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Interregional analysis of integrated crop, livestock, and forest production: A goal programming model

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Interregional analysis of integrated crop, livestock, and forest production: A goal programming model

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CHAPTER I. INTRODUCTION

Problems

Thousands of years ago, most of the land on the earth was covered with forests. As human population grows, the rapidly increased demands for food, fiber, and shelter have resulted in more and more forest land being converted to cropland and urban land. Currently, in the United States, forest land represents only 32% of the nation's total land base, rangeland occupies 34%, pasture and cropland represent 24%, and the remaining 10% is human related land. Thus, in total nearly 34% of the nation's land base has been converted from forest and range land to cropland, residential, and urban land (Bones, 1988).

With these dramatic shifts in land use have come many social benefits and costs of particular concern and unintended environmental impacts. Soil erosion, global warming, air pollution, water quality, and endangered plant and animal species are a few of the more critical impacts. The estimated amount of annual soil loss from cropland in the United States has exceeded 3000 million tons in total, with the average of more than 7 tons per acre per year. In some regions of this country, this problem is even worse. For example, in Iowa, one of the major crop producting states in the country, the amount of cropland soil erosion has been estimated to be about 12 tons per acre per year on average (USDA Soil Conservation Service, 1987a). The huge amount of soil loss has caused many problems such as water contamination and excessive stream bed sediment loading.

Global warming has recently received increasing attention. The Earth's surface temperature is being changed at an unprecedented rate because of the buildup in the atmosphere of carbon dioxide and other greenhouse gasses produced by fossil fuel burning, deforestation, and food production for the rapidly increasing global population. Research has shown that the earth's surface temperature has increased by between 0.5 and 0.7 °C since 1860. And, if the present rates of growth in greenhouse gas emissions were to continue, the earth's surface temperature would increase by at least 3 °C and perhaps as much as 5 °C by the year 2030 (Abrahamson, 1989). Scientists have warned that if this would happen, it could have disastrous impacts on the earth, second only to nuclear war. The effects of global warming cover the entire spectrum of our environmental concerns: endangered species, habitat preservation, coast zone protection, groundwater protection, soil erosion and desertification, air quality, wildlife, fisheries, forestry, and so on (Abrahamson, 1989). Although the final solution to this problem is to reduce carbon dioxide emission, forests can play an important role in controlling global warming. To increase the forested area by planting more trees to store carbon dioxide in biomass can reduce its buildup in the atmosphere. To increase the use of the energy from biomass, for example, short rotation woody crops (SRWP) of fast-growing hardwood species such as hybrid poplars, sycamore, black locust, silver maple, willow, and green ash, also can reduce carbon dioxide emission.

Wildlife habitat preservation and endangered species are other critical issues. The extinction rate of vertebrate species in the world has been increased by 5 times (0.124 species/year to 0.767 species/year) between the periods 1600-1825 and 1826-1975 (Flesness, 1986). In the United States, the number of listed endangered and threatened species in each animal class also has been increased, especially since 1979. The increase in the number of listed species indicates that more species have become endangered, while reducing the backlog of candidate species in need of protection also contributes to this increase (Flather and Hoekstra, 1986). Many factors may have impacts on species endangerment, but man induced loss or degradation of habitat is the most important impact (USDI Fish and Wildlife Service, 1988). The increasing intensity of farming and urban expansion have contributed significantly to wildlife habitat degradation.

Meanwhile, advances in technology have increased, and will continue to increase agricultural productivity and crop yields. As a result of this, the number of acres of crop production required by domestic demands and exports can be significantly reduced. In the United States, there were about 106 million acres of cropland that were idle in 1982, and the amount is expected to increase considerably by the year 2000, then fall back to about 110 million acre by the year 2030 (USDA Soil Conservation Service, 1987b).

In response to the growing environmental awareness and grain surplus market conditions, agricultural policies have been adjusted to be more "conservation oriented". The Food Security Act of 1985 has put a considerable emphasis on resource conservation. The "Farm Bill", as it is generally called, strongly discourages the production of row crops on the "highly erodible land" and encourages farmers to convert the use of the "highly erodible land" from traditional row crop production to other less erosive uses, such as pasture, permanent grass, legumes, forbs, shrubs, and trees.

During the 1970s, the U.S. congress passed two laws: the Soil and Water Resources Conservation Act (RCA) of 1977 and the Forest and Rangeland Renewable Resources Planning Act (RPA) of 1974. The RCA directs the Secretary of Agriculture to prepare an assessment on the nation's privately owned agricultural lands. And, the RPA requires the Forest Service to evaluate both public and private forest resources in the country.

Since the passage of the two laws, many RCA and RPA analyses have been done (English et al., 1989a; and Ashton et al., 1980). But these analyses often focused on only one production sector, agriculture or forestry. Thus, they have ignored the interaction (competition or/and complement) between agricultural and forestry production in terms of resource use. Agricultural and forestry production often compete for the use of the same resource. For example, where climate and physiography permit, trees, crops, pasture, or range can be produced on the same unit of land.

Moreover, the tradeoff between the two sectors also may occur within a region or across regions as the production system responds to the economic and environmental requirements. Therefore, a multiresource planning model should incorporate both agriculture and forestry sectors in order to simulate the real world more accurately.

Objectives

One of the main objectives of this study is to develop a national level multiresource planning model capable of evaluating the long-term effects of alternative policies on resource uses and the interactions between the production sectors and among production regions and resources. The model to be developed will have the capability of evaluating policies which affect:

1. Resource availability;
2. Environmental requirement (soil erosion, C_2O reduction, and wildlife);
3. Commodity demand (domestic demand and export); and
4. Technology change.

The model will be used then to examine possible shifts in resource use between the production sectors and among the regions given projected future demands for foods and fibers, environmental requirements, resources available, and assumed technology change.

The present location and area of the different land cover types are the results of the historical and current land use in each region of the United States. As the factors affecting land use change, the land use pattern also will change. Forest and rangeland can be converted to cropland just as it happened in the past, and cropland in turn also can be shifted back to forest or pasture land as needed. As previously mentioned, a considerable amount of cropland in this country has been or will be withdrawn from crop production because of the grain surplus and environmental concerns. What can we do with these withdrawn croplands? What is the long-run use of these "marginal" cropland? Is forest production, including traditional timber production and short rotation woody energy crops (SRWC) competitive on the idle croplands given our demand for wood fiber, biomass energy, and environmental goods? To provide answers to these questions is another objective of this study.

Two time periods, the years 2000 and 2040, will be selected for these analyses to simulate both intermediate-term and long-term scenarios. The results of these analyses will provide the best spatial allocation of agricultural and forestry production activities in the United States given the alternative resource policy. Hopefully, these results will provide decision makers with some helpful guidelines for the utilization of the nation's natural resources.

CHAPTER II. LITERATURE REVIEW

Many analytical approaches have been used in projecting land use change, ranging from expert opinion to Markov chain process to mathematical programming. These approaches can generally be classified into two categories: subjective and objective methods. Subjective methods are those in which the process used to analyze the data has not been well specified. Projections are primarily based on experience and feelings. On the other hand, objective methods use well specified processes to analyze the data. The process used in the objective method can be exactly replicated by other researchers. Furthermore, the process in the objective methods could be done by computer, whereas the process in the subjective methods is done in a researcher's head.

In the early stage of projecting land use change, the subjective method was the primary approach. This method is still used today. For example, the forest area projections in 1980 RPA Assessment were based on the opinions of regional experts (USDA Forest Service, 1982). The details of the procedure were documented by Wall (1981). In the Assessment, expert opinions were first used to estimate the acreages of commercial timber land to be withdrawn in the future for other uses such as cropland and wilderness. The future commercial forest land was projected by subtracting the acreages withdrawn from the total potential commercial forest land area. These projections were then used to predict the future timber supply for the RPA Assessment.

This method is generally simple, inexpensive, and easy to understand. But its weaknesses are apparent. As pointed out by Sackman (1975), the accuracy of the expert estimates is necessarily suspect because the questions addressed are not empirically linked to objective and independently verifiable external criteria. He further concluded that this technique is basically unreliable and scientifically unvalidated in principle and probably in practice. Another weakness is that it cannot quantify the dynamic relationships between the land use change and the variables affecting the change.

Another approach for the analysis of land use change is to use economic efficiency criteria. Efficiency criteria require that land be allocated to its highest valued use. A conceptual framework of this approach was first presented by Vaux (1973) in a case example for California timber supply. This approach was documented by Hyde (1980). In using this approach, a timber supply schedule should be developed first by constructing a marginal cost curve. The derived supply schedule along with the projected demand are then used to determine how much forest land will be required to meet the demand, and the types of management strategies to be used.

Montgomery et al. (1975; and 1976) applied this principle to the analysis of the long-run development of Georgia forest resources. Parks et al. (1988) also used this approach to determine the possibility of tree plantation establishment on idle cropland in different major land resource areas (MLRAs) in the United States. They defined several crop production and forest investment alternatives for each MLRA and computed the before-tax annual land rent of all the alternatives. The crop with the highest return was then compared to the most profitable forest investment to determine whether or not the idle cropland in a specific MLRA could be converted to forest production.

This discount cash flow approach is simple and easy to apply, but it must be applied with care (Hyde, 1980). The only criteria used to determine land conversion were the economic criteria; others, such as environmental and social criteria, were not incorporated. Because it is static and deterministic, like the expert opinion approach, it lacks the mechanism for dynamic analysis of land shifts.

Burnham (1973) applied a Markov chain process to the analysis of the intertemporal land use shifts among six land groups: cropland, grassland, transition, forest, urban, and other. He used the historical data to derive the transition probability matrix, which defines the probability of land shifting from one land use to another. Then, the transition probability matrix was used with the initial conditions by the framework of Markov chain process to project future land use change. This method was also used later by MacDonald et al. (1979) to project bottomland hardwood area in the lower Mississippi alluvial plain.

Since the transition probability matrix was developed from historical data and no adjustment was made over time, they simply assumed that future land use shifts followed exactly the past trends. This assumption is unrealistic because economic and social conditions are likely to change over time. In order to identify the effects of the change in these factors on future land use, the relationships between the transition probability and these factors must be determined. But it is not an easy job to quantify these relationships.

Alig (1985) used an econometric approach to project major land use changes in the Southeast of the United States by developing the Southeast Area Model (SAM). The model was specified according to rent theory. Economic, demographic, and other variables were selected as the independent variables to predict acreages of the major land uses, forest ownerships, and forest types for the Coastal Plain, Piedmont, and Mountain region in the Southeast. The econometric equations were estimated using the seemingly unrelated regression estimation (SURE) and time series data. The estimated model was then used to project future land use change based on the projected future values of the independent variables.

This is an effective way for the analysis of land use change. It can project the land conversion both from cropland to forest land and from forest land to cropland. Also, it has the capability of simulating the dynamic change in land use as factors affecting land use vary by changing the values of the independent variables.

However, the results from this approach provide information only on acreage of land use types and cannot indicate how the shifts occur among the use types. Moreover, it is often difficult to collect enough time series data required by the SURE method. And, if the number of regions is large, it will be very complicated to estimate the equations because of the existence of serial and spatial correlations.

Another approach for land use planning is mathematical programming, especially linear programming (LP). LP has been widely used in allocating land and other resources among their competing uses. Compared with other methods, it has several advantages. It can efficiently select the optimal land use pattern from many alternatives, which is very valuable in analyzing multiple resource use at the national level. It also has the capability of quantifying the dynamic relationships between land use and the factors affecting land use. Moreover, the impacts of different policies on land use can easily be identified through sensitivity analysis.

However, it has weaknesses, too. Both the objective function and the constraints in an LP model are linear. This implies linear relationships between activities and resources. Thus, constant marginal productivity of input and constant returns to scale are arbitrarily assumed. Another weakness of linear programming is that it can optimize only one objective. To offset this weakness of linear programming, its variant, goal programming, was developed by

Charnes and Cooper (1961). Because goal programming can handle multiple objectives at the same time, it has been viewed as a promising analytical tool for multiple resource use planning. More will be discussed on using goal programming later.

The Center for Agricultural and Rural Development (CARD) has developed the Agricultural Resource Interregional Modelling System (ARIMS) for the Resources Conservation Act analysis (English et al., 1989a). The ARIMS is a large-scale linear programming model containing seven sectors: crop, livestock, pasture/range, irrigation and other inputs, land, transportation, and demand. This model minimized production and transportation costs subject to the constraints of resource availability, commodity demand, and shift restriction.

This system primarily focuses on crop production. The basic regions of crop production were the 105 crop producing areas, defined according to river basins. The production of 14 major crops, including barley, corn grains and silage, cotton, legume and nonlegume hay, oats, peanuts, sorghum grain and silage, soybeans, sunflower, and spring and winter wheat, was endogenously simulated in the system. The production of all other crops was exogenously determined. Cropping practices were defined on both dry and irrigated cropland. Cropland was classified into eight land groups according to land capacity and limitations in use. The crop production activities represented by crop rotations were defined on each land group in a specific producing area.

In the system there were 31 market regions, which served as the basic regions for commodity demand and livestock production. The production of dairy, pork, and beef was endogenously incorporated in the model. The production of other livestock was exogenously defined.

The activities of range and pasture production were defined for 34 ecosystems. These activities primarily represented forage production on range/pasture and forest land for livestock consumption (grazing). No timber production activities were incorporated.

This system is a useful analytical tool for agricultural and resource policy evaluation. It has been used for the second Resources Conservation Act appraisal and for other analyses of various resource policy issues. But this system can simulate land conversion only from range or forest land to cropland, no reverse conversions are allowed. Moreover, it is primarily focused on crop production, and no forest production is considered. So, unless modified, it cannot be used to analyze the interaction and the possible resource use movement between agricultural and forestry sectors.

To consider forestry production, Ashton et al. (1980) developed the National Interregional Multiresource Use Model (NIMRUM) for the RPA Assessment in 1980. It too was a linear programming model which allocated acres of land in the entire forest and range land base of the United States by ownerships to different management strategies. This model minimized operational costs of alternative programs under the constraints of land, demand, sustained timber yield, and legal requirements. All costs and outputs were converted to annual average levels over a 50-year period.

In the model, the nation's total forest and range lands were divided into 107 potential natural communities (PNC), in which a specific type of vegetation would dominate, if left unchanged by human intervention or natural disaster. These potential natural communities were then further broken into resource units (RU) by ownerships, productivity classes, and condition classes. The resource units were used as the basic units of the consideration for management level activities, costs, practices, and outputs. The management levels included in the model ranged from no action to highly intensive.

This model was assembled with three other models: Regional Employment and Earnings Model, Future Foregone Model, and Social Conflict Model, to provide useful information on the economic, environmental, and social impacts of alternative multiple resource use policies (Ashton et al., 1980). However, because it is a model focused only on forest and range production, this model cannot simulate the interaction between agricultural and forestry sectors in resource uses.

Therefore, to analyze the interaction between agricultural and forestry sectors and the possible land and other resource movement between the two sectors caused by alternative policies, the development of a new system has become necessary.

CHAPTER III. MODEL

General Description of Model

The model developed here is classified as a goal programming model. Goal programming has many advantages over linear programming for solving multiple objective problems (Charnes and Cooper, 1961). In a linear programming model, only one objective is optimized. If the user has other objectives which may be complementary or conflicting, they must enter the model as constraints. Consequently, the single objective function is optimized over all possible feasible solutions, and all constraints are satisfied first with equal importance before the objective is optimized.

Goal programming, however, can handle multiple objectives. Instead of optimizing only one objective as in an LP model, goal programming minimizes the deviations from multiple goals subject to a set of constraints, which are goal statements or physical constraints. Usually in a goal programming model the constraint set and the objectives are all referred to as goals.

A goal programming model requires a priority system for all goals. There are two basic ways to establish the priority system: preemptive ordering and archimedean ordering. Preemptive ordering, or ordinal ordering, does not assign a numeric value to each goal. It is concerned with only the relative importance of the goals. On the other hand, archimedean ordering, or cardinal ordering, ranks the goals by assigning a specific weight to each goal. In solving a goal programming model the higher-ordered goals will be satisfied first to their fullest extent possible, before any lower-ordered goals are considered. Moreover, the goals in a goal programming model are satisfied as closely as possible, but all need not be met completely, except those with absolute priority. This flexibility is very useful in solving a problem with conflicting goals. In this case no feasible solution may exist if one used linear programming.

When applying goal programming to natural resource management, there are usually many conflicting or complementary goals in multiple resource use. For example, most public forests are managed for multiple uses, such as timber, range, water, wildlife, and outdoor recreation. So, goal programming seems to be an appropriate tool for multiple resource planning, although sometimes it is not easy to establish the priority system for the goals.

