10^5	$D_1^- = 0$ $D_2^- = 0$	q4 650459 Total 650459	x1 0 x2 31797 x3 20539 x4 59921 x5 24934 x6 0 Total 137191
- 1st - 2nd** - 3rd	1.24×10^9 6.5×10^5 77600	1.97×10^9 6.5×10^5 72216	$D_1^- = 0$ $D_2^- = 0$ $D_3^- = 5384$	q1 109866 q2 47965 q3 49249 q4 155217 q5 142852 q6 145310 Total 650459	x1 33383 x2 31117 x3 19682 x4 63849 x5 26436 x6 30327 Total 204794
- 1st - 2nd** - 3rd - 4th	1.24×10^9 6.5×10^5 77600 4.09×10^8	1.97×10^9 6.5×10^5 72216 5.25×10^8	$D_1^- = 0$ $D_2^- = 0$ $D_3^- = 5384$ $D_4^- = 0$	same as above	same as above
- 1st - 2nd** - 3rd - 4th - 5th	1.24×10^9 6.5×10^5 77600 4.09×10^8 5.89×10^7	1.63×10^9 6.5×10^5 60249 4.39×10^8 5.89×10^7	$D_1^- = 0$ $D_2^- = 0$ $D_3^- = 17339$ $D_4^- = 0$ $D_5^- = 0$	same as above	x1 33383 x2 7845 x3 0 x4 63849 x5 26436 x6 30327 Total 161840
- 1st - 2nd** - 3rd - 4th - 5th - 6th	1.24×10^9 6.5×10^5 77600 4.09×10^8 5.89×10^7 7.33×10^7	1.97×10^9 6.5×10^5 72216 5.25×10^8 7.08×10^5 7.08×10^5	$D_1^- = 0$ $D_2^- = 0$ $D_3^- = 5384$ $D_4^- = 0$ $D_5^- = 0$ $D_6^- = 2.58 \times 10^6$ $D_6^+ = 1.18 \times 10^7$	same as above	x1 33383 x2 31117 x3 19682 x4 63849 x5 26436 x6 30327 Total 204794

* not area specific;
** area specific

*** regions: 1 -- Cariboo; 2 -- Kamloops; 3 -- Nelson; 4 -- Prince George; 5 -- Prince Rupert; 6 -- Vancouver

Table 12: <u>Resource Use under Various Packages of Goal Items</u>

Goal package	Region	Resource use level (million m3)	Upper limit (million m3)	Potential left (million m3)
-1st	Cariboo	0	8.56	8.56
	Kamloops	8.14	8.14	0
	Nelson	6.10	6.10	0
	P.George	17.77	17.77	0
	P.Rupert	9.44	9.44	0
	Vancouver	3.01	23.32	20.31
	Total	44.46	73.33	28.87
-1st -2nd*	Cariboo	0	8.56	8.56
	Kamloops	8.14	8.14	0
	Nelson	6.10	6.10	0
	P.George	17.77	17.77	0
	P.Rupert	8.53	9.44	0.91
	Vancouver	0	23.32	23.32
	Total	40.54	73.33	32.79
-1st -2nd** -3rd	Cariboo	8.11	8.11	0
	Kamloops	7.97	7.97	0
	Nelson	5.85	5.85	0
	P.George	17.43	17.43	0
	P.Rupert	9.04	9.04	0
	Vancouver	22.35	22.35	0
	Total	70.75	70.75	0
-1st -2nd** -3rd -4th	Cariboo	8.11	8.11	0
	Kamloops	7.97	7.97	0
	Nelson	5.85	5.85	0
	P.George	17.43	17.43	0
	P.Rupert	9.04	9.04	0
	Vancouver	22.35	22.35	0
	Total	70.75	70.75	0
-1st -2nd** -3rd -4th -5th	Cariboo	8.11	8.11	0
	Kamloops	2.01	7.97	5.96
	Nelson	0	5.85	5.85
	P.George	17.43	17.43	0
	P.Rupert	9.04	9.04	0
	Vancouver	22.35	22.35	0
	Total	58.94	70.75	11.80
-1st -2nd** -3rd -4th -5th -6th	Cariboo	8.11	8.11	0
	Kamloops	7.97	7.97	0
	Nelson	5.85	5.85	0
	P.George	17.43	17.43	0
	P.Rupert	9.04	9.04	0
	Vancouver	22.35	22.35	0
	Total	70.75	70.75	0

* not area specific;
** area specific.

Table 13: **First Test Results in Altering Goal Ranking**

Goal Item	Target	Achievement	Deviation	Area cut (ha)	Wilderness expansion (ha)
- Employment	77600	74853	2747	x1 35226 x2 31797 x3 20539 x4 65092 x5 27602 x6 31642 Total 211898	0
- Employment - Wilderness*	77600	73406	4194	x1 35226 x2 31797 x3 20539 x4 59921 x5 27602 x6 31642 Total 206727	q4=650459
- Employment - Wilderness**	77600	72216	5384	x1 33383 x2 31117 x3 19682 x4 63849 x5 26436 x6 30327 Total 204794	q1 109866 q2 47965 q3 49249 q4 155217 q5 142852 q6 145310
- Employment - Wilderness - Net benefits - Stumpage	77600	72216	5384	same as above	same as above
- Employment - Wilderness - Net benefits - Stumpage - Sustained yield	77600	60261	17339	x1 33383 x2 7845 x3 0 x4 63849 x5 26436 x6 30327 Total 161840	same as above

* not site specific;
** site specific.