The model developed in this study is a sequential linear goal programming model. There are 2500 activity variables and 290 constraint rows in the model. This model consists of six sectors, which are crop, livestock, forest and range, resource availability, demand, and environment sectors (Figure 1). The first three sectors simulate the production processes. The resource availability sector includes land resource and irrigation water, which defines resources available for the production of crop, livestock, and forest and range products. The demand sector identifies the demands for foods and fibers. The last sector, the environment sector, includes activities

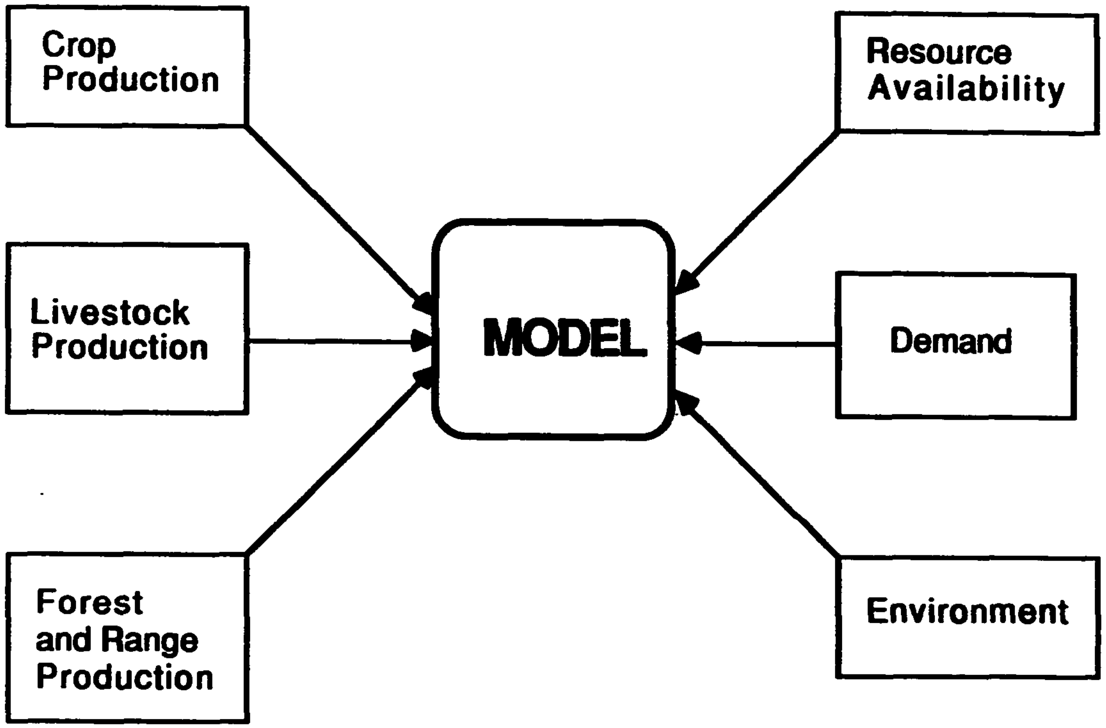

Figure 1. Model framework

representing environmental and nonmarket benefits such as wildlife habitats and carbon dioxide reduction. All the six sectors are linked by a goal programming framework. The basic formulation of the model is expressed in matrix form as follows:

(1) $\text{Min } \{g_1(d^+, d^-), \ldots, g_m(d^+, d^-)$

such that

(2) $CX - d^+ + d^- = b_1$

(3) $AX \leq b_2$

(4) $YX \geq D$

(5) $X \leq S$

(6) $X, d^+, d^- \geq 0$

where

m is the number of priority levels,

X is the vector of production activities,

C is the vector of goal coefficient values,

d^+ is the vector of positive deviation variables,

d^- is the vector of negative deviation variables,

$g_i(d^+, d^-)$ is the linear function of deviation variables at priority level i,

A is the vector of technical coefficient values, Y is the vector of yields corresponding to X,

b_1 is the vector of aspiration or goal levels,

b_2 is the vector of resource availability,

D is the vector of commodity demand,

S is the vector of shift restriction to X.

Equation (1) is the objective function to be minimized. Goal (Equation) type (2) is not required to be exactly met. It can be satisfied inexactly. In this model, the goals of the production cost, soil erosion, wildlife habitats, and carbon dioxide reduction take this form. Equation set (3) defines the constraints of land and irrigation water resources. Equation type (4) represents the constraints of commodity demands. The demands for foods and fibers along with the requirements for wildlife habitats and carbon dioxide reduction are the driving force of the model. Equation type (5) describes land shift restrictions. And, the last equation, equation (6), is the nonnegativity constraint. The goals represented by equations (3), (4), and (5) have absolute priorities over the other goals. A solution not satisfying these goals is not acceptable.

The goal of production costs will be minimized, and those of carbon dioxide reduction and wildlife habitats will be maximized. The model is designed so that it will provide a solution for multiple resource use planning that can satisfy our demands for foods and fibers fully and our desired levels for soil erosion, carbon dioxide reduction, and wildlife habitats as closely as possible within our resource limits with minimum cost. The use of a cost minimization criterion is consistent with the economic principle that in a long-run competitive equilibrium producers minimize long-run average cost (Silberberg, 1974).

Crop sector

The crop sector is an important part of the model. This sector describes the crop production. Its main inputs include land, irrigation water, energy, labor, capital, and fertilizer. The outputs of this sector are crop yields and soil erosion. It is linked to the livestock sector by providing feedgrains and roughum for livestock. And, it is related to the forest and range sector because of their competition for land and other resource use and the environmental concerns such as soil erosion, wildlife habitats, and carbon dioxide reduction.

Crop production activities are defined for crop producing areas. Land resource regions are used as the crop producing areas. There are a total of twenty land resource regions in the contiguous 48 states of this country (Figure 2). They are:

1. Northwestern Forest, Forage, and Specialty Crop Region;
2. Northwestern Wheat and Range Region;
3. California Subtropical Fruit, Truck, and Specialty Crop Region;
4. Western Range and Irrigated Region;
5. Rocky Mountain Range and Forest Region;
6. Northern Great Plains Spring Wheat Region;

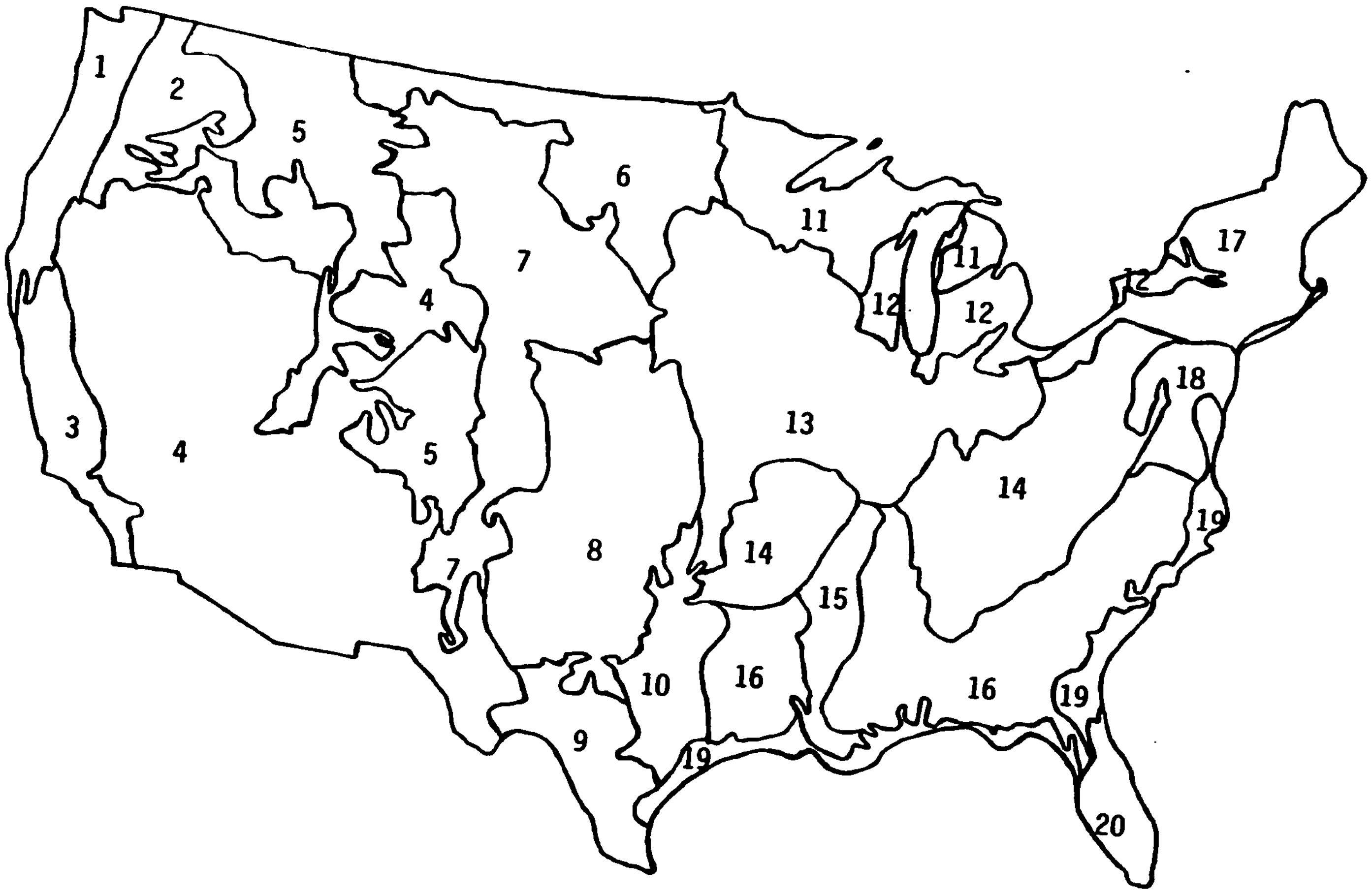

Figure 2. Crop producing areas (US Water Resources Council, 1970)

7. Western Great Plains Range and Irrigated Region;
8. Central Great Plains Winter Wheat and Range Region;
9. Southwestern Plateaus and Plains Range and Cotton Region;
10. Southwestern Prairies Cotton and Forage Region;
11. Northern Lake States Forest and Forage Region;
12. Lake States Fruit, Truck, and Dairy Region;
13. Central Feed Grains and Livestock Region;
14. East and Central General Farming and Forest Region;
15. Mississippi Delta Cotton and Feed Grains Region;
16. South Atlantic and Gulf Slope Cash Crop, Forest, and Livestock Region;
17. Northeastern Forage and Forest Region;
18. Northern Atlantic Slope Truck, Fruit, and Poultry Region;
19. Atlantic and Gulf Coast Lowlands Forest and Truck Crop Region; and
20. Florida Subtropical Fruit, Truck Crop, and Range Region.

These land resource regions consist of geographically associated major land resource areas. Their identification is most significant for national planning associated with the agricultural land use (Austin, 1965). A detail description of these regions has been documented by Austin (1965).

Eleven major crops: barley, corn grain and silage, cotton, hay, oats, sorghum grain and silage, soybeans, and winter and spring wheat, are endogenously defined in the model for dry and irrigated land farming practices. Summer fallow and double cropping also are considered wherever applicable. The production of all other crops are exogenously determined. The exogenous crops include peanuts, sugarcane, sugar beets, tobacco, vegetables and melons, Irish potatoes, sweet potatoes, dry beans, dry peas, flaxseed, rice, rye, citrus fruits, noncitrus fruits, nuts, and others.

The basic activity for crop production is a crop rotation on a land group with a given conservation practice in a specific producing area. There are numerous possible crop rotations. To consider all the possible rotations is impossible and unnecessary. The crop rotations used as production activities in the model are selected primarily based on the following criteria: (1) that the rotations currently widely used or having a significant potential to be developed should be included, and (2) that adequate coverage should be maintained. The selection of crops and crop rotations for each producing area is also based on personal communication with Dr. Irvin C. Anderson (1990) in Department of Agronomy, Iowa State University. Three conservation practices (strip cropping, contouring, and terracing) and one nonconservation practice (straight row) are incorporated with the crop rotations.

Cropping practices on both dry and irrigated cropland are incorporated in the model. But irrigated cropping practices are defined only for the western part of the country, i.e., in producing areas 1-10. This is because these areas occupy the majority of the irrigated cropland of the nation.

In addition to the crop rotations, some pasture and forest production activities are defined on cropland. Introducing these pasture and forest activities into cropland allows the competition for cropland use among crops, grasses, and trees. The pasture activity on cropland is to establish pasture. Current "average" management level in a specific region is selected as the management strategy for the established pasture. The forest activities on cropland include the establishments of the traditional forest and short rotation woody crops (SRWC). Only one major species is chosen as the representative species for the forest production activity in a specific producing area. For the regions which have more than one dominant species, the one that provides the highest economic return will be selected as the representative species. The rotation ages and management strategies for the representative species are similar to those to be discussed later in the forest sector.

The most promising woody species discussed by Cushman and Ranney (1982) are used as the representative species for short rotation woody crop (SRWC) production in a given producing area. The cultural treatments for SRWC production include weed and disease control, fire protection, and fertilization. No irrigation practice will be used for SRWC production, because it is generally not profitable to do so (Cushman and Ranney, 1982). The rotation age of SRWC is determined according to an economic criterion, which is the highest net economic return from the production. This rotation age is approximately 10 years for most producing areas.

Livestock sector

Livestock production is fully exogenously defined in the model due to the consideration of limited model size. Human demands for livestock products and livestock requirements for feedstuff (feedgrain, roughum, and pasture) and water link this sector with other sectors in the model.

The exogenous livestock sector requires that the amount of livestock production and its demand for water, feedgrains, roughums, and pasture be determined and provided to the model before solving it. The production of beef, broilers and chickens, dairy, eggs, pork, turkey, and sheep is incorporated in the model. The estimation of the water and feedstuff demand by these productions will be discussed later in the data section.

Forest and range sector

Forest and range play a very important role in providing food (meat), wood and fiber, and environmental protection. This sector describes the production of woods, forage, and environmental goods. Land, labor, capital, and energy are the major inputs of this production sector, and wood, forage, and energy, soil erosion, and environmental goods are its outputs. The demand for wood, forage, and environmental goods relates this sector with other sectors and are the driving force for this sector to compete with other production sectors in land and other resource use.

The basic regions of forest and range production are 34 ecosystems, classified using the Forest and Range Environmental System (FRES) (Garrison et al., 1977). The geographical distribution of these ecosystems is shown in Figure 3. The numbers and names of the 34 FRES ecosystems are presented as follows:

10[1]. White-red-jack pine

11. Spruce-fir

12. Longleaf-slash pine

13. Loblolly-shortleaf pine

14. Oak-pine

15 Oak-hickory

16. Oak-gum-cypress

17. Elm-ash-cottonwood

18. Maple-beech-birch

19. Aspen-birch

20. Douglas-fir

21. Ponderosa pine

22. Western white pine

23. Fir-spruce

24. Hemlock-sitka spruce

25. Larch

26. Lodgepole pine

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[1]The number of FRES ecosystems.