Table 14: **Second Test Results in Altering Goal Ranking**

Goal Item	Region	Wilderness expansion (million ha)	Annual cut (ha)
- Sustained yield	Cariboo		35226
	Kamloops		31797
	Nelson		20539
	Prince George		65092
	Prince Rupert		27602
	Vancouver	2.15	12121
	Total	2.15	192377
- Sustained yield	Cariboo		0
- Wilderness*	Kamloops		26033
	Nelson		20539
	Prince George		65092
	Prince Rupert		27602
	Vancouver	0.65	25737
	Total	0.65	165003
- Sustained yield	Cariboo	same as Valhalla plan	33383
- Wilderness**	Kamloops		7845
- Employment	Nelson		0
	Prince George		63849
	Prince Rupert		26436
	Vancouver		30327
	Total		161840
- Sustained yield	Cariboo	same as above	33383
- Wilderness	Kamloops		7845
- Employment	Nelson		0
- Net benefits	Prince George		63849
	Prince Rupert		26436
	Vancouver		30327
	Total		161840
- Sustained yield	Cariboo	same as above	33383
- Wilderness	Kamloops		7845
- Employment	Nelson		0
- Net benefits	Prince George		63849
- Stumpage	Prince Rupert		26436
	Vancouver		30327
	Total		161840
- Sustained yield	Cariboo	same as above	33383
- Wilderness	Kamloops		31117
- Employment	Nelson		19682
- Net benefits	Prince George		63849
- Stumpage	Prince Rupert		26436
- Harvesting	Vancouver		30327
	Total		204794

* not site specific;
** site specific

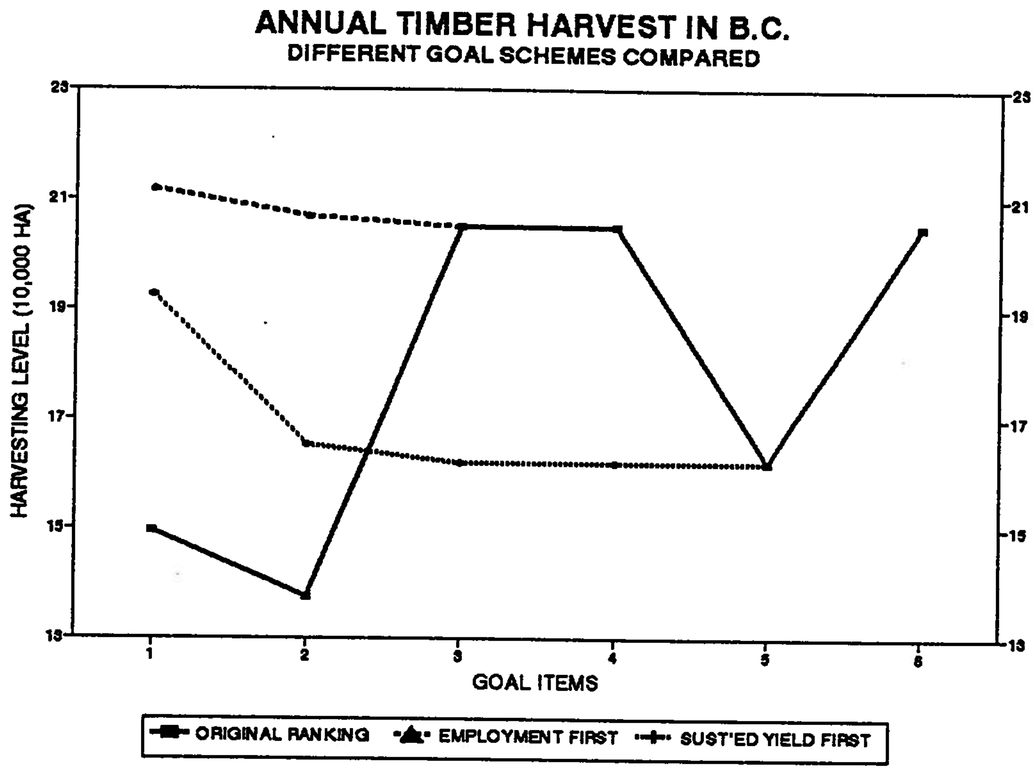
Table 15:

Trade-off Ratio between Wilderness Expansion and Forest-related Employment Reduction under Different Scenarios

Goal items	Wilderness expansion (thousand ha)	Direct forest employment	Wilderness gained per job lost
- Employment	0	74853	0
- Employment - Wilderness (not site specific)	650	73406	- 450
- Employment - Wilderness (site specific)	650	72216	- 247
- Employment - Wilderness - Net benefits - Stumpage	650	72216	- 247
- Employment - Wilderness - Net benefits - Stumpage - Sustained yield	650	60261	- 45

Figure 1:

Annual Timber Harvest Scenarios in B.C. - Different Goal Schemes Compared



Chapter 6

Summary and Conclusions

British Columbia is endowed with large areas of old-growth forests that afford its residents ample opportunities to pursue diverse goals. However, intensification of activities related to the old growth over the last few decades has run parallel with a growing awareness of limits to the resource base. Conflicts arise primarily from rival human needs for both timber and non-timber products that may be translated into jobs on the part of local communities, profits on the part of forest industries, and revenues on the part of the provincial government. From the standpoint of the province at large, the old growth has an essential role to play in the well-being of the average British Columbian.

Managing the old-growth forests for multiple uses is a decision-making process that involves diverse goals. Identification of goal items provides a framework in which a problem may be addressed, and specification of goal targets puts the problem into perspective, which, along with the consideration of resource availabilities, delineates the required decision environment.