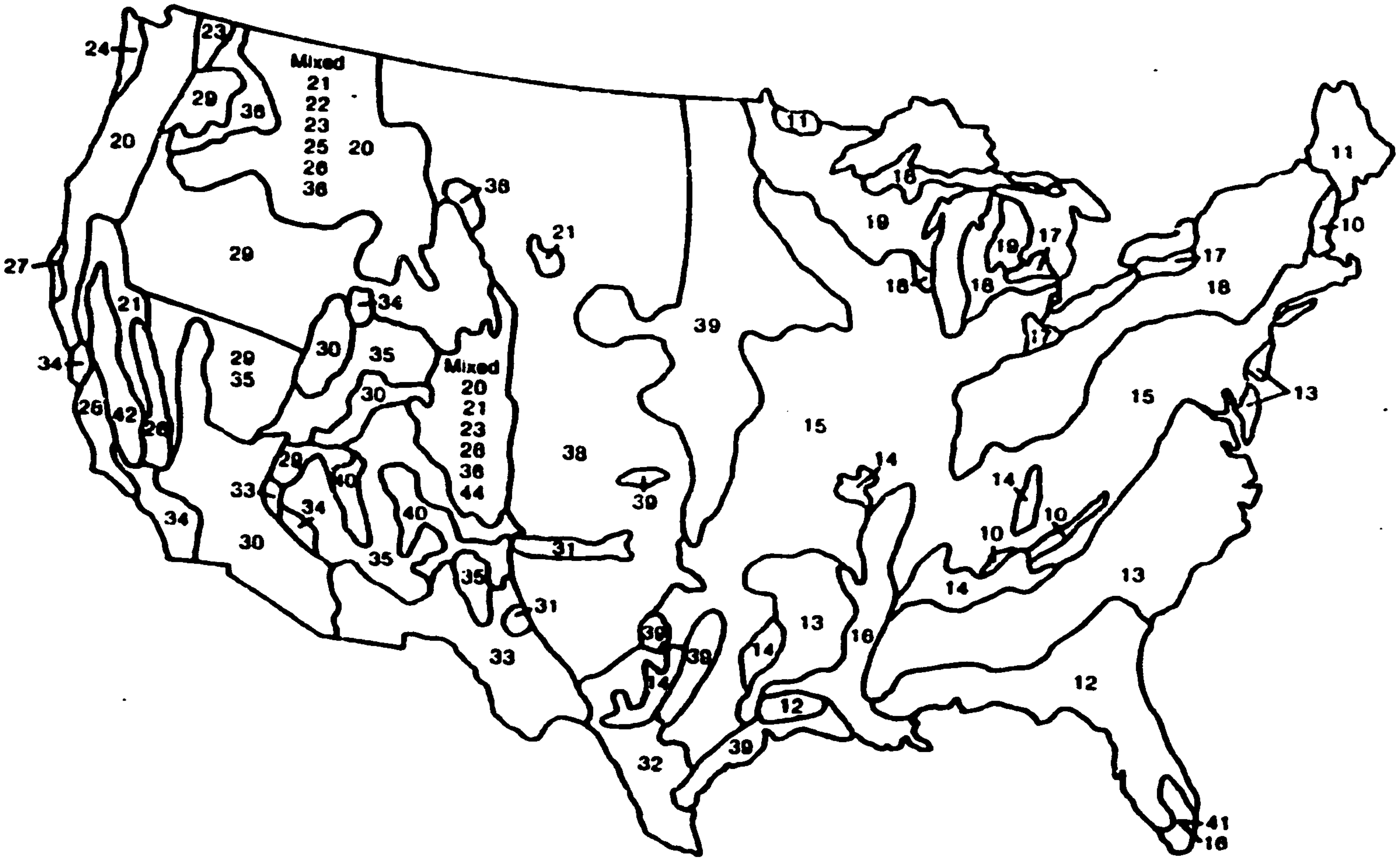

Figure 3. Forest and range ecosystems (Joyce, 1989)

27. Redwood
28. Western hardwood
29. Sagebrush
30. Desert shrub
31. Shinnery
32. Texas savanna
33. Southwestern shrubsteppe
34. Chaparral-mountain shrub
35. Pinyon-juniper
36. Mountain grasslands
37. Mountain meadows
38. Plains grasslands
39. Prairie
40. Desert grasslands
41. Wet grasslands
42. Annual grasslands
44. Alpine

These ecosystems represent the diversity of vegetation in the United States resulted from climatic, geological, and elevational differences across the country. The detailed explanation of these FRES ecosystems can be found in Garrison et al. (1977).

Forest and range production activities are represented by management strategies defined for a specific productivity class in each ecosystem. The management strategies can be classified into three categories: environmental, extensive, and intensive management. The objective of environmental management is focused on resources conservation, wildlife habitat preservation, and environmental protection. No timber production and livestock grazing are allowed under this strategy. The main management practices of this strategy are fire protection and pest control. On the other hand, the extensive and intensive management are primarily for timber or/and forage (livestock grazing) production. Forest extensive management strategy employs few management practices. The only management practices used in this strategy are protection and minimum assistance in regeneration as needed. Any other forest management strategies are classified into the intensive management category if they use all the practices in the extensive strategy and at least one of the following practices: density control (release, and precommercial and commercial thinning), fertilization, stand improvement, and stand conversion. The management strategies for each forest ecosystem are developed based on the information from Barrett (1980) and USDA Forest Service (1982).

The basic management practices for the extensive range management strategy are fire protection, pest control, fencing, and water development as needed. No attempt is made to maximize livestock forage production by cultural practices such as seeding. In the intensive range management strategy, however, all available technology for range and livestock management is considered. Management seeks to maximize livestock forage production consistent with the constraints of environmental maintance and multiple use.

Land conversion activities also are incorporated in the forest and range sector. These activities describe the conversion of forest or range land to cropland. These conversions include only those by draining forest and range/pasture land in Soil Conservation Service capability subclasses II_w and III_w to cropland. No other types of conversions from forest and range/pasture land to cropland are considered in the model because there are no data available for such conversions and it seems very unlikely to do so.

<u>Resource availability sector</u>

This sector identifies the land and irrigation water resources available for the production. All production alternatives should satisfy our resource limits.

<u>Land</u> Land is an important input for crop, pasture/range, and forest production. Different land has different capabilities and limitations.

The USDA Soil Conservation Service (SCS) has classified all land into eight capability classes according to land capability and limitations in use. The lands from Class II to Class VIII are further divided into four subclasses. The four subclasses represent four types of limitations: erosion, wetness, rooting zone limitation, and climatic limitation. They are designated by symbols e, w, s, and c, respectively. From Class I to Class VIII, the erosion hazard and limitation in use increase progressively. In general, lands in the first four classes can be used for the traditional row crop production and will not result in deterioration in the productive capacity sustained over a long period of time under good management. Lands in Classes V, VI, and VII are suited primarily for forest and pasture. Lands in Class VIII are not suited for crop, grass, or trees without major reclamation. A detailed interpretation about the capability and limitation of each land class and subclass can be found from Klingebiel and Montgomery (1961).

In this study, cropland is classified into five land groups by aggregating some SCS land classes and subclasses together. The five cropland groups are shown in Table 1. Land Groups 1 and 2 generally have comparative advantages for crop production. Land Group 3 contains highly erodible land, on which conservation practices are highly desired for crop production. Marginal cropland is included in Land Group 4. Land Groups 4 and 5 are generally not suited for crop production. Forest and range/pasture may have potentials to compete with crops in the use of these two land groups.

Forest and range land in a specific ecosystem is classified further into four groups according to productivity classes. There are four productivity classes for both forest and range land. Forest productivity class is a measure of the mean annual growth measured in cubic feet per acre in fully stocked naturally occuring stands. Productivity Class 1 contains the forest land capable of producing more than 120 cubic feet per acre per year. The forest land with a mean annual growth of between 85 and 120 cubic feet is classified into Productivity Class 2. The forest land with a mean annual growth of between 50 and 85 cubic feet is classified into Productivity Class 3. And the forest land with a mean annual growth of less than 50 cubic feet belongs to Productivity Class 4.

Table 1. Classification of land groups

Land Group	SCS Classes/Subclasses
1	I
2	II, III_s, III_w, III_c, IV_s, IV_w, IV_c
3	III_e, IV_e
4	V, VI_s, VI_w, VI_c
5	VI_e, VII, VIII

Range land productivity classes are expressed in terms of herbage production. Productivity Class 1 is the first quartile in potential herbage production, Class 2 the second quartile, Class 3 the third quartile, and Class 4 the fourth quartile.

In this model there are four types of land constraints (goals) to define the amount of land available and to restrict land use shifts. They are (1) the dry cropland availability constraint, (2) the irrigated cropland availability constraint, (3) the forest and range land availability constraint, and (4) the minimum crop acreage constraint. The cropland availability constraint is defined at the level of the land group for each producing area. The forest and range land availability constraint is defined at the level of the productivity class for a given ecosystem. And the minimum crop acreage constraint is specified for a specific producing area.

Rapid shifts in land use are unlikely because of capital and other resource limitations and the inertial nature of land management. To reflect these and to offset the impacts of the factors not considered in the model, the minimum crop acreage constraint is imposed to avoid unreasonable and imperfect movement of land and other resources among the production sectors and regions.

Two types of land conversion activities are included in the model. They are the conversion of cropland to forest or pasture land and the conversion of forest and range/pasture to cropland by draining.

Water There is only one type of water resource constraint (goal) in the model. The water constraint, defined at the producing area level, serves to limit the amount of water used for crop irrigation within the amount available for this use. The amount of water available for endogenous crop irrigation use is the total amount of dependable surface and groundwater supply less the amount of water required by nonagricultural use, livestock production, and the exogenous crops. For simplicity, no water transfer activity across the different regions is considered.

Demand sector

This sector identifies the demand for intermediate and final goods. It is the driving force of the model. All demands in the model are defined at the national level. The total demands for final goods include domestic demands and net exports. The commodities demanded include crop commodity (barley, corn, cotton, oats, sorghum, soybeans, and wheat), livestock feedstuffs (feedgrains, roughums, and pasture), and timber (softwood and hardwood timber). The demand for livestock products is converted to the feedstuff demand by the livestock production.

Environment sector

This sector describes the environmental aspects of natural resource management. In this model there are three types of environmental goals, (1) minimizing soil erosion, (2) maintaining wildlife habitats, and (3) offsetting carbon dioxide emission. These goals are a driving force in the model, meaning that they should be achieved at the highest possible levels subject to resource limitations. The introduction of this sector into the model can better simulate the impacts of alternative policies on land and other resource use.

Soil erosion from cropland is defined at the producing area level as well as at the national level. Soil erosion from forest and range land is specified at the national level. The goal for carbon dioxide reduction is represented in terms of the acreage of forested land in the U.S., which is defined also at the national level. According to "Tree for U.S." program, to achieve a 5% carbon dioxide offset in this country, the forest area should be increased by 10 million acres from its current level in next 20 years.

Wildlife habitats are quantified by an index reflecting the quality of the habitats for endangered and rare species. The values of the index range from 1 to 5, with 5 standing for excellent, 4 for good, 3 for fair, 2 for poor, and 1 for bad. Due to the consideration of model size, only endangered and rare species are considered in model because they face immediate needs in terms of habitats and changes in land use practices.

Mathematical Expression of Model

In this section, the mathematical forms of the objective function and the goals of the model will be presented. The mathematical forms will be expressed in the first part of this section. The meanings of the symbols used will be explained in the final part of this section.

Objective function

The objective function of the model is to minimize the goals of production cost and soil erosion and to maximize the goals of wildlife habitats, and carbon dioxide reduction. It takes the following forms:

$$\text{Min } \{g_1(d1^+),\ g_2(d2^+),\ g_3(d3^-),\ g_4(d4^-)\}$$

Cost

The cost goal represents the total cost of crop, pasture/range, and forest production. All costs are specified in 1982 dollars. This goal will be minimized. Its mathematical expression is as follows:

$$\sum_i \sum_j \sum_k \sum_m CD_{ijkm}XD_{ijkm} + \sum_i \sum_j \sum_k \sum_m CI_{ijkm}XI_{ijkm}$$

$$+ \sum_i \sum_j CDP_{ij}XDP_{ij} + \sum_i \sum_j \sum_s \sum_g CDF_{ijsg}XDF_{ijsg}$$

$$+ \sum_i \sum_j CID_{ij}XID_{ij} + \sum_i \sum_j CII_{ij}XII_{ij}$$

$$+ \sum_e \sum_f \sum_g CFR_{efg}XFR_{efg} + \sum_i \sum_j CMID_{ij}XMID_{ij}$$

$$+ \sum_i \sum_j \sum_e \sum_f CMFRD_{ijef}XMFRD_{ijef} - d1^+ + d1^- = b1$$

Soil erosion

There are two types of soil erosion goals in the model. One is defined at the national level. The other is specified at the producing area level. Soil losses from forest and range land are defined only at the national level, whereas soil losses from cropland are defined at both national and producing area levels. The goal of soil erosion from cropland defined at the national level serves to restrict the total soil losses from the cropland. This goal will be minimized. It takes the following forms:

$$\sum_i \sum_j \sum_k \sum_m SED_{ijkm} XD_{ijkm} + \sum_i \sum_j \sum_k \sum_m SEI_{ijkm} XI_{ijkm}$$

$$+ \sum_i \sum_j SEDP_{ij} XDP_{ij} + \sum_i \sum_j \sum_s \sum_g SEDF_{ijsg} XDF_{ijsg}$$

$$+ \sum_i \sum_j SEID_{ij} XID_{ij} + \sum_i \sum_j SEII_{ij} XII_{ij}$$

$$- d2^{+} + d2^{-} = b2$$

The goals of the soil erosion from the cropland, as defined at the producing area and from forest and range land, are designed as accounting rows. They serve to account for the amount of soil losses from dry and irrigated cropland in each producing area and from forest and range land, respectively. These goals are minimized as requested by the alternative policies. The following is their mathematical expression:

Cropland erosion:

$$\sum_{j}\sum_{k}\sum_{m} SED_{ijkm}XD_{ijkm} + \sum_{j}\sum_{k}\sum_{m} SEI_{ijkm}XI_{ijkm}$$

$$+ \sum_{j} SEDP_{ij}XDP_{ij} + \sum_{j}\sum_{s}\sum_{g} SEDF_{ijsg}XDF_{ijsg}$$

$$+ \sum_{j} SEID_{ij}XID_{ij} + \sum_{j} SEII_{ij}XII_{ij} \geq 0.00$$

Forest and range land erosion:

$$\sum_{e}\sum_{f}\sum_{g} SEFR_{efg}XFR_{efg} \geq 0.00$$

Wildlife habitat

The wildlife habitat goal represents the quantity and quality of wildlife habitats for endangered and rare species, and it will be maximized. Its mathematical form is expressed as follows:

$$\sum_{i}\sum_{j}\sum_{s}\sum_{g} IWF_{ijsg}XDF_{ijsg} + \sum_{e}\sum_{f}\sum_{g} IW_{efg}XFR_{efg}$$

$$- d3^{+} + d3^{-} = b3$$

Carbon dioxide offset

The carbon dioxide offset goal is designed to achieve a carbon dioxide offset by a desired level through increasing and maintaining forest area. It will be maximized. The goal takes the following forms:

$$\sum_{i} \sum_{j} \sum_{s} \sum_{g} XDF_{ijsg} + \sum_{e=F} \sum_{f} \sum_{g} XFR_{efg} - d4^{+} + d4^{-} = b4$$

Land availability

The land availability goals include those of the dry cropland, irrigated cropland, and forest and range land. The cropland availability goals restrict the number of acres of the cropland used for crop, pasture, and forest production not to exceed the total amount of the cropland available on a given land group in a specific producing area. The forest and range land availability goals limit the number of acres of the forest and range land to be managed under all the possible management strategies and to be converted to cropland within the limits of the total forest and range land available in a given productivity class for each ecosystem. These goals are presented as follows:

Dry cropland:

$$\sum_{k} \sum_{m} XD_{ijkm} + XDP_{ij} + \sum_{s} \sum_{g} XDF_{ijsg} + XID_{ij}$$

$$- XMID_{ij} - \sum_{e} \sum_{f} XMFRD_{ijef} \leq LD_{ij}$$

<u>Irrigated cropland</u>:

$$\sum_{k} \sum_{m} XI_{ijkm} + XII_{ij} + XMID_{ij} \leq LI_{ij}$$

<u>Forest and range land</u>:

$$\sum_{g} XFR_{efg} + \sum_{i} \sum_{j} XMFRD_{ijef} \leq LFR_{ef}$$

<u>Land shifts</u>

There are two types of land shift restrictions. First, minimum crop acreage and second, maximum amount of forest and range land that can be potentially converted to cropland. The presence of the land shift restrictions can offset the impacts of factors not considered in the model on the resource use to avoid the possible imperfect movement of land and other resources across the production regions and sectors. These goals (constraints) take the following forms:

<u>Minimum crop acreage</u>:

$$\sum_{j} \sum_{k} \sum_{m} XD_{ijkm} + \sum_{j} \sum_{k} \sum_{m} XI_{ijkm} \geq MINCA_{i}$$

Potential conversion:

$$\sum_{i}\sum_{j} XMFRD_{ijef} \leq LPC_{ef}$$

Irrigation water

The goals of the irrigation water are to restrict the amount of water used for crop irrigation not to exceed the amount of water available for this use in a specific producing area in the western part of the country. The goals take the following forms:

$$\sum_{j}\sum_{k}\sum_{m} WR_{ijkm}XI_{ijkm} \leq WT_{i}$$

Demand

Commodity demand includes the human demand for agronomic crops and wood (timber), and the livestock demand for feedgrains, roughums, and pasture. The following is the mathematical expression of the goals associated with these demands:

Crop:

$$\sum_{i}\sum_{j}\sum_{k}\sum_{m} YCD_{nijkm}XD_{ijkm} + \sum_{i}\sum_{j}\sum_{k}\sum_{m} YCI_{nijkm}XI_{ijkm}$$

$$- \sum_{l} XJ_{nl} \geq DC_{n}$$

Feedgrains:

$$\sum_{n} FC_{nl}XJ_{nl} \geq DFG_l$$

Roughums:

$$\sum_{i}\sum_{j}\sum_{k}\sum_{m} YRD_{rijkm}XD_{ijkm} + \sum_{i}\sum_{j}\sum_{k}\sum_{m} YRI_{rijkm}XI_{ijkm}$$

$$\geq DRG$$

Pasture:

$$\sum_{e}\sum_{f}\sum_{g} YG_{efg}XFR_{efg} + \sum_{i}\sum_{j} YGD_{ij}XDP_{ij} \geq DPG$$