For a multiple-use decision problem, instead of any single item, the objective is necessarily to seek the achievement of all goals concerned to the largest extent possible. What underlies the optimal solution is a most preferred status characterized by a well-placed system of goals related to one another via an exchange rate or trade-off function that may or may not be directly expressible in value terms. The result is the choice, among all alternatives available, of the one most satisfactory to the stakeholders.

The identification of goals serves the purpose of focusing decision makers' attention on fewer selected aspects of an issue. The specification of goal levels creates concrete criteria by which judgement may be formed. And ranking goals in an ordinal fashion establishes a rule of procedure that guides a sequential treatment of the goals. All this leads to the ultimate objective of maximizing the contribution of the old growth to the well-being of British Columbians. Alternatively, the objective can be expressed as minimizing deviations from established targets, which is precisely what this study is concerned with.

The aim of this study is to evaluate a specific plan concerning the use of old-growth forests for timber harvesting and wilderness preservation at the provincial level in British Columbia. In the context of B.C.'s Protected Areas Strategy, the old growth is placed under two polarized land use considerations, namely, commercial harvesting for the realization of timber values and designation as wilderness status for the provision of non-timber benefits. Of the six goals that have been identified, the wilderness expansion plan is represented by the Valhalla proposal on account of its similarity to PAS in terms of philosophy and scale. As a matter of fact, it is an essential item whose impacts on other goals are subject matters for assessment.

6.1 Summary of model results

The goal programming model has generated the following results.

(1) In view of the priority rankings of the goals, implementations can proceed from the first goal through the fourth. Of the goals that are included, the wilderness plan serves as an institutional framework in which action plans are pursued and evaluated. Under the Valhalla scheme, the chosen levels for the goals of total net benefits from the old growth and government stumpage revenues are unlikely to suffer from any underachievement. However, under the same circumstances, direct forest employment is expected to fall from the recent ten-year average by 5,384 jobs.

(2) It is not possible to consider the fifth and sixth goals in the decision package without jeopardizing the accomplishments of higher-ranking goals. In the case of the sustained timber yield goal, its inclusion is likely to worsen forest-related employment shortfalls from 5,384 to 17,339. This problem might be partially rectified by insisting on the current timber harvesting goal; but the cost of minimising employment losses back to 5,384 is the breaking of the sustained yield ceiling by 2.58 million cubic metres in terms of AAC.

(3) The six goal items tend to fall into the following four categories:

a) wilderness expansion plan;

b) employment goal;

c) total net benefits and government stumpage revenues; and

d) sustained timber yield and current level of timber harvesting.

Conflicts are evident between the employment goal, on the one hand, and the sustained timber yield goal on the other. The impacts of the wilderness expansion plan as a constraint on timber harvesting operations are clearly visible. The two goals of net benefits and stumpage revenues are not binding on the rest.

(4) As far as resource use is concerned, the results of the model seem to indicate that resource allocation has a tendency of gravitating towards its efficient use on the basis of unit area stock volume and prevailing value terms. For instance, the specified target of the net benefits goal may be attained at least cost in terms of old-growth resource use by not involving Cariboo due to its low level of stock volume and timber values per hectare and by incurring limited logging activities in the Vancouver forest region. As far as wilderness expansion is concerned, should there be no geographical requirements, a program on the scale of the Valhalla proposal is least costly to occur in Cariboo judging by site index alone, and the task is likely going to Prince George if minimizing negative effects on AAC is the sole consideration.

In the model, when the site specific wilderness plan is introduced in conjunction with the employment goal, excess resource reserves immediately drop to zero. The pressure on resource uses can be mitigated, mainly in the Southern Interior, when the sustained yield goal is brought into consideration, but the associated cost is enormous in terms of the reduction in the level of direct forest employment.

(5) Altering the priority ordering of goals has been undertaken for the

purposes of sensitivity analysis. Unlike in Linear Programming problems, the alteration of goal rankings is merely to change the sequences by which the same problem is approached. The test has proved helpful in generating supplementary information.

Suppose that the system of goals is altered in such a way that employment is upgraded to the first priority. Given the current AAC constraints, the maximum level of timber harvest is then 211,898 hectares, allowing no wilderness expansion. This so-called optimal level could only support 74,853 jobs. In other words, given the current technology, the annual employment level of 77,600 is actually higher than what can be supported by the forest industry in the province and, therefore, the negative deviation of 2,747 from the average level is the minimum required due to the AAC constraints. It then follows that any schemes that erode the AAC will have adverse impacts on forest employment. A wilderness expansion program such as the Valhalla plan, but without specific requirements on geographic sites, is likely to result in a total shortage of 4,194 jobs. That is, the net impact is to sacrifice 1,447 jobs, but the wilderness designated for protection is 0.65 million hectares of mature stands in the Prince George forest. Implementation of a full-fledged Valhalla proposal is likely to cause a net loss of 2,637 jobs across the province. The negative effects are almost double those of a similar plan that is non-site specific. Adding a sustained timber yield goal over and above the Valhalla plan would cause forest employment to shrink to 60,261, which is 17,339 below the average level of the past decade, or 14,592 below the current level. To say the very least, the negative impacts of this additional constraint more than doubles the total effects of the Valhalla proposal alone on direct forest employment.

A similar test has been done in altering the priority ranking of the sustained yield goal. The most important information is that the pursuit of a sustained timber yield goal favours wilderness preservation in the Vancouver region. Such a scheme tends to drive wilderness expansion activities entirely to the Vancouver forest region.

The implications of these results of the model are the following. First, the old-growth forests are resources that should be managed for multiple uses. The recognition that wilderness is a land use category as well has secured a place for it to be included in any decision package concerning the old-growth issue. Hence, it is legitimate and justifiable for PAS to be pursued, and in the case of this study, for the Valhalla plan to be considered. Second, the lack of information on non-timber values makes it difficult to evaluate a wilderness expansion program by means of benefit/cost analysis. Instead, consequences of the given program may be analyzed by looking at common linkages such as the AAC in the case of this study. Third, British Columbia is currently operating at its upper limit of the available old-growth resources, and reliance on old growth for employment opportunities is so strong that a slight reduction in the availability of resources for harvesting is likely to bring about immediate negative effects. As the model ignores job increases associated with wilderness expansion, there is a possibility that employment losses to the whole province may not be as high as what the forest industry would be confronted with.

6.2 Recommendations

The recommendations fall into two parts. The first part is targeted towards policy makers at the provincial level, and the second part is concerned with future research.

6.2.1 Recommendations for Policy Changes

The Protected Areas Strategy has emerged in response to calls for preserving a sound environment in the interests of the inhabitants in British Columbia. It is an undertaking that involves planning and implementation, and clearly, planning is of much more concern to policy makers. During the planning process, three essential things need to be considered -- state of technology, resource allocation effects, and human aspirations. The first point is to know about the *status quo* of natural endowments and inherent relationships in terms of transformation from inputs to outputs. This knowledge leads to understanding production functions that hold promises as well as constraints for human activities. The second point is about what the resource situation is to be like as the result of a specific action plan. Its concern with resource allocation is virtually the same as the first point, although different time horizons are involved. The third point is an interface that connects the first two, and is about human preferences and their desire to be satisfied. The pursuit of welfare is constrained by the limited availability of resources.

Although, in the long run, advances in technology can alter the rate of transformation between inputs and outputs to allow a greater degree of human satisfaction, the reality of resource scarcity has to be faced in the short run. The solution to such a problem lies in equating human valuation of products to the rate of production transformations, taking sustainability into due account.

In view of the foregoing observation, recommendations for decision makers on the issue of old growth for wilderness expansion in British Columbia are the following.

(1) Although there exist a large amount of data about the inventory aspects of the mature stands in the province, information is lacking on many bio-physical aspects of old growth. What accounts for this is the historical predominance of timber extraction. Acquisition of adequate information on the non-timber uses is helpful for understanding production functions of timber and non-timber products, and new knowledge of this kind may generate a more convincing case in support of an old-growth preservation plans such as the Valhalla proposal.

(2) There is an imperative need to carry out studies on the non-timber values of old growth. Current information falls short of providing a sound basis for estimating the benefits from implementing the ambitious PAS program.

(3) Talking about PAS specifically, withdrawal of old-growth forests into wilderness, for instance, at the scale of the Valhalla proposal, is acceptable

provided that the overall gain from the standpoint of the province outweighs the combined losses of the regions concerned. This will ensure that the program can be paid for on its own account.

(4) The necessary administrative costs associated with PAS can be huge, and hence should not be neglected. Generally known as transactions costs, expenditures are required both at the planning stage and in various implementation phases. It is indeed a dilemma that a well conceived and carefully prepared PAS program should improve the efficiency of the program, but the enormous expenses for doing this may be so costly as to make the program uneconomic.

(5) Lastly, a temptation should be avoided in turning PAS into a gigantic all-in-one project. Beyond a certain point, the plan would be too clumsy to move ahead. Should decision makers choose a large size for the program, meticulous planning and coordination are necessary, and realistic targets along with clearly defined time-tables will facilitate implementation.

6.2.2 Recommendations for future research

Future research is required to deal with the following concerns.

(1) The employment generation capacities associated with wilderness tourism need to be studied.

(2) The relationships among the various goal items of the model need to be studied in terms of assigning cardinal weights to various goals so that trade-off functions can be accurately determined.

(3) The dynamic aspect of the issue of old-growth preservation deserves attention.

6.3 Conclusion

The issue of old growth is of concern to virtually every inhabitant in British Columbia for the simple reason that it concerns the economy and the environment. Although it may be right to say that there is no ultimate conflict between economic development and the preservation and enhancement of a healthy environment and a sustainable resource base, it is more of an expectation than a reality (B.C. Environment 1991). The journey to that end starts with concrete steps in finding the correct path. It will be a long way to zigzag through the thick old-growth forests before British Columbia is on the road to the destination of balance between environmental beauty and economic prosperity.

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Appendix A

QUESTIONNAIRE

Identifying Priority Rankings on Old-Growth Uses in British Columbia

British Columbia is one of the few places where substantial areas of temperate old-growth forests and wilderness still exist. It has been proposed that some of the old growth should be protected or preserved along with other areas of wilderness. Government policy is to increase the amount of wilderness area from the current 6 percent of the province's land base to about 12% by the year 2000; somewhere between 4% and 10% of the wilderness area to be protected is actually old-growth forest.

At the Forest Economics and Policy Analysis Research Unit at UBC, we are investigating both the larger issue of wilderness (old-growth) protection and resolution of forestland use conflicts at the local level -- the Tangier watershed between Revelstoke and Glacier National Parks in eastern B.C.

In order to help us in these research projects, we would appreciate your cooperation in completing the following questionnaire. We are attempting simply to get some idea concerning the importance of various issues that can provide guidance for a mathematical model an M.Sc. student is developing to study province-wide wilderness protection. Your answers will be anonymous and, hence, confidential.