Timber:

$$\sum_{e}\sum_{f}\sum_{g} YT_{tefg}XFR_{efg} + \sum_{i}\sum_{j}\sum_{s}\sum_{g} YTD_{tijsg}XFD_{ijsg} \geq DT_t$$

where:

e = 1, ..., 44 for the forest and range ecosystems,

e=F = the forest ecosystems,

f = 1, ..., 4 for the forest and range productivity classes,

g = 1, ..., G for the forest and range management strategies,

i = 1, ..., 20 for the crop producing areas,

j = 1, ..., 5 for the land groups,

k = 1, ..., K for the crop rotations,

l = 1, ..., 8 for the livestock types,

m = 1, ..., 4 for the conservation practices,

n = 1, ..., 7 for the nonroughum crops,

r = 1, ..., 3 for the roughum crops,

s = 1, 2 for the forest types (1 = traditional forest and 2 = SRWC),

t = 1, 2 for the timber types (1 = softwoods and 2 = hardwoods),

b1 = the aspiration level of the production cost,

b2 = the aspiration level of the soil erosion,

b3 = the aspiration level of the wildlife habitats,

b4 = the aspiration level of the carbon dioxide offset,

CD_{ijkm} = the per acre cost of dry land crop production in producing area i, land group j, rotation k, and conservation practice m,

CDF_{ijsg} = the per acre cost of forest production on cropland in producing area i, land group j, for forest type s, and under management strategy g,

CDP_{ij} = the per acre cost of pasture production on cropland in producing area i and land group j,

CFR_{efg} = the per acre cost of forest or range production in ecosystem e, productivity class f, and under management strategy g,

CI_{ijkm} = the per acre cost of irrigated land crop production in producing area i, land group j, rotation k, and conservation practice m,

CID_{ij} = the per acre cost of idling dry cropland in producing area i and land group j,

CII_{ij} = the per acre cost of idling irrigated cropland in producing area i and land group j,

$CMFRD_{ijef}$ = the cost of converting one acre of forest or range land in ecosystem e and productivity class f to cropland in producing area i and land group j,

$CMID_{ij}$ = the cost of converting one acre of dry cropland to irrigated cropland in producing area i and land group j,

$d1^+$ = the positive deviation of the production cost goal,

$d1^-$ = the negative deviation of the production cost goal,

$d2^+$ = the positive deviation of the soil erosion goal,

$d2^-$ = the negative deviation of the soil erosion goal,

$d3^+$ = the positive deviation of the wildlife habitat goal,

$d3^-$ = the negative deviation of the wildlife habitat goal,

$d4^+$ = the positive deviation of the carbon dioxide goal,

$d4^+$ = the negative deviation of the carbon dioxide goal,

DC_n = the amount of the total demand for crop commodity n,

DFG_l = the amount of feedgrains demanded by livestock l,

DPG = the amount of pasture grazing demanded by the entire livestock production,

DRG = the amount of roughums demanded by the entire livestock production,

DT_t = the amount of the total demand for timber type t,

FC_{nl} = the feedgrain conversion coefficient for crop n and livestock l,

IW_{efg} = the wildlife habitat index per unit of ecosystem e in productivity class f and under management strategy g,

IWF_{ijsg} = the wildlife habitat index per unit of establishment of forest type s under management strategy g in producing area i and land group j,

LD_{ij} = the number of acres of dry cropland available in producing area i and land group j,

LI_{ij} = the number of acres of irrigated cropland available in producing area i and land group j,

LFR_{ef} = the number of acres of forest and range ecosystem e in productivity class f,

LPC_{ef} = the number of acres of forest or range land in ecosystem e and productivity class f that can potentially be converted to cropland,

$MINCA_i$ = the required minimum acreage of the crop production in producing area i,

SED_{ijkm} = the number of tons of annual sheet and rill erosion per acre dry cropland farming in producing area i, land group j, crop rotation k, and conservation practice m,

$SEDF_{ijsg}$ = the number of tons of annual sheet and rill erosion per acre of forest type s, under management strategy g, in producing area i, and land group j,

$SEDP_{ij}$ = the number of tons of annual sheet and rill erosion per acre of pasture established in producing area i and land group j,

$SEFR_{efg}$ = the number of tons of annual sheet and rill erosion from one acre of forest or range land in ecosystem e, productivity class f, and under management strategy g,

SEI_{ijkm} = the number of tons of annual sheet and rill erosion per acre irrigated cropland farming in producing area i, land group j, crop rotation k, and conservation practice m,

$SEID_{ij}$ = the number of tons of annual sheet and rill erosion per acre idle dry cropland in producing area i and land group j,

$SEII_{ij}$ = the number of tons of annual sheet and rill erosion per acre idle irrigated cropland in producing area i and land group j,

WR_{ijkm} = the number of acre feet of irrigation water required by one acre of crop production in producing area i, land group j, crop rotation k, and conservation practice m,

WT_i = the number of acre feet of the total water available for the endogenous crop production in producing area i

XD_{ijkm} = the activity level of dry land crop production in producing area i, land group j, crop rotation k, and with conservation practice m,

XDF_{ijsg} = the activity level of forest production on cropland in producing area i , land group j, forest type s, and under management strategy g,

XDP_{ij} = the activity level of pasture production on cropland in producing area i and land group j,

XFR_{efg} = the activity level of forest and range production in ecosystem e, productivity class f, and under management strategy g,

XI_{ijkm} = the activity level of irrigated land crop production in producing area i, land group j, crop rotation k, and with conservation practice m,

XID_{ij} = the activity level of idle dry cropland in producing area i and land group j,

XII_{ij} = the activity level of idle irrigated cropland in producing area i and land group j,

XJ_{nl} = the quantity of crop n consumed by livestock l,

$XMFRD_{ijef}$ = the amount of forest or range land in ecosystem e and productivity class f converted to cropland in producing area i and land group j,

$XMID_{ij}$ = the amount of irrigated cropland converted to dry cropland in producing area i and land group j,

YCD_{nijkm} = the dry cropland yield for nonroughum crop n in producing area i, land group j, crop rotation k, and conservation practice m,

YCI_{nijkm} = the irrigated cropland yield for nonroughum crop n in producing area i, land group j, crop rotation k, and conservation practice m,

YG_{efg} = the pasture/range yield in ecosystem e, productivity class f, and under management strategy g,

YGD_{ij} = the pasture yield in producing area i and land group j,

YRD_{rijkm} = the dry cropland yield for roughum crop r in producing area i, land group j, crop rotation k, and conservation practice m,

YRI_{rijkm} = the irrigated cropland yield for roughum crop r in producing area i, land group j, crop rotation k, and conservation practice m,

YT_{tefg} = the yield of timber type t in ecosystem e, productivity class f, and under management strategy g,

YTD_{tijsg} = the yield of timber type t in producing area i, land group j, forest type s, and under management strategy g.

Data Sources and Coefficient Development

To build the model, the coefficients required by the model need to be determined before solving it. In this section, the sources of the input data and the methodology used to develop the coefficients in the model will be discussed.

Crop sector

Cost Several sources of data (Economic Research Service, 1989; Eyvindson, 1970; James, 1979; and Stoecker, 1974) are used to estimate crop production costs. The total costs include the costs of labor, machinery, energy, fertilizers, pesticides, irrigation (only for the irrigated cropland farming), and others. No land costs are considered. These costs reflect the regional average costs and are all specified in 1982 dollars.

The costs are adjusted for the different land groups because of the yield difference, which requires different drying and hauling costs. Also, the conservation practice costs are incorporated with the crop production. The costs of the conservation practices are developed based on the data from Alexander (1985). No cost adjustment is made for the different slope of the land groups because the impacts of slope on the production costs seem not to be very significant.

Yield The base-level yields for each producing area are the average of 1985 and 1986 crop yields, which are derived based on the county and state level yields from each State's Agricultural Statistics. The base-level yields are then adjusted for the different land groups using the data from Follett and Stewart (1985). The yields for the crop with summer fallow are assumed to be 5% higher than the yields of the same crop without summer fallow (English, 1981). Irrigated crop yields are developed from dry land yields by multiplying a proportional index specified by crop, land group, and producing area. These indices are derived from the modified Spillman function (English et al., 1982).

Table 2. Projected percentage increase in crop yields resulting from technological advances

Crops	Year 2000	Year 2040
	(percent)	
Alfalfa	20	60
Barley	40	120
Corn grain and silage	40	120
Cotton[a]	50	50
Oats	40	120
Sorghum grain and silage	40	120
Soybeans	60	140
Wheat[b]	50	117

[a]Cotton yield projection for San Joaquin Valley in the Pacific is 10% higher than the national average.

[b]South Plains, North Plains, and Mountain regions will have wheat yield gains 10% below the national average gain in year 2000, and 20% below in year 2040.

All crop yields are also adjusted for technological advances for the future years. A Resources Conservation Act (RCA) symposium (English et al., 1984) has reported projections of crop yield growth rates resulting from the technological advance up to the year 2030 under several scenarios. This study uses the "most probable" projections from the research results presented at the RCA symposium. These data are extrapolated to the year 2040. The estimated crop yield growth rates are shown in Table 2.

Livestock sector

Livestock sector is fully exogenously incorporated in the model. The fully exogenous livestock sector requires the following data:

1. Projected production levels for the years 2000 and 2040;
2. Consumption of feedgrains, roughums, and pasture;
3. Improvement of feed efficiency for the future years;
4. Feedgrain substitution coefficients with the fixed ration;
5. Livestock water requirement coefficients.

The data for the production levels, feedgrain consumption, feedgrain substitution coefficients, and water requirement are obtained from the Center for Agricultural and Rural Development, CARD (English et al., 1989b). The livestock production levels for the years 2000 and 2040 are presented in Table 3.

The feedgrains and roughum consumption are developed from average state feed consumption by livestock production based on the historical data, primarily the data from 1968 to 1977. Only beef, dairy, and sheep are expected to consume roughums in their diet. No other livestock production is assumed to require roughums. The crops in the roughum category include hay, corn silage, and sorghum silage. Barley, corn grain, oats, and sorghum grain are all in the feed grain category.

Table 3. Projected livestock production in the years 2000 and 2040

Livestock	Unit	Year 2000	Year 2040
		(thousand units)	
Beef	cwt	56527051	68963000
Broiler	cwt	21247709	25312396
Chicken	cwt	2408173	2868857
Eggs	dozen	72817	97997
Milk	pound	137316000	167855000
Pork	cwt	27117679	31440237
Sheep	cwt	621571	756327
Turkey	cwt	3840306	5183261

CARD has developed livestock feed conversion equations, which can be used to transfer the amount of barley, corn grain, oats, and sorghum grain into feedgrain units for different livestock types (English et al., 1989b). These equations are presented as follows:

(a) Beef:

$$FG = C + 0.96 * S + 0.92 * O + 0.94 * B$$

$$+ 0.5 * (0.27 * CS + 0.22 * SS)$$

(b) Hog:

$$FG = C + 0.9*(S + O + B)$$

(c) Dairy:

$$FG = B + C + S + 0.9*O + 0.5*(0.2*CS + 0.18*SS)$$

(d) Eggs:

$$FG = C + 0.95*S + 0.9*O + 0.8*B$$

where:

B is barley,

C is corn grain,

CS is corn silage,

O is oats,

S is sorghum grain,

SS is sorghum silage.

Although corn silage and sorghum silage appear in the equations for beef and dairy, most of corn silage and sorghum silage are counted as roughums.

The livestock rations under current technology are estimated according to the information from CARD (English et al., 1989b). These estimated livestock rations represent the national average levels under the current technology. They are shown in Table 4. The detailed information on the development of these rations are available from English et al. (1989b).

The estimated rations are adjusted for the feed efficiency improvement resulting from assumed technology change for the years 2000 and 2040. The livestock feed efficiency improvement is derived based on the information from a Resources Conservation Act symposium (English et al., 1984). The projected feed efficiency improvement is shown in Table 5.

Table 4. Livestock rations under current technology

Livestock	Feed-grains	Other Concentrates	Wheat	Roughum
	(bu/cwt)	(bu/cwt)	(bu/cwt)	(tons/cwt)
Beef	282.397	0.135	0.116	0.368
Broiler	136.636	0.592	0.122	0.000
Eggs[a]	63.715	0.666	0.545	0.000
Milk	37.090	0.040	0.010	0.020
Pork	335.130	0.590	0.070	0.000
Sheep	59.695	0.762	0.029	0.197
Turkey	196.522	0.755	0.508	0.000

[a]The units for eggs are bushels or tons per hundred eggs.

Table 5. Projected percentage improvement in livestock feed efficiency

Livestock	Year 2000	Year 2040
	(percent)	
Beef	15	30
Broiler	15	25
Dairy	10	25
Eggs	10	18
Pork	12	30
Sheep	15	35
Turkey	20	35

After the production level and feed rations are determined, the total livestock feed requirement can be computed by multiplying the production level by the ration for each type of livestock commodity and then summing over all the livestock types.

The information on the livestock pasture consumption is very limited. The total number of AUMs (animal unit months) of beef cattle, dairy cows, and sheep grazing on private and public pasture, range, and forest land in 1985 is used as the base-level of livestock pasture consumption. Then, the pasture consumption in 2000 and 2040 is derived by multiplying the base-level pasture consumption by a ratio of the projected livestock production level in 2000 or 2040 to the production level in 1985.

Forest and range sector

Cost Forest production costs vary by regions and management strategies. Forest practice costs in different regions are estimated from several sources of data (Mills, 1988; Moak et al., 1983; Straka et al., 1989; USDA Forest Service, 1982; and Winebar and Gunter, 1984). Logging costs are included with the timber production strategies. The data from Kemper and Lawrence (1976), Klock (1976), and Wiener (1981) are used to develop the logging costs. Tractor logging is chosen as the representative harvest method for the cost estimation because it is most widely used in this country (Fowler et al., 1983).

Two adjustments on the forest production costs are made for the different productivity classes. One is the logging costs, and the other is the thinning (precommerciai and commercial thinning) costs. The logging costs are adjusted directly by multiplying the per thousand board feet (MBF) logging cost by timber yields in different productivity classes. The thinning costs are adjusted based on the data from Duran and Kaiser (1972). No cost adjustment is made for the difference in the slope of forest land because the impacts of slope on the costs of forest practices seem not to be very important (Conkin, 1971; and Richard et al., 1989).

SRWC production costs are derived primarily from Dutrow and Saucier (1976), Meridian Corporation (1986), Rose (1977), and Twarok (1990).

Duran and Kaiser (1972) have reported the costs of range management practices for all the ecosystems and the productivity classes. These data are the basic source of the data used to develop the range production costs.

All costs occurred in forest and range production are specified in 1982 dollars to negate the effects of inflation and converted to annual equivalent costs to offset the difference in the length of the production periods among forest, range, and crop activities. A real discount rate of 5% is used to discount the stream of costs and revenues for the forest and range activities. The discount rate is chosen by considering both the historical investment returns and the rate recommended by Row et al. (1981) for long-term resource management planning.

<u>Yield</u> Mean annual increment is used as the timber yield. The basic data sources of the timber yields are yield tables and growth models (Barnes, 1962; Barrett, 1980; Fowells, 1965; Lindquist and Palley, 1967; McArdle et al., 1961; McClure and Knight, 1984; Oliver and Powers, 1978; Roe, 1951; Solomon, 1977; and Wiley, 1978). The timber yields are adjusted for different cultural practices and intermediate operations, such as precommercial and commercial thinning, fertilization, and stand improvement. The information from Barrett (1980), Cochran (1973), Reukema and Bruce (1977),

USDA Forest Service (1982), and Worthington and Staebler (1961) is used to make these adjustments.

The yields of the SRWC in the different regions are obtained from Cushman and Ranney (1982). These yields represent the possible large-scale productivity rates of SRWC.

Range and pastures yields are estimated based on the data from USDA Forest Service (1972) and English et al. (1989b). The unit used for range and pasture yields is animal unit month (AUM) per acre per year. The yields measured in tons are converted to AUMs by assuming that one AUM is equivalent to 800 pounds of forage. The productivity of range and pasture is assumed to increase by 0.7% per year to account for the technological change (Joyce, 1989).

Resource availability

Land The model requires three types of land data. They are (1) the quantity of the dry and irrigated cropland available by producing area and land group, (2) the number of the existing forest and range land by ecosystem and productivity class, and (3) the amount of forest and range/pasture land that can be potentially converted to cropland.

National Resource Inventory (USDA Soil Conservation Service, 1987a; and 1989) reported the number of acres of privately owned cropland by soil capability classes and subclasses. These data are aggregated into the five land groups for each producing area. These data are then adjusted for the acreages of nonagricultural use, exogenous crops, and double cropping. The nonagricultural use includes the cropland used for urban, highways, airports, reservoirs, surface mining, second homes, and recreation. Spaulding (1974) provided detailed information on the nonagricultural land use for the years 2000 and 2030. These data are extrapolated to the year 2040 (Table 6). These total acreages of the nonagricultural use will be converted from all types of lands including cropland, pasture/range, and forest land. In computing the proportion of the nonagricultural use taken out of cropland, it is assumed that the nonagricultural land use will be converted independently from all types of lands.