Please rank the following policy items from 1 (most important) to 7 (least important). If you feel two items should be given the same rank, please assign the same number to them. The rankings will be used to help construct a goal programming model for wilderness protection.

Item	Rank
Maintain the current level of timber harvest in B.C.	
Permanently withdraw ______ % (please fill in) of the old growth scheduled for future timber harvest	
Maintain the maximum sustainable yield in timber harvest	
Secure regional stability by maintaining the current level of employment in forest industries	
Maintain the level of provincial government revenue from forest harvesting	
Maximize the net revenue from all forestland uses, even if that means less timber harvest	
Other (please specify)	

Appendix B

Supplementary Data

Table B.1: **Land Use in British Columbia**

Category	Area (ha)	Percentage
Forest	43264603	45.6
Grazing	8490602	9.0
Agriculture	2369226	2.5
Recreation	5848628	6.2
Settlement	549000	0.6
Other	229776	0.2
Uncategorized	32221165	34.0
Total land area	92973000	98.1
Total water area	1807000	1.9
B.C. total area	94780000	100.0

Source: *British Columbia Land Statistics.*
B.C. Ministry of Crown Lands. Victoria. 1989.

Table B.2: **B.C. Ministry of Forests' Regulated Land**

(ha)

Region	Land area	Productive forests	Mature stands
Cariboo	7531982	5949000	3634000
Kamloops	5887756	4438000	2446000
Nelson	6456748	3448000	1320000
Prince George	29571666	17421000	9552000
Prince Rupert	23033169	9395000	6396000
Vancouver	10564875	4945000	3293000
MOF total	83046196	45596000	26641000
B.C. total	92973000	49054000	28774200

Source: *Compendium of Canadian Forestry Statistics 1992*;
B.C. *Ministry of Forests Annual Report 1991-92*; and
SFU-NRM Report NO.6 *Wilderness and Forestry* (SFU 1990).

Table B.3: **Quality of Productive Forest Land in British Columbia**

(ha)

Site class	Immature	Mature	Total	Percentage
TFL				
Good	180363	253309	433672	10.9
Medium	817188	1103545	1920733	48.4
Poor	280523	1003608	1284131	32.4
Low	53733	275077	328810	8.3
Sub-total	1331807	2635539	3967346	100.0
TSA				
Good	968435	1918350	2886785	7.3
Medium	5038709	8693931	13732640	35.0
Poor	7690895	00990318	19681213	50.1
Low	1374213	1609960	2984173	7.6
Sub-total	15072252	24212559	39284811	100.0
TFL and TSA				
Good	1148798	2171659	3320457	7.7
Medium	5855897	9797476	15653373	36.2
Poor	7971418	12993926	20965344	48.5
Low	1427946	1885037	3312983	7.6
Total	16404059	26848098	43252157	100.0

Source: *British Columbia Land Statistics.* B.C. Ministry of Crown Lands. Victoria. 1989.

Table B.4: **Distribution and Proportion of Mature Stands in B.C.**

(ha)

Region	Mature stands	Total productive	Percentage
Cariboo	3634000	5949000	0.61
Kamloops	2446000	4438000	0.55
Nelson	1320000	3448000	0.38
Prince George	9552000	17421000	0.55
Prince Rupert	6396000	9395000	0.68
Vancouver	3293000	4945000	0.67
B.C. total	26641000	45596000	0.58

Source: B.C. *Ministry of Forests Annual Report 1991-92*.

Table B.5: **Inventory of Mature Stands by Species and by Region**

(million m^3)

Species	Coast	%	Interior	%	Total	%
Douglas fir	275.7	9.0	260.0	4.7	535.7	6.2
Red cedar	703.0	23.0	172.5	3.1	875.5	10.2
Hemlock	1234.6	40.3	583.7	10.6	1818.3	21.2
Balsam	497.3	16.2	1130.8	20.4	1628.1	19.0
Spruce	146.4	4.8	1625.0	29.4	1771.4	20.6
Lodgepole pine	23.3	0.8	1385.6	25.1	1408.9	16.4
Other conifers	164.7	5.4	60.3	1.1	225.0	2.6
Deciduous	15.9	0.5	309.5	5.6	325.4	3.8
Total	3061.1	100.0	5527.4	100.0	8588.5	100.0

Source: *1992 British Columbia Economic & Statistical Review.* B.C. Ministry of Finance and Corporate Relations. 1993.

Table B.6: **Species Composition of Log Production in B.C. - 1991**

(in percentage)

Region	Doug. fir	Ced/Hem	Pines	Balsam	Spruce	Others
Cariboo	12.8	1.6	59.8	5.0	19.9	0.9
Kamloops	17.3	8.4	41.1	10.2	21.2	1.8
Nelson	14.4	18.0	40.6	6.5	15.6	4.9
Prince George	2.4	0.4	36.8	10.4	44.6	5.4
Prince Rupert	0	30.3	24.6	25.4	18.5	1.2
Vancouver	13.4	60.2	0.3	18.0	3.6	4.5
Province	9.9	26.8	26.6	13.8	19.3	3.6

Source: *British Columbia Forest Industry Fact Book 1992.* COFI.

Table B.7: **Withdrawal of Prime Forest Land into Park Areas in B.C.**

Year	Annual level (ha)	Cumulative (ha)
1965-85	399900	399900
1986	11620	411520
1987	74390	485910
1988	183	486093
1989	2550	488643
1990	147010	635653
1991	3703	639356

Source: *Parks and Conservation Areas on Prime Forest Land in B.C., 1965-1985*. Environment Canada 1987;
B.C. *Ministry of Forests Annual Reports 1986-1992*.

Table B.8: **Regional Variations in Withdrawal of Prime Forest Land into Park Areas**

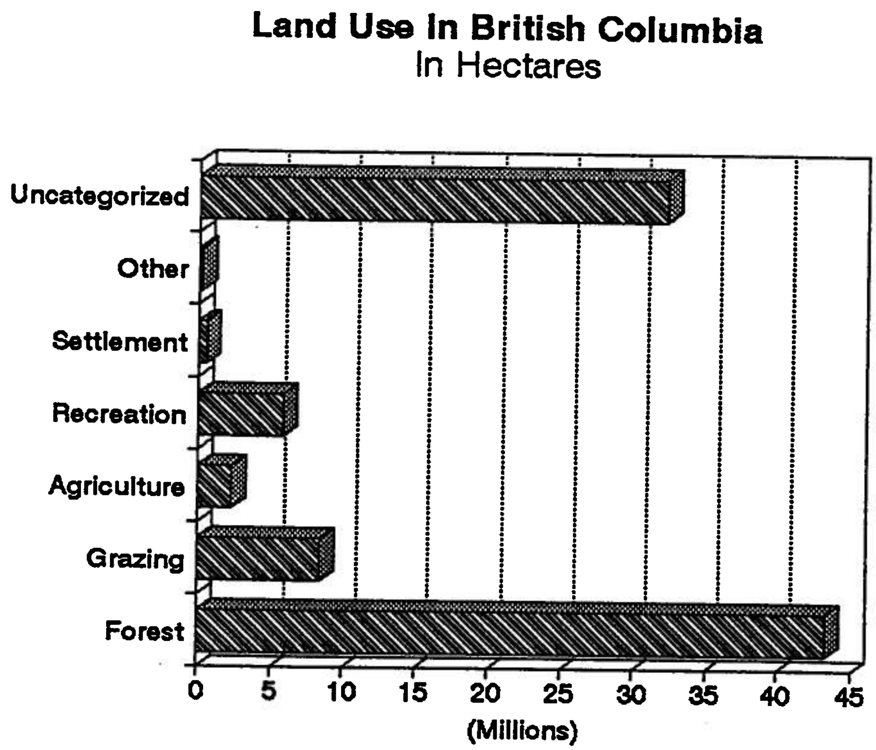
(ha)

Year	Coast	Southern Interior	Northern Interior	Total
1983	0	662	5	667
1984	0	14	608	622
1985	1	1	3573	3575
1986	0	11620	0	11620
1987	0	357	74033	74390
1988	162	21	0	183
1989	1976	529	45	2550
1990	146680	330	0	147010
1991	3662	0	41	3703

Source: B.C. *Ministry of Forests Annual Reports 1983-1992.*

Figure B.1

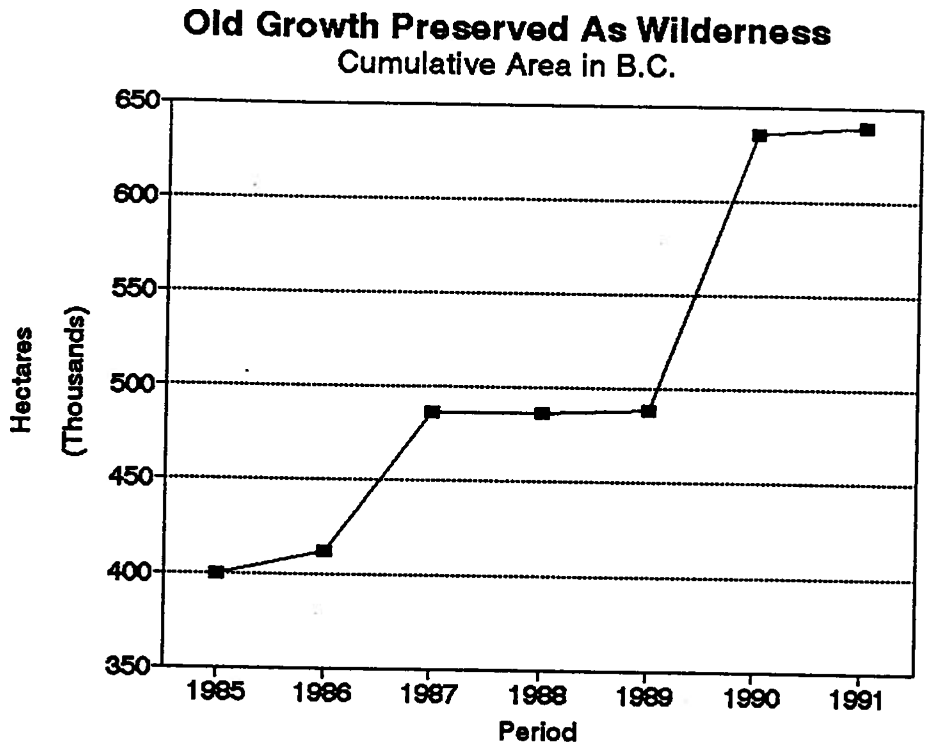
Land Use in British Columbia



Source: *British Columbia Land Statistics.* B.C. Ministry of Crown Lands. Victoria. 1989.

Figure B.2:

Old Growth Preserved as Wilderness - Cumulative Area in B.C.



Source: Environment Canada 1987. "*Parks and Conservation Areas on Prime Forest Land in B.C., 1965-1985*"; and B.C. Ministry of Forests Annual Reports 1986-1992.