Table 6. Projected nonagricultural land use

	Year	
Category	2000	2040
	(million acres)	
Urban	12.29	23.53
Highways	0.52	0.72
Airports	0.41	0.80
Second Homes	1.73	5.61
Recreational Areas	10.21	13.89
Reservoirs	1.93	1.93
Strip Mines	2.76	7.44
Total	29.85	53.92

Another land adjustment is the acreages required by the exogenous crops. The exogenous crops excluded from the model include rye, rice, vegetables and melons, flax, peanut, sugarcane, sugar beets, sunflower, citrus fruits, noncitrus fruits, and other crops. English and Campos (1989) have projected the acreages of these exogenous crops, except peanuts and sunflower. These data are aggregated into the producing areas defined in the model. The acreages in 2040 are assumed to the same as the projected level in 2030. The number of acres required by peanuts and sunflower production is estimated by dividing the total projected production levels by the projected nation's average yields of them in the years 2000 and 2040. The projected acreages of the exogenous crops is presented in Table 7.

The remaining cropland after adjusted for nonagricultural use and exogenous crops is the amount available for crop, pasture, and forest production.

The amount of pasture/range and forest land that can be potentially converted to cropland by draining is obtained from English et al. (1982). They derived the maximum conversion of pasture/range and forest land up to the year 2030 based on the average annual rate of conversion and the inventory acreages of Class II_W and III_W pasture/range land and forest land. The maximum conversion in the year 2040 is assumed to be the same as that in the year 2030 in this study. The maximum amount of pasture/range and forest conversion is shown in Tables 8 and 9, respectively.

Table 7. Projected acreages of exogenous crops

Crop	Year 2000	2040
	(million acres)	
Rye	472.2	309.0
Rice	4184.8	4864.9
Vegetables and Melons	3481.5	2680.3
Flax	964.4	632.4
Peanuts	2.2	3.1
Sugarcane	292.8	261.2
Sugar Beets	538.5	519.7
Tobacco	900.0	678.0
Irish Potato	1408.4	1108.5
Sweet Potato	102.3	72.7
Dry Beans	936.4	602.2
Dry Peas	73.1	47.5
Citrus Fruit	1340.7	1091.5
Noncitrus Fruit	4076.6	2699.3
Other Crop	8306.9	8574.3
Total	27080.7	24144.6

Table 8. Potential conversion of pasture/range land to cropland

River Basin	Year 2000	Year 2040
	(thousand acres)	
New England	32.13	65.57
Middle Atlantic	95.73	35.77
South Atlantic	1669.59	1510.97
Great Lakes	384.40	1510.97
Ohio	761.42	1072.01
Tennessee	187.82	292.26
Upper Mississippi	1424.41	1739.30
Lower Mississippi	832.36	2321.18
Souris-Red-Rainy	212.19	277.10
Missouri	812.11	1092.88
Arkansas-White-Red	787.73	405.31
Texas-Gulf	288.98	28.60
Rio Gande	0.00	0.00
Upper Colorado	0.00	0.00
Lower Colorado	0.00	0.00
Great Basin	0.00	0.00
Columbia-N. Pacific	0.00	0.00
California-S. Pacific	0.00	0.00
Total	7488.87	9504.16

Table 9. Potential conversion of forest land to cropland

	Year	
River Basin	2000	2040
	(thousand acres)	
New England	40.04	81.16
Middle Atlantic	286.72	481.17
South Atlantic	4700.80	5389.09
Great Lakes	1282.15	1374.18
Ohio	489.02	923.59
Tennessee	124.85	317.02
Upper Mississippi	960.10	1315.51
Lower Mississippi	1426.28	2884.84
Souris-Red-Rainy	250.38	265.96
Missouri	190.51	234.82
Arkansas-White-Red	461.12	242.06
Texas-Gulf	326.89	14.71
Rio Gande	0.00	0.00
Upper Colorado	0.00	0.00
Lower Colorado	0.00	0.00
Great Basin	0.00	0.00
Columbia-N. Pacific	0.00	0.00
California-S. Pacific	0.00	0.00
Total	10538.86	13524.11

The acreages of range land are derived from the data reported by Joyce (1989) and Darr (1988). The quantity of forest land by ecosystem and productivity class is obtained from Waddell et al. (1989). Range and forest land is also adjusted for the urban and nonagricultural use using the same procedures for cropland adjustment.

Water Dependable water supply for each producing area (Table. 10) is derived from Collette (1976). The dependable water supply including surface water and groundwater supply represents the amount of water which will be equalled or exceeded in 95 out of 100 years. In determining the dependable water supply the pumping rate of groundwater is not allowed to exceed its recharge rate so that sustained groundwater supply can be obtained. Also, conveyance efficiency for groundwater and surface water is incorporated in estimating the water supply.

Three adjustments are made from the dependable water supply. One adjustment is nonagricultural water consumption. The information used for this adjustment is from Collette (1976). Collette (1976) has projected the nonagricultural water consumption up to the year 2000. The nonagricultural water consumption in 2040 is estimated by assuming that the growth rate of the nonagricultural water use from 2000 to 2040 is the same as that from 1985 to 2000.

Another adjustment is livestock water consumption. Livestock water conversion factor is obtained from English et al. (1989b) and presented in Table 11. The livestock water conversion factor represents gallons of water daily required by per unit of livestock production. The total livestock water consumption is derived by multiplying the livestock production level by the livestock water conversion factor and summing over all of the livestock types.

Table 10. Dependable water supply

Producing Area	Surface Water	Ground-water	Total
		(million acre feet)	
1	96467.9	948.7	97416.6
2	24149.4	3565.2	27714.6
3	10555.0	8507.7	19062.6
4	23877.9	8088.3	31966.2
5	39439.8	1643.6	41083.4
6	824.8	30.1	854.9
7	18105.6	2795.3	20900.9
8	6193.8	2964.2	9158.0
9	2956.7	1377.6	4334.3
10	6696.6	1165.2	7861.8

Table 11. Livestock water conversion factor

PA	Beef	Pork	Milk
	(gallons per pound of liveweight)		
1	0.0150	0.0090	0.0028
2	0.0350	0.0090	0.0028
3	0.0250	0.0105	0.0028
4	0.0550	0.0105	0.0028
5	0.0350	0.0090	0.0032
6	0.0350	0.0090	0.0032
7	0.0350	0.0080	0.0032
8	0.0350	0.0090	0.0036
9	0.0450	0.0105	0.0036
10	0.0450	0.0105	0.0036

The final adjustment for water supply is the water required by the exogenous crops. The crop consumptive irrigation requirement, representing the number of acre feet of water required by one acre of crop, is derived from Smith et al. (1989) and shown is Table 12. The exogenous crop production in a specific producing area times the crop consumptive irrigation requirement provides the amount of water consumed by the exogenous crops in the area.

After subtracting the water consumption by the nonagricultural sector, livestock, and the exogenous crops, the balance is the water available for the endogenous crop, pasture, and forest production.

Table 12. Crop water consumptive requirement by crop and producing area

Crop	Producing Area									
	1	2	3	4	5	6	7	8	9	10
Barley	0.9	1.1	0.6	1.5	0.9	0.8	0.9	1.2	2.0	1.5
Corn Grain	1.0	1.3	1.6	1.6	1.1	0.9	1.2	1.3	1.3	1.2
Corn Silage	1.0	1.3	1.6	1.6	1.1	0.9	1.2	1.3	1.3	1.2
Cotton	1.2	1.6	2.1	2.1	1.1	1.2	1.2	1.2	1.4	1.1
Hay	1.2	1.7	1.3	2.3	1.3	1.3	1.5	2.7	3.1	2.4
Oat	0.9	1.1	0.6	1.5	0.9	0.8	0.9	1.3	2.0	1.5
Peanut	1.0	1.6	1.7	2.0	1.1	1.2	1.2	1.3	1.4	1.1
Sorghum Grain	1.3	1.4	1.6	1.6	1.1	0.9	1.1	1.2	1.2	1.3
Sorghum Silage	1.3	1.4	1.6	1.6	1.1	0.9	1.1	1.2	1.2	1.3
Soybean	1.3	1.4	1.6	1.6	1.1	0.9	1.0	1.2	1.2	1.2
Sunflower	1.0	1.3	1.6	1.6	1.1	0.9	1.2	1.3	1.3	1.2
Spring Wheat	0.9	1.2	0.6	1.5	1.0	0.8	0.9	1.3	2.0	1.5
Winter Wheat	0.9	1.2	0.6	1.5	1.0	0.8	0.9	1.3	2.0	1.5

During irrigation some water will be lost. Thus, the incidental efficiency representing the irrecoverable water losses that occur during irrigation is incorporated in this study. The incidental efficiency for each producing area is developed from the data reported by Smith et al. (1989).

Demand sector

This model requires the data on domestic demands for and net exports of food and fiber, and livestock feed demands. The livestock feed demands have been discussed in the livestock sector. In this section, the demands for food and fiber will be described.

Domestic crop demand consists of domestic human demand and domestic industrial demand. Two pieces of information, per capita crop consumption and total population, are needed to determine the domestic crop demand. U.S. Bureau of Census (1988) has projected the total U.S. population up to the year 2000. This projection of the population is directly used for the year 2000. The population level in the year 2040 is computed using the projected population growth rate between 2000 and 2040 from the 1989 RPA assessment (Haynes, 1988). The total projected population in the United States by the years 2000 and 2040 is 267.7 and 324.3 millions, respectively.

Per capita consumption for crop commodities (Table 13) is obtained from English and Campos (1989). The product of the population level by per capita consumption is the projected domestic human demand for crop.

The industrial demand for crops (Table 14) is derived from the data reported by English and Campos (1989). They have projected the amount of crops demanded by industry up to the years 2030. These data are extrapolated to the year 2040.

The same source of data and methods used in determining the industrial crop demand are used to derive the net exports of crops in the years 2000 and 2040. The "most likely" export levels projected by CARD (English and Campos, 1989) are used in this study. These projections are presented in Table 15.

Table 13. Per capita consumption of crop commodity

	Year	
Crop	2000	2040
	(pounds per capita)	
Barley	35.0	35.9
Corn	67.5	61.0
Cotton	8.5	8.5
Oat	4.2	34
Sorghum	0.0	0.0
Soybean	0.1	0.1
Wheat	156.5	146.4

Table 14. Industrial crop demand

Crop	Year 2000	Year 2040
	(million	bushels)
Barley	19.1	23.8
Corn	1685.4	1812.5
Oats	33.8	40.6
Sorghum	10.3	14.1
Soybean	269.7	466.9
Wheat	103.6	137.3

Table 15. Net exports of crops

Crop	Unit	Year 2000	Year 2040
		(million	units)
Barley	bushel	58.7	129.2
Corn	bushel	4202.9	9519.0
Cotton	bale	8.1	14.4
Oats	bushel	5.2	9.2
Sorghum	bushel	369.3	834.2
Soybean	bushel	1641.5	4413.2
Wheat	bushel	2313.2	4929.7

Timber is classified into two categories: softwood and hardwood. USDA Forest Service (1982) has reported its projections of domestic demand for and net import of timber up to the year 2030. The medium levels of these projections are chosen as the future timber demand and net import in this model. Its projected demand in the year 2000 is directly used. The demand level in the year 2040 is projected using the trend of the demand growth from 1990 to 2030. The projected domestic demand for and net import of timber are shown in Table 16.

Table 16. Timber demand and net imports

Timber	Domestic Demand	Net Import
	(million cubic feet)	
Year 2000		
Softwoods	16300	1900
Hardwoods	6400	400
Year 2040		
Softwoods	19200	2300
Hardwoods	10500	300

Environment sector

This sector requires the data related to the soil erosion, wildlife habitats, and carbon dioxide offset.

Soil erosion Only sheet and rill erosion is considered in this model. The Universal Soil Loss Equation (USLE), developed by Wischmeier and Smith (1978), is used to derive the gross soil loss coefficients of cropland, which represent the average annual tons of soil displaced within the field by water erosion. The Universal Soil Loss Equation is expressed as follows:

$$A = RKLSCP$$

where

R is the rainfall erosion factor,

k is the soil erodibility factor,

L is the slope length factor,

S is the slope gradient factor,

C is the crop management factor,

p is the erosion control practice factor.

The major soils are used to develop the soil loss coefficient in a specific land group in a given producing area. The detailed procedures used to develop the factors and soil loss coefficients can be found in Wischmeier and Smith (1978).

Soil loss from forest land is estimated using the Universal Soil Loss Equation. The methods and procedures developed by Dissmeyer and Foster (1984) are used to develop the value of factor C on forest land.

Logging will result in varying degree of disturbance that will cause accelerated suspended sediment rate. The effects of logging on soil loss are incorporated in the model. Fowler et al. (1983) have developed an equation to estimate soil loss on forest lands caused by logging. The equation takes the following forms:

$$ASR = 0.03592 + 15.31\ NSR$$

where

ASR is the accelerated sediment rate by logging (tons/acre/year),

NSR is the undisturbed suspended sediment rate (tons/acre/year).

The estimated value of ASR is then converted to the annual average level by dividing it by the length of the rotation period, because forests are harvested only at the end of their rotation. The total annual sheet and rill erosion from forest land is finally developed by summing the erosion from the undisturbed forest land and that occurring potentially from logging.

Wildlife habitats The quality of wildlife habitats is represented by an index. The values of index range from 1 to 5, with 5 representing the excellent, 4 representing the good , 3 representing the fair, 2 representing the poor, and 1 representing the bad. A group of wildlife management experts have developed the index values of the wildlife habitats for all the ecosystems (USDA

Forest Service, 1972). Their data are the primary source used to develop the index of the quality of the wildlife habitats.

Carbon dioxide One way to reduce the carbon dioxide concentration in the atmosphere is to plant more trees. In this model the goal for carbon dioxide reduction is represented by the number of acres of forest areas. The "Trees for U.S." program reported that a net increase of 10 million acres in forest area is required in order to achieve the goal of 5% carbon dioxide offset.

Computer Software Package

Several software packages for solving a linear goal programming model are available. IBM's Mathematical Programming System Extended (MPSX) was used to solve this model. This powerful system can easily handle a relatively large-scale model. MPSX requires a specific control program. A control program for solving a sequential linear goal programming problem has been developed by Sposito (1989). This control program can solve a linear goal programming problem with up to 10 objectives.

The model is solved by using a sequential optimization approach. A sequential linear goal programming problem is actually a series of linear programming problems solved in an order determined by a user-specified priority system. The goals with higher priority will be satisfied to their full extent possible before any other lower-ordered goals are considered. After the linear programming problem for a priority level is solved, its original constraint will be augmented to a new equality constraint with its right hand side equal to the newly found objective function optimum. Thus, a new linear programming problem is formed and then solved in the same way. The same procedure continues until all the objectives are optimized.

CHAPTER IV. RESULTS

In this section, the results found in this study will be presented and discussed. The results reported here include the land use, the regional production, the shadow prices of forest and SWRC production on the cropland for different regions, and the management strategies for the forest and range ecosystems. The results of the crop production in the twenty crop producing areas will be aggregated and reported for the 10 USDA Farm Program regions (Figure 4). The results of the forest and range production will be reported on the basis of the ecosystems.