Appendix C

The GAMS Command File for the Goal Programming Model

This command file is compiled for the GP model concerning the multiple uses of the old-growth forests in British Columbia. The objective is to minimize deviations from specified goal targets subject to predetermined constraints. In the work file, every equation stands on its own to allow sequential treatment. The goal items follow the original ordering based on the results of a survey.

```
SETS
 J Harvesting
   /X1  Cariboo
    X2  Kamloops
    X3  Nelson
    X4  Prince George
    X5  Prince Rupert
    X6  Vancouver/
 K Withdrawal
   /Q1  Cariboo
    Q2  Kamloops
    Q3  Nelson
    Q4  Prince George
    Q5  Prince Rupert
    Q6  Vancouver/
 L Deviation
   /D1  NEGDEV1
    D2  NEGDEV2
    D3  NEGDEV3
    D4  NEGDEV4
    D5  NEGDEV5
    D6  NEGDEV6
    D7  POSDEV1
    D8  POSDEV2
    D9  POSDEV3
    D10 POSDEV4
    D11 POSDEV5
    D12 POSDEV6/
 I Inputs  all goals
   /INP1 benefits
    INP2 wilderness
    INP3 employment
```

```
    INP4 stumpage
    INP5 newAAC
    INP6 oldAAC/
  I1 first input  /INP1/
  I2 second input /INP2/
  I3 third input  /INP3/
  I4 fourth input /INP4/
  I5 fifth input  /INP5/
  I6 sixth input  /INP6/
 H Resource by region
   /RES1 Cariboo
    RES2 Kamloops
    RES3 Nelson
    RES4 Prince George
    RES5 Prince Rupert
    RES6 Vancouver/
Parameter P(L) Objective function coefficients
   /D1  1
    D2  1
    D3  1
    D4  1
    D5  1
    D6  1
    D7  0
    D8  0
    D9  0
    D10 0
    D11 1
    D12 1/ ;
Parameter B(I) Requirements of inputs
   /INP1  1244000000
    INP2      650459
    INP3       77600
    INP4   408730000
    INP5    58943000
    INP6    73330000/ ;
Parameter B1(I1) Requirements of first input
   /INP1  1244000000/ ;
Parameter B2(I2) Requirements of second input
   /INP2      650459/ ;
Parameter B3(I3) Requirements of third input
   /INP3       77600/ ;
Parameter B4(I4) Requirements of fourth input
   /INP4   408730000/ ;
```

```
Parameter B5(I5) Requirements of fifth input
  /INP5    58943000/ ;
Parameter B6(I6) Requirements of sixth input
  /INP6    73330000/ ;
Table A(I,J) Rate of inputs per harvesting activity
        X1   X2   X3   X4    X5    X6
  INP1 5002 6905 8106 5778 14080 22803
  INP2
  INP3 0.25 0.26 0.30 0.28  0.35  0.75
  INP4 1198 1569 1458 2331  1748  6994
  INP5  243  256  297  273   342  737
  INP6  243  256  297  273   342  737 ;
Table A1(I1,J) Rate of first input per activity
        X1   X2   X3   X4    X5    X6
  INP1 5002 6905 8106 5778 14080 22803 ;
Table A2(I2,J) Rate of first two inputs per activity
        X1   X2   X3   X4    X5    X6
  INP2                        ;
Table A3(I3,J) Rate of first three inputs per activity
        X1   X2   X3   X4    X5    X6
  INP3 0.25 0.26 0.30 0.28  0.35  0.75 ;
Table A4(I4,J) Rate of first four inputs per activity
        X1   X2   X3   X4    X5    X6
  INP4 1198 1569 1458 2331  1748  6994 ;
Table A5(I5,J) Rate of first five inputs per activity
        X1   X2   X3   X4    X5    X6
  INP5  243  256  297  273   342  737 ;
Table A6(I6,J) Rate of all six inputs per activity
        X1   X2   X3   X4    X5    X6
  INP6  243  256  297  273   342  737 ;
Table C(I,K) Rate of inputs per wilderness activity
          Q1    Q2    Q3    Q4    Q5    Q6
  INP1   312   915   1641   247   429   4304
  INP2     1     1     1     1     1     1
  INP3
  INP4
  INP5
  INP6                              ;
Table C1(I1,K) Rate of first input per activity
         Q1    Q2    Q3    Q4    Q5    Q6
  INP1   312   915  1641   247   429  4304 ;
Table C2(I2,K) Rate of first two inputs per activity
         Q1    Q2    Q3    Q4    Q5    Q6
  INP2    1     1     1     1     1     1 ;
```

```
Table C3(I3,K) Rate of first three inputs per activity
       Q1    Q2    Q3    Q4    Q5    Q6
 INP3                              ;
Table C4(I4,K) Rate of first four inputs per activity
       Q1    Q2    Q3    Q4    Q5    Q6
 INP4                              ;