The model was run under four scenarios for both the year 2000 and the year 2040. Each scenario represents a specific ordering system for the goals to be optimized. The ordering of the goals in Scenario I is cost, soil erosion, wildlife habitats, and carbon dioxide reduction. In Scenario II the ordering is soil erosion, cost, wildlife habitats, and carbon dioxide reduction. In Scenario III the ordering is wildlife habitats, cost, soil erosion, and carbon dioxide reduction. In Scenario IV the ordering is carbon dioxide reduction, cost, soil erosion, and wildlife habitats. Different goals are emphasized under the different scenarios. In Scenario I, the cost has the highest priority. It will be satisfied to its full extent possible before the other three environmental goals (the soil erosion, wildlife habitats, and carbon dioxide reduction) will be considered. This scenario reflects our traditional desire to produce

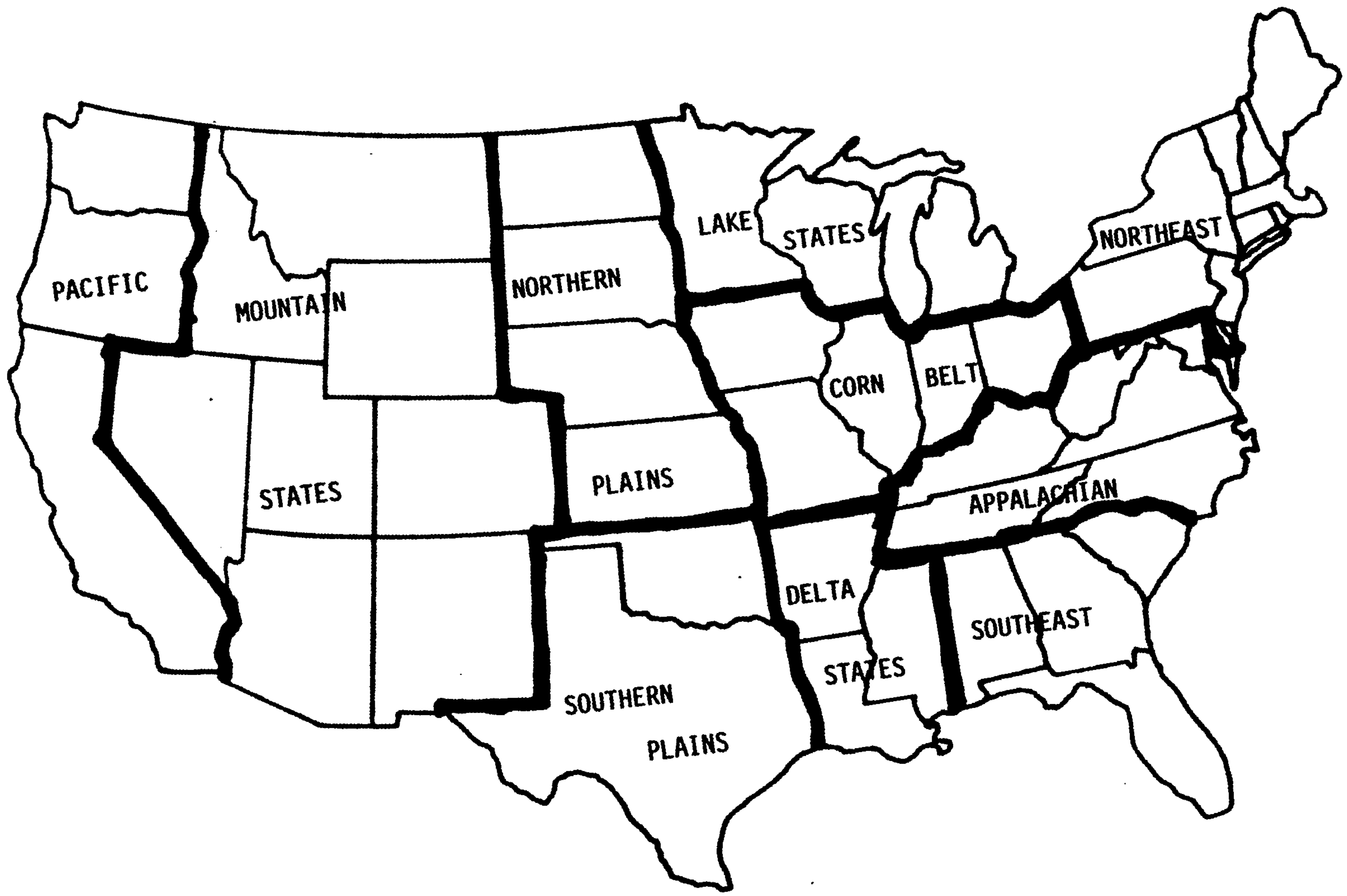

Figure 4. U.S. Department of Agriculture Farm Program regions

what we need with the minimum possible cost with less consideration of the environmental effects of the production. On the other hand, in Scenarios II, III, and IV one of the three environmental goals will be set to have the highest priority, respectively. The results in these three scenarios will be more environmentally orientated than those in Scenario I.

Land Use

The demands for foods and fibers require the use of land for the production. The present pattern of land use in the United States of America is the result of the historical function of human and nature. This pattern is affected by economic, political, and social factors. Changes in these factors will induce the change in land use. In this section, the nation's cropland use and the possible shifts of the land use among the sectors under the four scenarios will be examined.

The total land use for the endogenous crop production by land group and scenario for the years 2000 and 2040 is shown in Tables 17 and 18, respectively. The least amount of the cropland will be required for the endogenous crop production in Scenario I. Scenario II will require the largest amount of cropland for the endogenous crop production. The amount of land used for the crop production in Scenarios III and IV will be approximately the same. The amount of land required by the crop production will increase from the year

Table 17. Cropland used for the endogenous crop production by land group and scenario in 2000

Land Group	Scenario I	II	III	IV
	(thousand acres)			
1	32704	47649	41964	44825
2	216147	205689	239918	239856
3	30355	97283	9423	9604
4	1091	587	261	0
5	607	133	156	156
Total	280904	351341	291722	294441

Table 18. Cropland used for the endogenous crop production by land group and scenario in 2040

Land Group	Scenario I	II	III	IV
	(thousand acres)			
1	37786	50869	46792	45953
2	220911	220820	240627	240817
3	40303	94255	8995	10282
4	803	584	574	259
5	0	135	45	0
Total	299805	366663	297033	297311

2000 to 2040 in all the four scenarios because the demand for crops will increase during the period.

That more land will be required for the crop production in Scenario II than in other scenarios is due to several reasons. Often, the regions with higher crop yields produce larger amount of soil erosion than less productive regions. As the soil erosion goal is set with the highest priority, some crop production in more productive regions with higher erosion will be shifted to less productive region with less erosion to reduce the total amount of the soil erosion from the cropland. This results in that more land will be used for the crop production. Further, as the soil erosion goal becomes more important relative to other goals, the portion of continuous row crop rotations will decline and more row crops will be rotated with small grain crops to reduce the soil erosion. This will also cause more land to be used for the crop production.

In addition to the use of the cropland for the crop production, some cropland in Land Groups 3, 4, and 5 will be used for the forest (the traditional forest and SRWC) production (Tables 19 and 20). In Scenario I, only a small portion of the cropland will be planted with trees. As the environmental goals are considered to be more important, more and more cropland will be used for tree plantations.

Different policies may have significant impacts on the land use and shifts. The land shifts among the sectors in all the four scenarios are presented in Tables 21 and 22 for the years 2000 and 2040, respectively. The least amount of land conversion will occur in Scenario I. When the cost becomes the most important goal, the high land conversion costs will limit the shifts of the land use among the sectors. The conversion of the pasture land to the cropland will reach its maximum amount in Scenario II. For the year 2040 the amount of the pasture land converted to the cropland will be the same in Scenarios II, III, and IV. The conversion of the forest land to the cropland will occur only in Scenario II. This is because land in Land Group 1 has the least erosion hazard. When the soil erosion goal is set with the highest priority, the conversion of Class II_W and III_W pasture and forest land to cropland will increase to provide more less erodible land for the crop production so that the crop production on the highly erosive land can be reduced. Therefore, more pasture and forest land will be converted to the cropland in Scenario II than in other scenarios. When the wildlife habitat or carbon dioxide reduction goal is set with the highest priority, no conversion of the forest land to the cropland will occur and the conversion of the pasture land to the cropland will also be reduced.

The amount of the cropland used for planting the traditional forests and short-rotation woody crop (SRWC) will increase from Scenario I to III as the environmental goals become more important. The same amount of the cropland will be shifted to the traditional forest and SRWC production in Scenarios III and IV. In Scenario I, 7.434 million acres of the cropland will be converted to forest (including the traditional forest and SRWC) area in the year 2000,

Table 19. Cropland used for the forest production by land group and scenario in 2000

Land Group	Scenario I	II	III	IV
		(thousand acres)		
Traditional Forest				
1	----	----	----	----
2	----	----	----	----
3	7434	8236	86180	83751
4	----	4902	4586	5170
5	----	14138	12291	12600
Total	7434	27276	103057	101521
SRWC				
1	----	----	----	----
2	----	----	----	----
3	----	----	8763	10931
4	----	----	642	319
5	----	----	1824	1514
Total	----	----	11228	12764

Table 20. Cropland used for the forest production by land group and scenario in 2040

Land Group	Scenario I	II	III	IV
		(thousand acres)		
Traditional	Forest			
1	----	----	----	----
2	----	----	----	----
3	7452	12655	74995	83119
4	570	4930	3650	3089
5	1420	14044	7605	5888
Total	9442	31629	86250	92096
SRWC				
1	----	----	----	----
2	----	----	----	----
3	----	----	19510	11138
4	----	----	1257	2021
5	----	----	6529	8291
Total			27296	21450

Table 21. Shifts of land use among the sectors by scenario in 2000

Type of Conversion	Scenario I	Scenario II	Scenario III	Scenario IV
	(thousand acres)			
Pasture to Cropland	2146	7510	4529	7490
Forest to cropland	----	2296	---	---
Cropland to Forest	7434	27276	114286	114286

Table 22. Shifts of land use among the sectors by scenario in 2040

Type of Conversion	Scenario I	Scenario II	Scenario III	Scenario IV
	(thousand acres)			
Pasture to Cropland	2441	9503	9503	9503
Forest to cropland	----	4249	---	---
Cropland to Forest	9442	31629	113546	113546

and this amount will increase to 9.442 million acres in the year 2040. In Scenario II more cropland will be used for the forest production. The net gains of the forest area (the amount of the tree plantations on the cropland minus the amount of the forest converted to the cropland) will be 24.98 million acres in 2000 and 27.38 million acres in 2040, respectively. In Scenarios III and IV, the tree plantations on the cropland will reach its maximum amount: 114.286 million acres in 2000 and 113.546 million acres in 2040. If this happens, it will be a significant amount of addition to the nation's forest resources and may significantly improve the environmental quality in the nation.

The land conversion among the sectors will increase from the year 2000 to 2040 in most scenarios except the conversion of the cropland to the forest land in Scenarios III and IV. As the demands for crops go up and more cropland will be converted to urban and nonagricultural use, less cropland will be left for forest production. Subsequently, the tree plantations on the cropland will decrease from the year 2000 to 2040 in Scenarios III and IV. The amount of forest production on the cropland, however, will be reduced only by less than 1% (738 thousand acres) from the year 2000 to 2040. This indicates that most of trees planted on the cropland in the year 2000 will not need to be converted back to the cropland in the year 2040 despite the increase in the crop demand and the decrease in the cropland available.

Regional Production

Different regions have different advantages and/or disadvantages in producing a specific type of crop or forest. The regional advantages and disadvantages lead to a specific pattern of the crop production distribution across the country under a given policy. In this section, we will discuss the distribution of the crop production among the regions along with the corresponding forest production on the cropland in the four scenarios (Tables 23 to 40).

Barley production will be concentrated in only a few regions in Scenarios I and II (Tables 23 and 32). In Scenario I, it will be produced in the Mountain, Pacific, and Lake States for the year 2000, and in the Mountain and Pacific regions for the year 2040. In Scenario III the Mountain and Pacific regions will produce all the barley in the nation in both the years 2000 and 2040. In Scenarios III and IV, barley production will shift out to more regions, while the Lake States, Northern Plains, and Mountain States will still be the three major barley producing regions.

The Corn Belt will be the most important region for corn production (Tables 24 and 33). It will share about half of the total national corn production in Scenarios I, III, and IV. The other important corn producing regions will be the Lake States and Northern Plains. In Scenario II, a large portion of the corn production will shift out of the Corn Belt to other regions. But the Corn Belt, Lake States, and Northern Plains will still be the three most important corn producing regions. In this scenario, the Lake states and Northern Plains each will share the approximate same portion of the total national corn production as the Corn Belt does. The Corn Belt produces higher yield of corn than other regions. If more corn is grown in the Corn Belt, less land will be required for corn production and more cropland will be available for planting trees. As more trees are planted, the achievements of the wildlife

Table 23. Regional shares of barley production by scenario in 2000

Region	Scenario I	II	III	IV
		(percent)		
Northeast	--	--	9	8
Appalachian	--	--	1	1
Southeast	--	--	--	--
Delta States	--	--	--	--
Corn Belt	--	--	14	12
Lake States	37	--	25	15
Northern Plains	--	--	22	27
Southern Plains	--	--	2	8
Mountain States	42	89	22	25
Pacific	21	11	5	4
Total	100	100	100	100

Table 24. Regional shares of corn production by scenario in 2000

Region	Scenario I	II	III	IV
		(percent)		
Northeast	3	10	1	3
Appalachian	--	2	9	1
Southeast	--	4	14	3
Delta States	--	2	8	1
Corn Belt	52	20	43	55
Lake States	19	21	8	12
Northern Plains	18	23	11	16
Southern Plains	2	8	5	5
Mountain States	3	9	1	2
Pacific	3	1	--	2
Total	100	100	100	100

Table 25. Regional shares of cotton production by scenario in 2000

Region	Scenario I	II	III	IV
	(percent)			
Northeast	--	--	--	--
Appalachian	22	13	36	15
Southeast	10	6	15	7
Delta States	45	3	9	4
Corn Belt	--	--	--	--
Lake States	--	--	--	--
Northern Plains	--	--	--	--
Southern Plains	16	8	40	44
Mountain States[a]	--	8	--	13
Pacific[b]	7	62	--	17
Total	100	100	100	100

[a]Cotton is produced only in Arizona and New Mexico in the mountain states.

[b]Cotton is produced only in California in the Pacific region.

Table 26. Regional shares of oat production by scenario in 2000

Region	Scenario I	II	III	IV
		(percent)		
Northeast	7	1	--	3
Appalachian	39	7	2	17
Southeast	10	2	1	5
Delta States	10	2	--	4
Corn Belt	17	39	1	8
Lake States	--	9	--	--
Northern Plains	7	28	8	--
Southern Plains	3	2	81	63
Mountain States	7	10	8	--
Pacific	--	--	--	--
Total	100	100	100	100

Table 27. Regional shares of sorghum production by scenario in 2000

	Scenario			
Region	I	II	III	IV
		(percent)		
Northeast	2	6	--	3
Appalachian	14	35	1	15
Southeast	4	9	--	4
Delta States	3	16	--	58
Corn Belt	6	16	--	12
Lake States	--	--	--	--
Northern Plains	19	--	5	--
Southern Plains	45	18	89	8
Mountain States	7	--	5	--
Pacific	--	--	--	--
Total	100	100	100	100

Table 26. Regional shares of soybean production by scenario in 2000

Region	Scenario I	II	III	IV
		(percent)		
Northeast	2	4	1	--
Appalachian	3	3	5	4
Southeast	22	4	20	29
Delta States	11	4	10	14
Corn Belt	31	20	25	23
Lake States	8	33	5	5
Northern Plains	15	17	16	10
Southern Plains	6	11	16	14
Mountain States	2	4	2	1
Pacific	--	--	--	--
Total	100	100	100	100

Table 29. Regional shares of wheat production by scenario in 2000

Region	Scenario I	II	III	IV
	(percent)			
Northeast	9	3	3	2
Appalachian	3	5	8	13
Southeast	10	10	12	24
Delta States	5	7	8	15
Corn Belt	1	1	4	5
Lake States	17	--	1	13
Northern Plains	19	5	18	8
Southern Plains	11	12	19	11
Mountain States	21	38	18	6
Pacific	4	19	9	3
Total	100	100	100	100

Table 30. Forest plantation on cropland by region and scenario in 2000

Region	Scenario I	II	III	IV
	(thousand acres)			
Northeast	2357	1163	3922	5091
Appalachian	----	1427	5278	6463
Southeast	----	1455	1424	6649
Delta States	----	951	2269	4567
Corn Belt	512	2780	19737	14330
Lake States	4565	1806	10050	7973
Northern Plains	----	3463	22841	21476
Southern Plains	----	7272	16375	13812
Mountain States	----	5789	16482	16482
Pacific	----	1170	4679	4679
Total	7434	27276	103057	101522

Table 31. SRWC plantation on cropland by region and scenario in 2000

Region	Scenario I	II	III	IV
	(thousand acres)			
Northeast	----	----	1259	90
Appalachian	----	----	1185	----
Southeast	----	----	5284	59
Delta States	----	----	2298	----
Corn Belt	----	----	----	5407
Lake States	----	----	----	2077
Northern Plains	----	----	----	1364
Southern Plains	----	----	1203	3767
Mountain States	----	----	----	----
Pacific	----	----	----	----
Total	----	----	11229	12764

Table 32. Regional shares of barley production by scenario in 2040

Region	Scenario I	II	III	IV
		(percent)		
Northeast	--	--	5	2
Appalachian	--	--	2	--
Southeast	--	--	--	1
Delta States	--	--	--	--
Corn Belt	--	--	3	2
Lake States	--	--	30	32
Northern Plains	--	--	24	25
Southern Plains	--	--	--	--
Mountain States	87	89	30	32
Pacific	13	11	6	6
Total	100	100	100	100

Table 33. Regional shares of corn production by scenario in 2040

Region	Scenario I	II	III	IV
		(percent)		
Northeast	9	9	5	7
Appalachian	--	2	1	4
Southeast	--	4	--	1
Delta States	--	2	--	1
Corn Belt	42	26	45	49
Lake States	15	22	12	14
Northern Plains	18	23	21	14
Southern Plains	7	5	10	8
Mountain States	5	7	6	--
Pacific	4	--	--	2
Total	100	100	100	100

Table 34. Regional shares of cotton production by scenario in 2040

Region	Scenario I	Scenario II	Scenario III	Scenario IV
	(percent)			
Northeast	--	--	--	--
Appalachian	12	27	17	--
Southeast	29	12	27	--
Delta States	8	7	14	--
Corn Belt	--	--	--	--
Lake States	--	--	--	--
Northern Plains	--	--	--	--
Southern Plains	16	15	12	3
Mountain States[a]	21	4	--	41
Pacific[b]	14	35	30	56
Total	100	100	100	100

[a]Cotton is produced only in Arizona and New Mexico in the mountain states.

[b]Cotton is produced only in California in the Pacific region.

Table 35. Regional shares of oat production by scenario in 2040

Region	Scenario I	II	III	IV
	(percent)			
Northeast	5	2	--	12
Appalachian	31	9	3	25
Southeast	8	2	1	7
Delta States	7	2	1	6
Corn Belt	14	47	9	21
Lake States	--	9	8	27
Northern Plains	16	17	59	--
Southern Plains	3	9	1	2
Mountain States	16	3	18	--
Pacific	--	--	--	--
Total	100	100	100	100

Table 36. Regional shares of sorghum production by scenario in 2040

Region	Scenario I	II	III	IV
	(percent)			
Northeast	--	2	--	1
Appalachian	--	6	1	5
Southeast	--	2	--	1
Delta States	--	17	28	27
Corn Belt	--	11	4	5
Lake States	--	1	--	--
Northern Plains	32	20	8	17
Southern Plains	57	35	51	28
Mountain States	11	4	8	16
Pacific	--	--	--	--
Total	100	100	100	100

Table 37. Regional shares of soybean production by scenario in 2040

Region	Scenario I	Scenario II	Scenario III	Scenario IV
	(percent)			
Northeast	3	4	8	8
Appalachian	4	3	11	4
Southeast	15	4	20	16
Delta States	8	5	11	9
Corn Belt	39	24	31	27
Lake States	9	28	6	5
Northern Plains	14	21	7	14
Southern Plains	7	7	6	15
Mountain States	1	4	--	2
Pacific	--	--	--	--
Total	100	100	100	100

Table 38. Regional shares of wheat production by scenario in 2040

Region	Scenario I	Scenario II	Scenario III	Scenario IV
	(percent)			
Northeast	4	3	1	2
Appalachian	12	6	8	12
Southeast	12	9	14	17
Delta States	7	9	11	13
Corn Belt	5	2	3	5
Lake States	17	--	3	5
Northern Plains	16	9	16	14
Southern Plains	12	11	22	16
Mountain States	11	36	16	16
Pacific	4	15	6	4
Total	100	100	100	100

Table 39. Forest plantation on cropland by region and scenario in 2040

Region	Scenario I	Scenario II	Scenario III	Scenario IV
	(thousand acres)			
Northeast	3047	1177	3047	2487
Appalachian	----	1411	10	4761
Southeast	----	1468	----	2128
Delta States	----	936	938	1280
Corn Belt	654	1745	15394	16610
Lake States	5741	1791	9583	8310
Northern Plains	----	6672	22186	22109
Southern Plains	----	6920	15482	13436
Mountain States	----	7673	16459	16459
Pacific	----	836	3151	4516
Total	9442	31629	86250	92096

Table 40. SRWC plantation on cropland by region and scenario in 2040

Region	Scenario I	II	III	IV
		(thousand acres)		
Northeast	----	----	2178	2738
Appalachian	----	----	6476	1726
Southeast	----	----	6735	4497
Delta States	----	----	3586	3244
Corn Belt	----	----	4144	2928
Lake States	----	----	379	1651
Northern Plains	----	----	460	537
Southern Plains	----	----	1754	3910
Mountain States	----	----	----	----
Pacific	----	----	1584	219
Total	----	----	27296	21450

habitat and carbon dioxide reduction goals will be enhanced. In Scenarios III and IV, corn production will be concentrated again in the Corn Belt. The distribution pattern of the corn production will be similar for both the years 2000 and 2040.

Only a few regions in the country are suited for cotton production. The Southeast, Delta States, Southern Plains, Appalachian, Mountain (Arizona and New Mexico), and Pacific (California) will be the major cotton producing regions in the country. In Scenario I, the major portion of cotton will be produced in the Southeastern part of the nation. In Scenarios II, III, and IV, more and more cotton production will shift to California, Arizona, and New Mexico. These three western states will share a larger portion of the total national cotton production in the year 2040 than in the year 2000.

Many regions will share the production of oats, while the Corn Belt, Northern Plains, Southern Plains, and Appalachian will be the leading oat producing regions in the nation in the most scenarios. In Scenario II, the Corn Belt will share the largest portion of the total national oat production. When the soil erosion goal is set with the highest priority, more row crops such as corn and soybean will be rotated with oats to reduce the erosion. This results in more oats being produced in the Corn Belt.

Like barley, sorghum production will be relatively concentrated in a few regions. The Southern Plains, Northern Plains, Delta States, and Appalachian will be the most important sorghum producing regions. The Southern Plains will produce the largest portion of sorghum in the nation in the most scenarios.

The distribution of soybean production across the regions will be similar to corn. The Corn Belt will produce the largest amount of soybean in the nation if the cost goals is considered to be the most important. The second most important soybean producing region will be the Southeast. In Scenario II, the soybean production will shift out of the Corn Belt and Southeast to the Lake States and Northern Plains. In Scenarios III and IV, the Corn Belt and Southeast will once again become the two leading soybean producing regions in the nation.

Compared with other crops, wheat grows very extensively in all the scenarios. Almost all the regions will produce wheat. The only exception will be in Scenario II, in which the three regions of the Mountain, Pacific, and Southern Plains will produce approximate two thirds of the total national wheat.

Corresponding to the distribution of the crop production, the forest and SRWC production will also be distributed across the regions with a specific pattern under a given policy (Tables 30, 31, 39, and 40). Different policies represented by the four scenarios will have a significant impact on the distribution of the tree plantation on the cropland across the regions. In Scenario I, forest production will be competitive with the crops only in a few regions: the Northeast, Corn Belt, and Lake States. As the environmental goals are considered to be more important than the cost, trees will be planted on the cropland in all the regions. But a large portion of the new forest will be established in the Northern Plains, Southern Plains, Corn Belt, and Mountain regions.

Short rotation woody crop (SRWC) production will not be competitive with the crops in Scenarios I and II. In Scenarios III and IV, some of the cropland could be used for SRWC production. In the year 2000 SRWC will be produced in the Southeast, Delta States, Northeast, Appalachian, and Southern Plains in Scenario III. In Scenario IV, the Corn Belt, Lake States, and Northern Plains also will become the SRWC producing regions. In the year 2040, more regions will join to produce SRWC, and the total SRWC production will increase from 11.229 million acres in the year 2000 to 27.296 million acres in Scenario III, and from 12.764 million acres to 21.45 million acres in Scenario IV. Most of these SRWC productions will be concentrated in the Northeast, Appalachian, Southeast, Delta States, Corn Belt, and Southern Plains.

Shadow Price of Forest Production

Under Scenario I, SRWC production will not be competitive with agronomic crop production, and the traditional forest will be established on the cropland only in a few regions. To plant trees on cropland more than the levels defined by the optimal solution will cause the total national production cost to increase. The amount of the cost increased for an additional unit of tree plantation on the cropland is defined as the shadow price of the forest production.

The shadow price implies the regional advantages or disadvantages for the SRWC and the traditional forest production.

The shadow prices per acre of SRWC production are presented in Table 41. In the year 2000, the Corn Belt will have the lowest shadow price, followed by the Pacific and Lake States. The shadow price in the Corn Belt will be $23.58/acre. This indicates that the total national production cost will be increased by 23.58 dollars, if an additional acre of SRWC is established in the Corn Belt. The highest shadow price per acre of SRWC production will occur in the Northeast region. To plant one more acre of SRWC in the Northeast will result in a increase in the production cost by 30.36 dollars.

In the year 2040, the lowest shadow price also will occur in the Corn Belt, followed by the Northeast and Appalachian regions. The Southern Plains will have the highest shadow price among all the regions. To establish an additional acre of SRWC in the Corn Belt will cause the production cost to increase by 20.44 dollars, but the production cost will be increased by as much as 26.13 dollars for an additional acre of SRWC planted in the Southern Plains.

The shadow prices per acre of SRWC production are based on the area of SRWC rather than the volume of biomass. If the objective of SRWC production is to produce the maximum amount of biomass, we probably will be more interested in the volume of biomass than in the area. Thus, the shadow prices per dry ton of biomass are identified in this study (Table 42). These shadow prices provide the

Table 41. Shadow prices per acre of SWRC production

Region	Year 2000	Year 2040
	($/acre)	
Northeast	30.38	21.67
Appalachian	27.13	21.93
Southeast	29.30	26.34
Delta States	28.38	25.52
Corn Belt	23.58	20.44
Lake States	25.33	24.00
Southern Plains	29.70	28.13
Pacific	23.79	25.36

information on the most economical region to produce an additional amount of biomass.

The Southeast will be the most economical region for additional biomass production in both the years 2000 and 2040. The Corn Belt will be ranked in the second in the regional comparative advantage for an additional ton of biomass production in the nation. The most expensive region for the biomass production will be the Northeast. To produce one more ton of biomass in the Southeast will

Table 42. Shadow prices per dry ton of SWRC production

Region	Year 2000	2040
	($/ton)	
Northeast	10.54	7.52
Appalachian	9.08	7.34
Southeast	4.97	4.47
Delta States	5.90	5.31
Corn Belt	5.24	4.54
Lake States	6.57	6.23
Southern Plains	7.54	7.14
Pacific	5.29	5.64

cause the production cost to increase by 4.97 dollars in the year 2000 and 4.47 dollars in the year 2040. But, the production cost will be increased by 10.54 dollars in 2000 and 7.52 dollars in 2040 for an additional ton of biomass produced in the Northeast.

The shadow prices per acre of the traditional forest production are shown in Table 43. In the year 2000, the Lake States will have the lowest shadow price, only $2.41/acre. The Corn Belt and Southeast will be ranked in the second and the third, respectively, in the regional comparative advantage for the traditional forest production. The highest shadow price will occur in the Northeast. If

Table 43. Shadow prices per acre of the traditional forest production

Region	Year 2000	2040
	($/acre)	
Northeast	13.94	7.59
Appalachian	11.93	7.58
Southeast	8.86	7.65
Delta States	9.08	7.59
Corn Belt	8.78	7.53
Lake States	2.41	7.89
Northern Plains	10.52	9.98
Southern Plains	10.10	9.61
Mountain	9.18	8.50
Pacific	10.97	8.67

one acre of forest is planted in the Northeast, the total national production cost will be increased by 13.94 dollars.

In the year 2040, the Corn Belt will be the most economical regional to increase the forest area. The shadow price of the traditional forest production on the cropland in the Corn Belt will be $7.53/acre. The Appalachian, Northeast, and Delta States will be the other regions which will have the relatively low shadow prices per acre of forest production on the cropland. It will be most expensive to increase the forest area in the Northern Plains. One additional acre of forest planted in the Northern Plains will result in an increase in the total national production cost by 9.98 dollars.

Like SRWC, the shadow prices for the traditional forest production are identified on the volume basis as well as on an area basis. The shadow prices per thousand board feet ($/MBF) of timber produced on the cropland are presented in Table 44. In the year 2000, the Lake States will have the lowest shadow price for the production of an additional MBF of timber. The Southeast will be ranked in the second in the comparative advantage for the timber production on the cropland. The Appalachian and Northern Plains will be the two most expensive regions to produce timber on their cropland. For an additional MBF of timber produced in the Appalachian, the production cost will be increased by 137.9 dollars. And, the production cost will be increased by 134.43 dollars if one more MBF of timber is produced in the Northern Plains.

In the year 2040, the Southeast, followed by the Northeast and Delta States, will become the most economical region for additional timber production. It will cause the production cost to increase by only 69.76 dollars to produce one more MBF of timber in the Southeast. The highest shadow price will occur in the Northern Plains. If one additional MBF of timber is produced in the Northern Plains, the total national production cost will increase by about 127.09 dollars.

Table 44. Shadow prices per MBF of the traditional forest production

Region	Year 2000	Year 2040
	($/MBF)	
Northeast	104.32	73.50
Appalachian	137.90	87.60
Southeast	80.80	69.76
Delta States	91.85	76.75
Corn Belt	109.82	100.74
Lake States	18.70	101.10
Northern Plains	134.43	127.49
Southern Plains	126.51	120.37
Mountain	120.87	111.88
Pacific	113.21	89.45

The shadow prices of the forest production will vary form the year 2000 to 2040. The regional comparative advantages for the forest production also will not be consistent if measured in the different terms such as the shadow prices per acre and the shadow prices per unit of volume. In general, the Corn Belt will have consistently relatively low shadow price for SRWC production, whereas the shadow price of SRWC production will be consistently high in the Southern Plains. Compared to other regions, the Southeast will have a relatively high shadow price per acre of SRWC production, but it also will be the most economical region for biomass production in terms of the shadow price per ton of biomass produced because the biomass yield is higher in this region than in any other regions. For the traditional forest production on the cropland, the shadow prices in the Southeast and Delta States will be relatively low, and it will be relatively high in the Northern Plains, Southern Plains, and Mountain regions. The Pacific region will have the relatively high shadow price on the per acre basis, but the shadow price on the per MBF basis in this region will be at the intermediate level. The shadow prices in other regions will be at the intermediate levels, or relatively high (low) in 2000 and relatively low (high) in 2040, or relatively high (low) on the area basis and relatively low (high) on the volume basis.

Management Strategies of Ecosystems

Another important result of this study is the optimal management strategies for the forest and range ecosystems. These management strategies represent the best combination of the management alternatives for all the ecosystems under the constraints of the model and a specific priority system for the goals of the cost, soil erosion, and wildlife habitats, and carbon dioxide reduction. The optimal management strategies for the ecosystems in Scenario I are presented in Tables 45 and 46 for the years 2000 and 2040, respectively.

In the year 2000, timber will be primarily produced from the longleaf-slash pine, loblolly-shortleaf pine, elm-ash-cottonwood, maple-beech-birch, aspen-birch, Douglas-fir, hemlock-sitka spruce, and redwood ecosystems. The ecosystems such as oak-pine, oak-hickory, oak-gum-cypress, lodegepole pine, western hardwoods, chaparral-mountain shrub, and pinyon-juniper will be managed mainly for the environmental purposes. The forest lands with high productivity in the white-red-jack pine, spruce-fir, ponderosa pine, fir-spruce, and larch ecosystems also will be managed for timber production. The less productive forest lands in these ecosystems will be under the environmental management. According to the optimal solution, the forest lands with high productivity will be first used for timber production, and almost all the forest lands with the productivity of less than 50 cubic feet per acre per year will be managed primarily for environmental purposes.

As the demand for timber increases, in 2040 more forest lands will be used for timber production (Table 46). In addition to the forest ecosystems managed primarily for the timber production in 2000, the white-red-jack pine, spruce-fir, oak-hickory, and fir-spruce ecosystems also will become the prime timber producing ecosystems in 2040. Furthermore, some highly productive forest lands in the ponderosa pine, western white pine, hemlock-sitka-spruce, larch, and lodgepole pine ecosystems also will be managed

Table 45. Management strategies of ecosystems in Scenario I in 2000

Ecosystem	Management Strategies		
Number	Environmental	Extensive	Intensive
		(percent)	
10	72.59	----	27.41
11	43.10	3.08	53.82
12	5.45	24.33	70.22
13	8.49	----	91.51
14	100.00	----	----
15	100.00	----	----
16	100.00	----	----
17	----	----	100.00
18	----	----	100.00
19	----	----	100.00
20	48.99	51.01	----
21	94.47	----	5.53
22	67.78	----	32.22
23	74.95	25.05	----
24	63.27	----	36.73
25	80.48	----	19.52
26	100.00	----	----
27	----	3.32	96.68

Table 45. (continued)

Ecosystem	Management Strategies		
Number	Environmental	Extensive	Intensive
		(percent)	
28	100.00	----	----
29	100.00	----	----
30	100.00	----	----
31	100.00	----	----
32	----	100.00	----
33	100.00	----	----
34	100.00	----	----
35	100.00	----	----
36	----	100.00	----
37	----	100.00	----
38	72.01	27.99	----
39	----	100.00	----
40	100.00	----	----
41	----	100.00	----
42	----	100.00	----
44	----	100.00	----

Table 46. Management strategies of the ecosystems in Scenario I in 2040

Ecosystem	Management Strategies		
Number	Environmental	Extensive	Intensive
		(percent)	
10	33.27	----	66.73
11	----	3.08	96.92
12	----	5.36	94.64
13	8.49	----	91.51
14	100.00	----	----
15	46.06	----	53.94
16	100.00	----	----
17	----	----	100.00
18	----	----	100.00
19	----	----	100.00
20	48.99	51.01	----
21	86.56	----	13.44
22	67.78	----	32.21
23	36.69	25.05	38.26
24	58.02	5.25	36.73
25	80.47	----	19.53
26	98.11	----	1.89
27	----	----	100.00

Table 46. (continued)

Ecosystem Number	Management Strategies: Environmental	Extensive	Intensive
		(percent)	
28	100.00	----	----
29	100.00	----	----
30	100.00	----	----
31	100.00	----	----
32	----	100.00	----
33	100.00	----	----
34	100.00	----	----
35	100.00	----	----
36	98.65	1.35	----
37	----	100.00	----
38	100.00	----	----
39	----	100.00	----
40	100.00	----	----
41	----	100.00	----
42	----	100.00	----
44	----	100.00	----

for the timber production. The less productive timber lands in these ecosystems will still be under the environmental management. The cosystems of the oak-pine, oak-gum-cypress, chaparral-mountain shrub, and pinyon-juniper will continue to be managed primarily for the environmental purposes. Furthermore, the optimal solution indicates that the increased demand for timber can be satisfied by intensifying the management of the existing forest resources. It is not necessary to increase the forest area to meet the increased demand for timber by the year 2040.