Table C5(I5,K) Rate of first five inputs per activity
       Q1    Q2    Q3    Q4    Q5    Q6
 INP5                               ;
Table C6(I6,K) Rate of all six inputs per activity
       Q1    Q2    Q3    Q4    Q5    Q6
 INP6                               ;
Table E(I,L) Deviation
      D1  D2  D3  D4  D5  D6  D7  D8  D9  D10  D11  D12
 INP1   1
 INP2      1
 INP3         1
 INP4            1
 INP5               1                  -1
 INP6                  1                   -1 ;
Table E1(I1,L)
      D1  D2  D3  D4  D5  D6  D7  D8  D9  D10  D11  D12
 INP1   1                ;
Table E2(I2,L)
      D1  D2  D3  D4  D5  D6  D7  D8  D9  D10  D11  D12
 INP2      1              ;
Table E3(I3,L)
      D1  D2  D3  D4  D5  D6  D7  D8  D9  D10  D11  D12
 INP3         1          ;
Table E4(I4,L)
      D1  D2  D3  D4  D5  D6  D7  D8  D9  D10  D11  D12
 INP4            1        ;
Table E5(I5,L)
      D1  D2  D3  D4  D5  D6  D7  D8  D9  D10  D11  D12
 INP5               1                  -1 ;
Table E6(I6,L)
      D1  D2  D3  D4  D5  D6  D7  D8  D9  D10  D11  D12
 INP6                  1                   -1 ;
Parameter N(H) Physical constraints
 /RES1  8560000
  RES2  8140000
  RES3  6100000
  RES4 17770000
  RES5  9440000
```

```
  RES6 23320000/ ;
Parameter NP(H) New physical constraints
  /RES1 8112077
   RES2 7966026
   RES3 5845689
   RES4 17430697
   RES5 9040954
   RES6 22351014/ ;
Table F(H,J) Technical coefficients of constraints per activity
       X1   X2   X3   X4   X5   X6
 RES1 243
 RES2      256
 RES3           297
 RES4                273
 RES5                     342
 RES6                          737 ;
Table G(H,K) Technical coefficients of constraints per activity
       Q1   Q2   Q3   Q4   Q5   Q6
 RES1  4.08
 RES2       3.61
 RES3            5.14
 RES4                 2.17
 RES5                      2.76
 RES6                           6.69 ;
Variables
Z   Total deviations
X(J) Harvesting levels
Q(K) Wilderness levels
D(L) Deviations
Positive variables X, Q, D ;
Equations
 TOD          objective function
 GOAL1(I1)    first goal
 GOAL11(I1)   altered first goal
 GOAL2(I2)    second goal
 GOAL21(I2)   altered second goal
 GOAL3(I3)    third goal
 GOAL4(I4)    fourth goal
 GOAL5(I5)    fifth goal
 GOAL6(I6)    sixth goal
 CONS1(H)     physical constraints with variable Q values
 CONS2(H)     physical constraints with fixed Q values;
 TOD..        SUM(L,D(L)*P(L)) =E= Z ;
 GOAL1(I1)..  SUM(J,X(J)*A1(I1,J))+SUM(K,Q(K)*C1(I1,K))
```

```
          +SUM(L,D(L)*E1(I1,L)) =G= B1(I1) ;
GOAL11(I1).. SUM(J,X(J)*A1(I1,J))+SUM(K,Q.L(K)*C1(I1,K))
          +SUM(L,D(L)*E1(I1,L)) =G= B1(I1) ;
GOAL2(I2)..  SUM(J,X(J)*A2(I2,J))+SUM(K,Q(K)*C2(I2,K))
          +SUM(L,D(L)*E2(I2,L)) =E= B2(I2) ;
GOAL21(I2).. SUM(J,X(J)*A2(I2,J))+SUM(K,Q.L(K)*C2(I2,K))
          +SUM(L,D(L)*E2(I2,L)) =E= B2(I2) ;
GOAL3(I3)..  SUM(J,X(J)*A3(I3,J))+SUM(K,Q.L(K)*C3(I3,K))
          +SUM(L,D(L)*E3(I3,L)) =G= B3(I3) ;
GOAL4(I4)..  SUM(J,X(J)*A4(I4,J))+SUM(K,Q.L(K)*C4(I4,K))
          +SUM(L,D(L)*E4(I4,L)) =G= B4(I4) ;
GOAL5(I5)..  SUM(J,X(J)*A5(I5,J))+SUM(K,Q.L(K)*C5(I5,K))
          +SUM(L,D(L)*E5(I5,L)) =E= B5(I5) ;
GOAL6(I6)..  SUM(J,X(J)*A6(I6,J))+SUM(K,Q.L(K)*C6(I6,K))
          +SUM(L,D(L)*E6(I6,L)) =E= B6(I6) ;
CONS1(H)..   SUM(J,X(J)*F(H,J))+SUM(K,Q(K)*G(H,K)) =E= N(H) ;
CONS2(H)..   SUM(J,X(J)*F(H,J)) =E= NP(H) ;
Q.L("Q1") = 109866;
Q.L("Q2") = 47965;
Q.L("Q3") = 49249;
Q.L("Q4") = 155217;
Q.L("Q5") = 142852;
Q.L("Q6") = 145310;
Model GP1 1stgoal /TOD, GOAL1, CONS1/ ;
Solve GP1 using LP minimizing Z ;
Model GP2 2ndgoal /TOD, GOAL2, GOAL1, CONS1/ ;
Solve GP2 using LP minimizing Z ;
Model GP3 3rdgoal /TOD, GOAL3, GOAL21, GOAL11, CONS2/ ;
Solve GP3 using LP minimizing Z ;
Model GP4 4thgoal /TOD,GOAL4,GOAL3,GOAL21,GOAL11,CONS2/;
Solve GP4 using LP minimizing Z ;
Model GP5 5thgoal /TOD,GOAL5,GOAL4,GOAL3,GOAL21,GOAL11,CONS2/;
Solve GP5 using LP minimizing Z ;
Model GP6 6thgoal/TOD,GOAL6,GOAL5,GOAL4,GOAL3,GOAL21,
 GOAL11,CONS2/
Solve GP6 using LP minimizing Z ;
```