In the year 2000, the range ecosystems of the Texas savanna, mountain grasslands, mountain meadows, prairie, wet grasslands, annual grasslands, and alpine will be managed primarily for animal grazing. And, a part of the plains grassland also will be grazed. The remaining range ecosystems will be under the environmental management. The management strategies for these range ecosystems in 2040 are similar to those in 2000 except that the plains grasslands and a large portion of the mountain grasslands will be under the environmental management in 2040. In addition to these range ecosystems, some forest ecosystems will be grazed.

Achievement of Objectives

Corresponding to an optimal solution, specific levels of the goals are achieved under a given scenario. When an goal is assigned with a different priority level a different level of the goal will be achieved.

In the year 2000, it will require a total amount of 34.58 billion dollars of the production cost to meet the projected demands for foods and fibers in Scenario I. Furthermore, a total amount of 2.5 billion tons of soil will be lost from the nation's cropland. On average, 6.2 tons/acre of soil will eroded annually from the cropland by the water erosion. In Scenario I, the achieved levels of the wildlife habitat and carbon dioxide goals will be close to their present levels. The achieved national average wildlife habitat index value will be 3.35 out of 5. As mentioned before, the carbon dioxide goal is represented by total forest area. Therefore, the value of this goal represents the number of acres of the forest area. In Scenario I, the total forest area will be 472.5 million acres.

In Scenario II, the total national production cost will be doubled from its level in Scenario I, but the soil erosion will be dramatically reduced. The national average soil erosion will be reduced to 2.8 tons per acre per year in the year 2000. And, the wildlife habitat index will increase to 3.40. The forest area will be increased by about 16 million acres from its present level, which can offset approximately 10% of the carbon dioxide emission according to the information from the "Trees for U.S." program.

In Scenario III, the total production cost will be decreased by about 8 billion dollars from its level in Scenario II. But the soil erosion will go up to as much as 6.47 tons per acre per year. The quality of wildlife habitats will be improved, and the index will reach its highest level of 3.74 in all the four scenarios. The forest area will be increased by about 106 million acres. If this occurs, more than 15% of the carbon dioxide emission can be offset.

The values of the objectives in Scenario IV will be approximately the same as those in Scenario III. This implies that the wildlife habitat and carbon dioxide goals are strongly related each other.

The change patterns of the achieved levels of the objectives in 2040 will be similar to those in 2000. Compared with the achieved levels of the objectives in 2000, more production cost will be required, more soil erosion will be produced, and lower levels of the wildlife habitat and carbon dioxide objectives will be achieved in the year 2040 because of the increased demands for food and fiber.

In the year 2040, in Scenario I it will cost 40.65 billion dollars to produce expected amount of the food and fiber demanded. The national average soil erosion will reach 7.41 tons per acre per year. The achieved wildlife habitat index will be 3.32. And, the total forest area will be decreased by about 4 million acres from the present level.

In Scenario II the total production cost will increase to 72.11 billion dollars, but the soil erosion will be reduced to 4.32 tons per acre per year. A wildlife habitat index of 3.36 will be obtained. The total forest will go up by 14 million acres from its present level.

In Scenario III, a higher level of the wildlife habitat index will be achieved, but the soil erosion will go up to 7.32 tons per acre per year. The total amount of the production cost will be 64.50 billion dollars. And, the forest area will be increased by as many as 100 million acres from its present level, which can offset more 15% of the carbon dioxide emission. The achieved levels of the objectives in Scenario IV will be approximately the same as those in Scenario III.

Compromise Programming and Solution

Decision-makers often prefer a solution as close as possible to the ideal one. Compromise programming is a sound and operational approach in helping the decision-makers to choose an optimal or best-compromise solution (Romero and Rehman, 1989).

Compromise programming is a natural and logical complement to multiple objective programming. One usually needs to introduce the decision-maker's preferences to determine the optimal solution of a multiple objective problem. Compromise programming can handle this issue in a very realistic way, without relying on the questionable assumptions of the traditional utility theory. The only assumption made by compromise programming is that decision-makers seek a solution as close as possible to the ideal point.

In general goal programming, the aspiration level of a goal is usually assigned with a reasonable or desired value. Whereas in compromise programming, the target is set with an ideal value. Because the objectives in a multiple objective problem are often conflicting, the ideal solution is infeasible. Therefore, one should seek compromise solutions. In solving a multiple objective problem using the compromise programming approach, first, one should run a set of linear programming models. Each of these linear programming models optimizes one of the multiple objectives subject to the physical constraints of the multiple objective problem. Then, the multiple objective problem is solved by setting the aspiration levels of the goals equal to the ideal values, the optima of the corresponding linear programming models.

The model developed in this study also was run using the compromise programming approach. The compromise solutions of this model are very close to those reported previously. There is no significant difference between the compromise solutions and the solutions presented previously. The regional production pattern, total land use, and land use shifts among the sectors are approximately the same. The shadow prices for SRWC and traditional forest production in the compromise solutions are exactly the same as those shown in Tables 41, 42, 43, and 44. The achieved levels of the objectives also are very close to those shown in the last section. The achievement of the four objectives in the two approaches differs by less than 3%.

CHAPTER V. SUMMARY AND CONCLUSIONS

Conclusions

A sequential linear goal programming model is developed in this study to examine the optimal land allocation among the agricultural and forest production activities, the regional production patterns, and the best management strategies for the nation's forest and range ecosystems under alternative resource policies. This model is a national level model, which consists of six sectors: crop, livestock, forest and range, resource availability, demand, and environment.

The activities incorporated in the model include the crop and forest production activities and land conversion activities. Four goals are optimized in the model under the constraints of land, irrigation water, minimum crop acreages, and the demands for crop and timber. These goals are the total national production cost, soil erosion, wildlife habitats, and carbon dioxide reduction.

The model is run under the four scenarios. Each scenario presents a specific ordering of the four objectives. In Scenario I, the production cost has the highest priority, followed by the soil erosion, wildlife habitats, and carbon dioxide reduction. In Scenario II, the ordering is the soil erosion, production cost, wildlife habitats, and carbon dioxide reduction. In Scenario III, the ordering is the wildlife habitats, production cost, and carbon dioxide reduction. And, in the final scenario, Scenario IV, the carbon dioxide reduction is set with the highest priority, followed by the production cost, soil erosion, and wildlife habitats. Moreover, the model is optimized for the years 2000 and 2040 to analyze both the intermediate and long-run impacts of the alternative policies on the resource use.

Different policies represented by the different scenarios have important impacts on land use. For the year 2000, in Scenario I, 281 million acres of the cropland will be used for the endogenous crop production. This amount will be increased to 351 million acres in Scenario II. In Scenario III, about 292 million acres of the cropland will be required for the crop production. Approximately the same amount of the cropland will be used to grow the crops in Scenario III and IV. The least amount of the cropland will be allocated to the crop production in Scenario I, whereas the largest amount of the cropland will be used for the crop production in Scenario II. As the soil erosion objective is set with the highest priority in Scenario II, some crop production on the more productive land with high erosion hazard will shift out to the less productive land, but with low erosion hazard. And, more row crop production, which generally produces more erosion than small grain crop in a given location, will be rotated with small grain crops. All of these contribute to the increase in the land use for the crop production in Scenario II. The changing patterns of the land use for the crop production in 2040 will be similar to those in 2000. But, the amount of land required by the crop production will increase from the year 2000 to 2040 in all the four scenarios because of the increase in the crop demand. In Scenario I, for example, the amount of the cropland required for the crop production will be increased to 300 million acres in 2040 from 281 million acres in 2000.

The conversion of the cropland to the forest land or the pasture land to the cropland will occur in all the scenarios in both the years 2000 and 2040. The conversion of the forest land to the cropland, however, will happen only in Scenario II. The amount of the tree plantations on the cropland will increase from Scenario I to IV as the environmental objectives are considered to be more important. In the year 2000, in Scenario I, 7.4 million acres of the cropland will be planted with trees. This amount will go up to 114.3 million acres in Scenarios III and IV. In the year 2040, 9.4 million of the cropland will be converted to the forest land in the Scenario I, and 113.5 million acres of the cropland will be planted with trees in Scenarios III and IV. In Scenarios I and II more cropland will be converted to the forest land in 2040 than in 2000. Although the tree plantations on the cropland will decrease from the year 2000 to 2040 in Scenarios III and IV, the reduced amount will be less than 1% of the total tree plantations. This suggests that most of the trees planted on the cropland in 2000 will not be required to be converted back to the cropland in 2040 despite the increase in the crop demand and the decrease in the cropland available by the year 2040.

Regional production is examined in this study. Accordingly, barley production will be relatively concentrated in a few regions.

The Mountain, Pacific, Lake States, and Northern Plains will be the major barley production regions.

The Corn Belt will be the most important corn producing region. About half of the total national corn will be produced in this region in Scenario I, III, and IV in both the years 2000 and 2040. In Scenario II, a large portion of the corn production will shift out of the Corn Belt to other regions although it will still be one of the leading corn producing regions. The Lake States and Northern Plains will be the other two important regions for corn production.

The Appalachian, Southeast, Delta States, Southern Plains, Arizona, New Mexico, and California will be the main cotton producing regions. In the year 2000, a major portion of cotton will be grown in the southeastern part of the country. In the year 2040, more cotton production will shift to the southwestern part of the country, except in Scenario II.

The Corn Belt, Northern Plains, Southern Plains, and Appalachian will be the leading oat production regions in the nation in the most scenarios. In Scenario II a large portion of the total national oats will be produced in the Corn Belt.

Sorghum production will also be concentrated in a few regions such as the Southern Plains, Northern Plains, Delta States, and Appalachian. The Southern Plains will be the most important region for the sorghum production in the most scenarios.

The Corn Belt will have the biggest share of the total national soybean production except in Scenario II. In Scenario II some soybean production will shift out of the Corn Belt to the Lake States, Northern Plains, and some other regions. Besides the Corn Belt, the other important soybean producing regions include the Southeast, Lake States, Northern Plains, and Southern Plains.

Wheat grows more extensively than any other crop. Almost all the regions will produce wheat. But the Northern Plains, Southern Plains, Mountain, Appalachian, and Southeast will be the major wheat production regions in most scenarios.

In Scenario I, the traditional forest will be established on the cropland only in the Northeast, Lake States, and Corn Belt, and SRWC will not be competitive with the crops in the cropland use. To plant additional trees on the cropland will cause the total national production cost to increase. The increased amount of the production cost for each additional unit of forest production on the cropland is defined as the shadow price of the forest production. It will be more economical to establish additional amount of forest in the region with the low shadow price than in the regions with the high shadow price.

The results indicate that the shadow prices of forest production in a given region will vary from the year 2000 to 2040. And, the ranking of a region based on the shadow price per acre is often different from that based on the shadow price per unit of volume or weight. But, in general, the Corn Belt will have consistently low shadow price for SRWC production. The Corn Belt will be the most economical region to plant SRWC. For each additional acre of SRWC plantation in the Corn Belt, the total production will be increased by only $23.58 in 2000 and $20.44 in 2040. The highest shadow price per acre of SRWC production will occur in the Northeast in 2000 and in the Southern Plains in 2040. The shadow price per acre of SRWC production in the Southeast will be relatively high, but it will have the lowest shadow price per dry ton of biomass produced. To produce one additional ton of biomass in the Southeast, the production cost will go up by $4.97 in 2000 and $4.47 in 2040. The second lowest shadow price per dry ton of biomass will occur in the Corn Belt. It will be most expensive to produce an additional ton of biomass in the Northeast.

The shadow price of the traditional forest production will be relatively low in the Southeast and Delta States and relatively high in the Northern Plains, Southern Plains, and Mountain. The Pacific will have the relative high shadow price on per acre basis, but the shadow price on the per MBF basis in this region will be at an intermediate level. In the year 2000, the Lake States will be the most economical region to increase the forest area. To plant one more acre of forest in the Lake States will cause the production cost to increase by only $2.41. The Northeast will have the highest shadow price per acre of the traditional forest production, which will be 13.94 dollars per acre. In the year 2040, the Corn Belt will be the most economical region to increase the forest area, whereas the highest shadow price per acre of the traditional forest will occur in the North Plains. The production cost will go up by $7.53

for each additional acre of the forest planted in the Corn Belt and $ 9.98 in the Northern Plains. In the year 2000, the Lake States also will have the lowest shadow price per MBF of timber, $18.70/MBF. The Southeast and Delta States will have relatively low shadow price per MBF of timber produced. The highest shadow price, $137/MBF, will occur in the Appalachian. In the year 2040, the Southeast will become the most economical region for the timber production on the cropland, whose shadow price will be $69.76/MBF. The Northern Plains will have the highest shadow price of timber production, $127.49/MBF.

To meet our national demand for timber with the minimum possible cost, in the year 2000 the ecosystems of the longleaf-slash pine, lobblolly-shortleaf pine, elm-ash-cottonwood, maple-beech-birch, aspen-birch, Douglas-fir, hemlock-sitka spruce, and redwood should be managed primarily for the timber production. And, the high productive forest land in the white-red-jack pine, spruce-fir, ponderosa pine, fir-spruce, and larch ecosystems also will be used for the timber production. The less productive forest land in these ecosystems and the other remaining ecosystems will be mainly under the environmental management. In the year 2040, the increased demand for the timber will require more forest land to be managed for the timber production and the increase in the intensity of the management of some ecosystems. In addition to the forest land primarily used for the timber production in 2000, the white-red-jack pine, spruce-fir, oak-hickory, and fir-spruce ecosystems will be managed mainly for timber production. And the high productive forest land in the western white pine and lodgepole pine ecosystems also will be used to produce timber. Only the oak-pine, oak-gum-cypress, chaparral-mountain shrub, and pinyon-juniper ecosystems will be remained under the environmental management.

For each scenario the specific levels of the goals are obtained along with the optimal solution. In Scenario I, the least amount of the cost will be required, but the amount of soil erosion will be relatively large, and the quality of the wildlife habitats and the forest area will be close to their present levels. In Scenario II, the soil erosion will be dramatically reduced, the wildlife habitats will be improved, and the forest area will be increased by 16 million acres in 2000 and 14 million acres in 2040, which can offset about 10% of the carbon dioxide emission. These shifts and goal attainments will be achieved with the production costs doubled from the level in Scenario I. The achieved levels of the objectives will be approximately the same in Scenarios III and IV. In these two scenarios the production cost and soil erosion will be relatively high. Further, the wildlife habitats will be improved most relative to Scenarios I and II, and the forest area will be increased by a considerable amount, which will be able to offset more 15% of the carbon dioxide emission.

Recommendations

Before using the results found in this study, one should be aware of the assumptions and limitations of this study. Since the model is a sequential linear goal programming model, the constant marginal productivity for inputs and constant returns to scale are arbitrarily assumed. Further, the model is run using a sequential optimization approach, in which the low-ordered goal will be considered only after the high-ordered goal is satisfied to its full extent possible. If a decision-maker's ordering of the importance of the goals is not consistent with those specified in this study, different results are expected.

Further studies on this topic are recommended. Due to the limit of funding and time, no transportation activities were included in this model. The transportation costs may have impacts on the resource use and the regional production patterns. To examine these impacts, it is recommended that one introduce a transportation sector into the model. During the course of doing this research, the author was frequently aware of the limits of the data on the environmental effects of the natural resource management. With the increasing concerns of the the environmental problems, the availability of these data is essential in the natural resource management modelling. Further research to obtain more comprehensive and accurate data on the environmental aspects related to the natural resource use is highly recommended.

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